

Designing Stone Matrix Asphalt Mixtures Volume II(b) – Research Results for Part 2 of Phase I

Final Report

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CHAPTER 1 - INTRODUCTION

1.1 BACKGROUND

Stone matrix asphalt (SMA) has been used successfully within the United States since 1991. Some states routinely use SMA even though a standard mixture design procedure is not available. If a good mixture design procedure is adopted, it should be possible to improve the performance of SMA. A procedure that provides guidance on material properties, aggregate gradation, determination of optimum asphalt content, and mixture properties is needed.

As a result of this need, the Transportation Research Board (TRB) contracted with the National Center for Asphalt Technology (NCAT) in 1994 to develop a mixture design procedure for SMA. An interim report was prepared and published in 1995 that provided a tentative mixture design procedure for SMA. The interim report summarized literature on SMA and provided initial research data. The interim report also presented a detailed test plan for Tasks 5, 6, and 7. The final report presented herein presents the finalized mix design procedures for SMA and supporting research data.

1.2 OBJECTIVE

The objectives of this study were to conduct a literature review and to perform sufficient laboratory testing to develop mixture design procedures for SMA using the Marshall hammer and Superpave Gyrotory Compactor (SGC).

1.3 SCOPE

This project involved obtaining samples of aggregate, fillers, asphalt binders, and fibers from a number of sources for evaluation. Detailed laboratory studies were performed to evaluate aggregate structure with the various aggregates. Work was also performed to evaluate the effect of asphalt binder, fillers, and fibers on the mortar properties. Mixtures were prepared and tested in the laboratory to evaluate the effect of various aggregate structures and various mortar properties on the SMA mixture properties. Tests that were conducted to evaluate the mixture properties included: volumetrics, stability, flow, tensile strength, creep, and moisture susceptibility. Proof testing included laboratory wheel tracking tests, and indirect tensile creep. A mixture design procedure was developed and tests were recommended for evaluating the SMA.

CHAPTER 2 - WORK COMPLETED IN PART 1

The research involved in developing an SMA mixture design procedure was completed in two distinct parts. Part 1 began in April 1994 and had as its main goal the development of a tentative SMA mixture design method. Part 2 began in early 1995 and is the subject of this report. Figure 2.1 shows the relationship of both parts along with their tasks. Note that Parts 1 and 2 are linked; Part 2 built on the results from Part 1.

In May 1995, the final version of the Interim Report was delivered to TRB. This report was written in three volumes and contained the results of Part 1. Volume I of the report contained the results of an extensive literature review of SMA as defined by Task 1. Volume II of the Interim Report contained the research results of Part 1. This volume was the direct result of the completion of Tasks 2 and 3. The third and final volume of the Interim Report was the tentative SMA mixture design procedure and represented the implementable results of the Part 1 research. This chapter provides a brief review of the Part 1 research.

2.1 LITERATURE REVIEW

The literature review completed in Part I was delivered to TRB as Volume I of the Interim Report. Individual reviews of 86 references are provided as well as a summary linking all the references together.

2.2 RESEARCH RESULTS

Volume II of the Interim Report contained the results of the research work completed in Part 1. This volume was the culmination of Tasks 2 and 3. The findings in this volume guided the development of the tentative SMA mixture design procedure. The research findings reported in Volume II of the Interim Report can be summarized under three main headings: Aggregate Properties, Mortar Properties, and Mixture Test Results.

2.2.1 Aggregate Properties

In order for an SMA mixture to develop sufficient stone-on-stone contact to carry the imposed loads, the coarse aggregate must have adequate strength. Currently, the Los Angeles abrasion test is most commonly used for determining the toughness of the aggregate particles. The research under Part 1 found that, while this abrasion test does show some correlation to aggregate breakdown during laboratory compaction, it does not accurately predict aggregate breakdown for every aggregate type.

Further, since the coarse aggregate in SMA mixtures must carry the load, fractured faces are required to provide a coarse aggregate structure with high internal friction. Part 1 research concluded that if the fractured face count is significantly less than 100 percent for the coarse aggregate, the SMA mixture is almost certainly going to be less resistant to shoving and rutting. This requirement for fractured faces eliminates the use of uncrushed gravels and will also

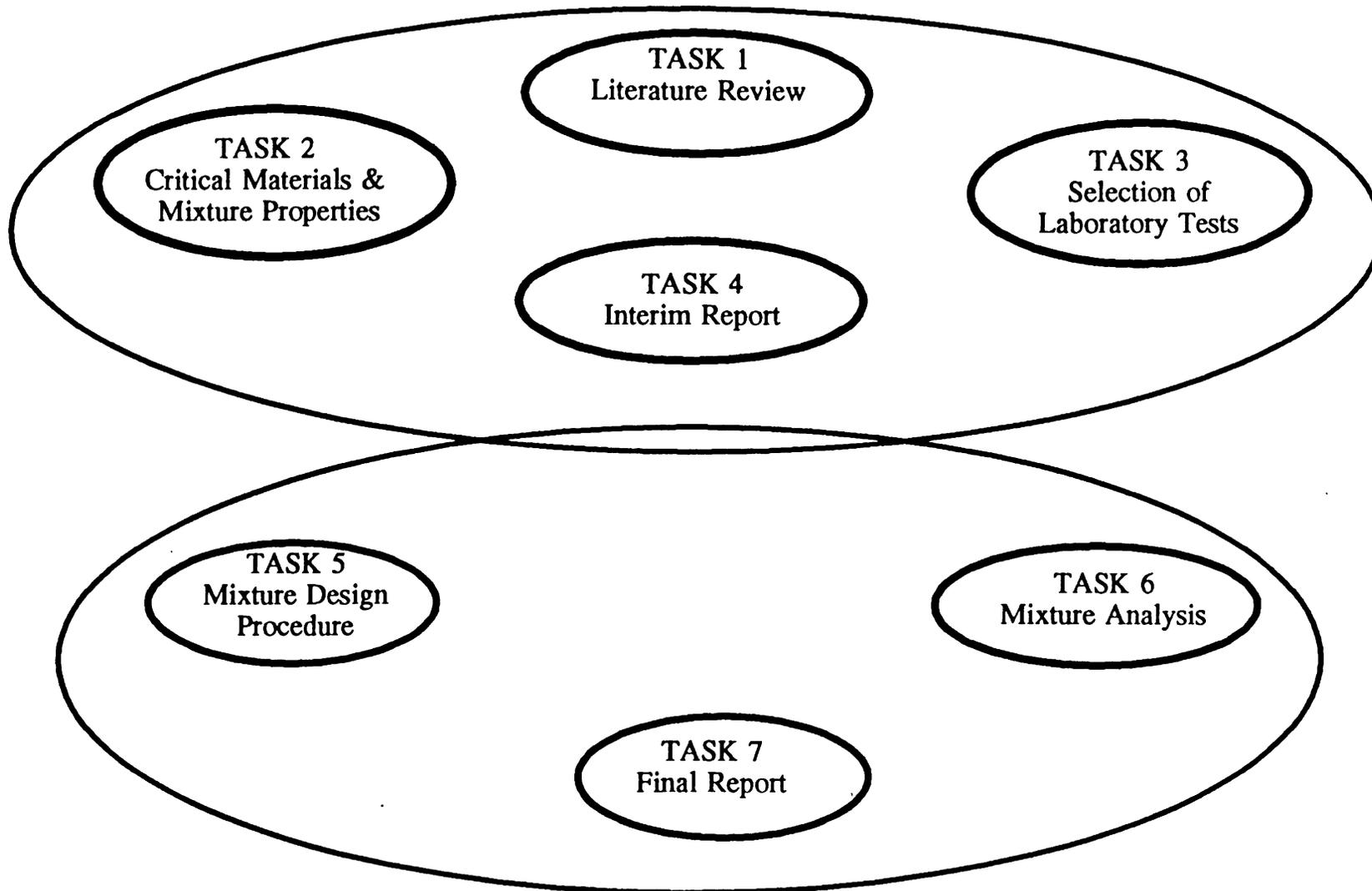


Figure 2.1: Relationship of the Two Parts of the Research Project

eliminate many crushed gravels if the fractured face count is not high enough to meet the desired requirements.

The amount of aggregate absorption can affect the performance of SMA mixtures just as it does dense-graded mixtures. Low absorptive aggregates are preferred but some locations, due to availability of aggregates, may be required to use aggregates with higher absorption values. Part 1 research indicated that when high absorptive aggregates are used, the optimum asphalt cement content should be selected on the high side but within the specification limits, to allow for some additional absorption of the asphalt cement during production and placement, and during the life of the pavement. When absorptive aggregates are used the effective asphalt cement content needs to be determined to ensure that a sufficiently high asphalt cement content is used for satisfactory durability.

Research completed in Part 1 supported conclusions made concerning the variation of VMA as a function of aggregate gradation. Specifically, three different sieve sizes were investigated to determine how they affect the VMA.

In an SMA mixture, the material finer than the 4.75-mm sieve acts to fill the voids in the coarse aggregate skeleton as long as stone-on-stone contact exists. This was clearly shown in Part 1 research as well as in work previously done by NCAT and the Federal Highway Administration (FHWA). Figure 2.2 shows data plotted from earlier work at NCAT. The figure clearly shows that as the percent passing the 4.75-mm sieve decreases, the VMA decreases to a point and then begins to increase rapidly. The point at which the VMA begins to increase occurs when approximately 30 percent of the aggregate passes the 4.75-mm sieve. It can therefore be concluded that for an SMA mixture having 100 percent passing the 19.0-mm sieve, the aggregate fraction smaller than the 4.75-mm sieve tends to spread the coarse aggregate skeleton if it is present in quantities higher than approximately 30 percent. If the percent passing the 4.75-mm sieve is kept below approximately 30 percent, it acts to fill the voids in the coarse aggregate skeleton. In this case, the SMA mixture VMA can be increased by decreasing the amount of material passing the 4.75-mm sieve.

The effect of percent passing the 0.075-mm sieve on VMA is similar to the effect of the 4.75-mm sieve (Figure 2.3). If the percent passing the 4.75-mm sieve is held constant and the percent passing the 0.075-mm sieve is decreased, the VMA will generally increase.

Part 1 research also concluded that changing the percent passing the 9.5-mm sieve affects the VMA. As the percent changes from 40 to 60 percent, with all other sieve sizes remaining the same, the VMA increases. Contrary to expectations, the higher percentage passing the 9.5-mm sieve resulted in a higher VMA in the SMA mixture (Figure 2.4).

It appears that the percentage passing the 4.75-mm sieve can be adjusted until stone-on-stone contact exists. In Part 1 research, five different methods were tried to determine the VCA at which stone-on-stone contact occurs. The five methods included: Marshall hammer, SGC, Kango hammer, vibrating table, and dry-rodded test. The vibrating table and dry-rodded test appeared to be the best two methods. The SGC and Marshall hammer compaction tended to cause more aggregate degradation. The Kango hammer was inconsistent and did not compact the samples enough and was thus not considered for further testing. The dry-rodded test appeared to be the easiest of the methods to use and it provided reasonable results. It appeared to be the most appropriate method for determining the VCA at which stone-on-stone contact occurs.

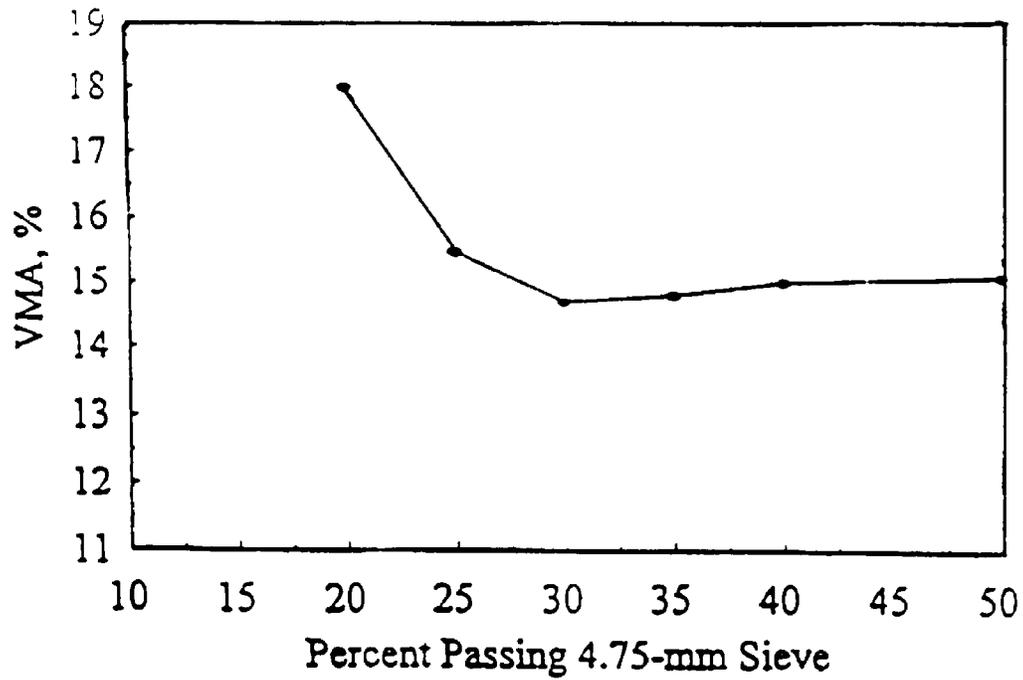


Figure 2.2: Effect of Percent Passing the 4.75-mm Sieve on VMA

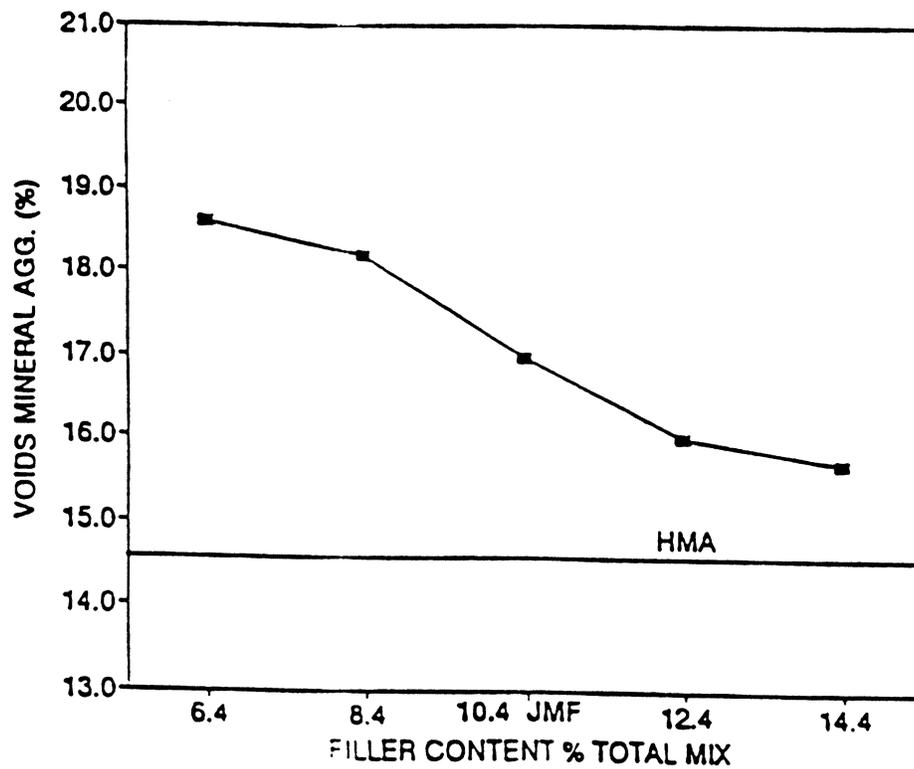


Figure 2.3: Effect of Percent Passing the 0.075-mm Sieve on VMA

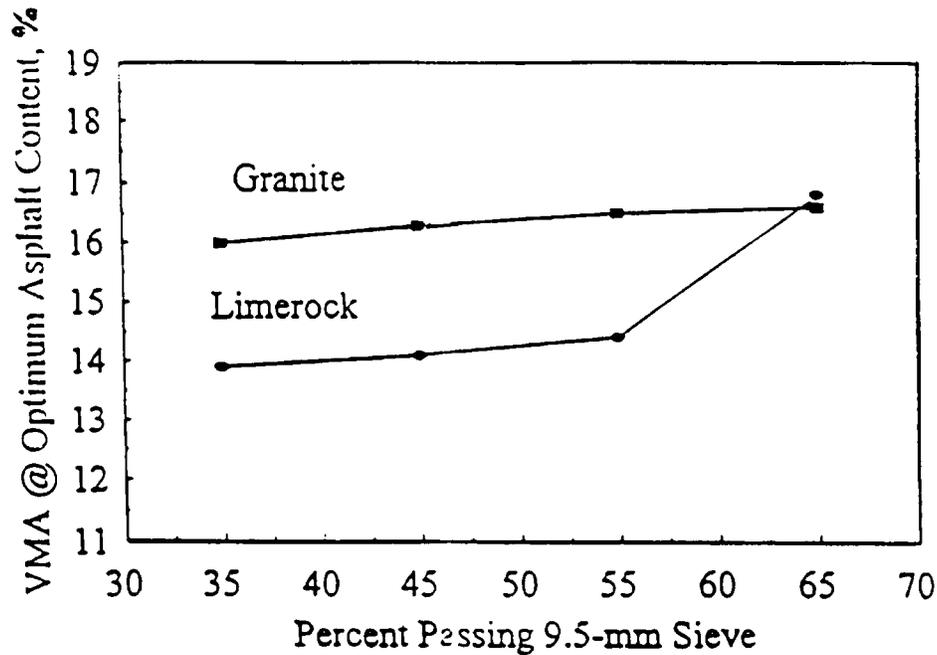


Figure 2.4: Effect of Percent Passing the 9.5-mm Sieve on VMA

2.2.2 Mortar Properties

The mortar properties are important to prevent draindown at mixing and placement temperatures, to prevent rutting during hot weather, to prevent fatigue cracking, and to prevent cracking in cold weather. The mortar consists of fine aggregate (material passing the 2.36-mm sieve and retained on the 0.075-mm sieve), mineral filler (material passing the 0.075-mm sieve), asphalt cement, and stabilizer additive. The main goal of mortar testing in Part 1 was to determine if the Superpave binder tests could be used to test and specify SMA mortars. Requirements for fine aggregates, mineral fillers, asphalt cement and stabilizer will be minimal and the contractor will have flexibility to choose his materials as long as the final mortar properties are satisfactory. For analysis in the laboratory, the mortar was divided into fine and total mortar fractions. The fine mortar consisted of mineral filler, asphalt cement, and stabilizing additive. The fine mortar was handled more like a binder and the total mortar was handled more like a mixture. The percentage of the various components in the fine and total mortar were those relative percentages that would be available in an SMA mixture.

The results of the mortar testing found that the fine mortar properties were closely related to the total mortar properties. Figure 2.5 shows a plot indicating the relationship between fine and total mortar BBR stiffness. It appears that the fine mortar can be evaluated without the need for the additional testing on the total mortar since these properties are related. In the laboratory it is much easier to prepare and test fine mortars than total mortars. It was therefore decided to focus on the testing and developing criteria for the fine mortar.

The mortar testing indicated that some of the Superpave binder tests could be used to evaluate the fine mortar and to establish criteria. Specifically, the dynamic shear and bending beam rheometers appeared to be satisfactory in evaluating the fine mortar. The direct tension

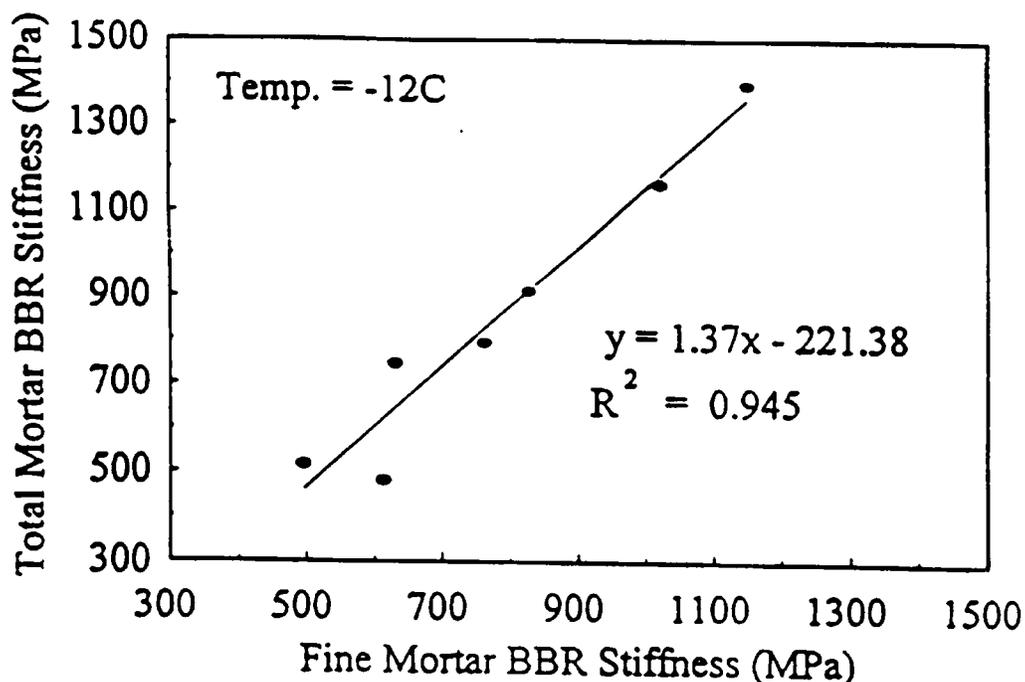


Figure 2.5: Relationship Between Fine and Total Mortar Stiffness at -12°C

device might prove adequate if samples can be properly made. These Superpave binder tests appear to have the capability to distinguish between filler types and may have the capability to accept or reject various fillers based on the stiffening effect of the asphalt cement binder. This approach of measuring the fine mortar stiffness should be much better than simply specifying the allowable filler size distribution.

2.2.3 Mixture Test Results

At this time, there is no good strength test to evaluate the quality of the final SMA mixture. Creep tests, resilient modulus, indirect tensile strength, and Marshall stability were conducted on the SMA mixtures in Part 1 research. Of these four tests, the dynamic creep test may hold the most promise to predict the rutting performance of SMA. It is believed that dense-graded mixtures are more sensitive to a change in voids. However, the creep testing completed in Part 1 showed that the SMA and dense-graded mixtures had about the same sensitivity to changes in air voids, but that the dense-graded mixtures always had less permanent deformation. This might be due to the fact that the dense-graded mixtures evaluated had gradations somewhat similar to the SMA mixtures. The percent passing the 4.75-mm sieve for these dense mixtures was 41 percent which is only about 10 percent finer than that for SMA mixes. Also, the amount of confining stress could make a difference in the results.

At the present time, the performance of SMA mixtures is controlled by specifying the aggregate properties and blended gradation, binder properties, stabilizer type and amount, and volumetric properties. This type approach is also used for dense-graded mixtures. The Superpave

simple shear test and wheel tracking should be evaluated to see if they can be used to evaluate SMA mixtures.

2.3 TENTATIVE SMA MIXTURE DESIGN METHOD

The tentative mixture design procedure recommended in Volume III of the Interim Report was basically followed to develop the designs for Part 1 of the study. The mixture design procedure is relatively straightforward and does not require any additional equipment other than that required for hot mix asphalt (HMA).

The tentative mix design procedure was developed 1) to ensure stone-on-stone contact, 2) to maximize optimum asphalt content, and 3) to prevent draindown. The procedure accomplishes these objectives.

The tentative mixture design method is relatively straightforward and easy to use. It is summarized in the following steps.

1. Choose materials and conduct tests to ensure they comply with material specifications.
2. Determine the optimum aggregate gradation.
3. Determine optimum asphalt cement content.
4. Perform moisture susceptibility testing using AASHTO T 283.

Fifty blows of the Marshall hammer are used to compact specimens. The coarse aggregate VCA is determined using the dry-rodded test.

CHAPTER 3 - TEST PLAN FOR PART 2

3.1 INTRODUCTION

This chapter outlines the test plan used in completing Tasks 5-7. The first objective of these tasks was to evaluate and modify the proposed design procedure established in Tasks 1-4 in order to produce a final mixture design procedure. The second objective was to analyze mixtures produced with the method in order to make any necessary refinements. To accomplish these objectives, Task 5 focused on mixture design evaluation while Task 6 was used to analyze SMA mixtures produced using the method. The last objective was to produce a final report detailing the research project. This was completed as Task 7.

3.2 TASK 5 - MIXTURE DESIGN PROCEDURE

The main goal of Task 5 was to finalize the mixture design procedure proposed under Tasks 1-4. To do so, it was necessary to accomplish several subtasks. These were:

1. Adapt the Superpave volumetric design procedure for use with SMA,
2. Establish a method for determining the proper laboratory mixing and compaction temperatures for SMA mixtures,
3. Establish fine mortar specification criteria, and
4. Evaluate the design procedure to further determine the effects of varying the two main components of SMA, namely the coarse aggregate skeleton and mortar. This includes looking at the effects of flat and/or elongated particles, and aggregate breakdown during laboratory and field compaction.

As an added evaluation, the permeability of laboratory compacted SMA mixtures was also determined and compared to that of conventional dense-graded HMA mixtures. Figure 3.1 is a graphic representation of the Task 5 research plan.

3.2.1 Mortar Testing

The mortar in an SMA mixture is comprised of fine aggregate (material passing the 2.36-mm sieve, but retained on the 0.075-mm sieve), mineral filler (material passing the 0.075-mm sieve), asphalt cement, and a stabilizing additive. For testing purposes, the total mortar can be further subdivided into the fine mortar. Fine mortar consists of mineral filler, asphalt cement, and stabilizing additive.

The mortar testing completed in Part 1 of the study indicated that the testing of the fine mortar was sufficient to characterize the behavior of the total mortar. Mortar testing in Task 5 focused on the fine mortar since it is easier than the total mortar to handle in the laboratory.

The goal of mortar testing in Task 5 was to characterize SMA mortars and use the information to set mortar specification limits. Various fine mortars were characterized at high, intermediate, and low temperatures. The characterization at high temperatures was done at 58° and 70°C on unaged and Rolling Thin Film Oven (RTFO) aged fine mortars using the Dynamic

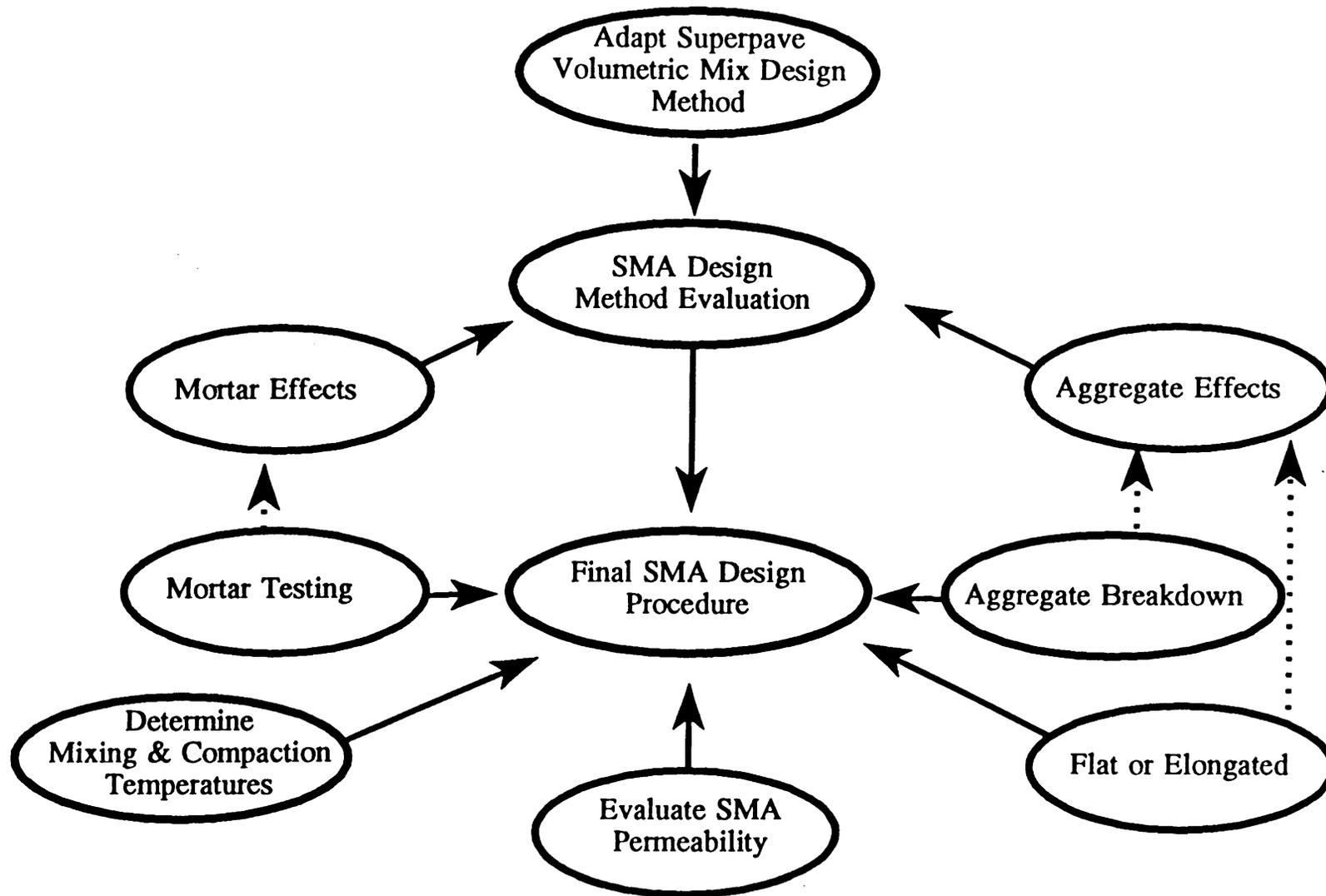


Figure 3.1: Diagram Showing How the Task 5 Elements Fit Together to Achieve the Goal of Finalizing a Mixture Design Procedure

Shear Rheometer (DSR). The intermediate test temperatures were 19° and 31°C. The DSR was again used at these temperatures to characterize fine mortars that had first been RTFO aged and then aged in the Pressure Aging Vessel (PAV). To characterize mortars at low temperatures, the Bending Beam Rheometer (BBR) was used. Fine mortars that had been aged in the RTFO, and then PAV, were tested in the BBR at temperatures of -6° and -18°C. Aging was accomplished by using the RTFO and PAV on the asphalt binders prior to preparing the mortars.

The various fine mortars were prepared by varying the type of filler, percent of filler, and type of stabilizing additive. The test matrix used 4 different filler types, 3 different filler percents, and 4 different stabilizing additives. In addition, fine mortars with various fillers and no stabilizers and various stabilizers with no fillers were also tested. This test matrix is shown in Table 3.1. As indicated, not every combination was tested; two repetitions were performed for each of the combinations tested.

Table 3.1: Fine Mortar Text Matrix for Task 5

Filler Type	Filler Percent	Stabilizer Type				
		None	Cellulose Fiber	Mineral Fiber	SBS	Polyolefin
None	0	X	X	X	X	X
Limestone Dust	8	X	X	--	X	--
	10	X	X	X	X	X
	12	X	X	--	X	--
Marble Dust	8	X	X	--	--	--
	10	X	X	X	X	X
	12	X	X	--	--	--
Traprock Dust	8	X	X	--	--	--
	10	X	X	X	X	X
	12	X	X	--	--	--
Diabase Dust	8	X	X	--	--	--
	10	X	X	X	X	X
	12	X	X	--	--	--

After completing the original test matrix, an additional 7 mineral fillers were tested. These additional materials were 2 flyash fillers, 2 limestone dust fillers, and 3 fillers obtained from Denmark. These additional fillers were tested at percentages of 8, 10, and 12 percent in combination with cellulose fiber only.

3.2.2 Mixture Design Evaluation

Evaluation of the SMA mixture design procedure required a significant amount of laboratory work. The mixture design evaluation was used to identify the effects that both aggregate properties and mortar characteristics have on the SMA mixture. The work for this subtask necessarily encompassed parts of several other subtasks as indicated in Figure 3.1. Data from the aggregate breakdown and flat or elongated subtasks was used when investigating the effects of aggregate properties on SMA mixture properties; the results of the mortar testing subtask were used to aid in the determination of how mortar characteristics affect SMA mixture properties. Also, the mixture design evaluation subtask was used to adapt the Superpave volumetric mixture design procedure for use with SMA. Evaluation of the SMA mixture design procedure used both the Marshall hammer and Superpave gyratory compactor (SGC) to produce specimens (Any reference to the Marshall hammer should be understood to mean the flat-faced, static base, mechanical Marshall hammer unless otherwise noted). Dense-graded HMA specimens were also included for comparison purposes. Figure 3.2 shows a diagram of the mixture design evaluation subtask.

For the aggregate effects determination, aggregates from 8 different sources were used. Coarse and fine aggregates were obtained from each of the sources. The aggregates were limestone (1), granite (1), traprock, granite (2), dolomite, limestone (2), blast furnace slag, and gravel. The aggregates were chosen to provide a wide variety of particle shapes, surface textures, absorptions, and mechanically measured properties (i.e. - LA abrasion, etc.).

From the aggregate effects portion of Figure 3.2, it can be seen that both the Marshall hammer and SGC were employed as compaction techniques. Two SMA mixtures were designed for each of the 8 aggregate sources. One design used 50 blows of the Marshall hammer to compact specimens; the second set of designs used 100 revolutions of the SGC to compact specimens. The interim report on this project showed that 100 revolutions of the SGC was comparable to 50 blows of the Marshall hammer. The evaluation schemes conducted for both these compaction techniques are shown in Figures 3.3 and 3.4 for the Marshall hammer and SGC, respectively. As seen in these figures, there were five main areas of testing conducted during and/or after the mixture design process. These areas were aggregate breakdown, determination of voids-in-the-coarse aggregate (VCA), permeability, moisture susceptibility, and mechanical testing. The permeability measurements were conducted for the permeability subtask and are discussed elsewhere. The aggregate breakdown and VCA testing relate both to the design of SMA and to other subtasks; both are discussed here.

The VCA for each design was determined in two ways. The dry-rodded method uses AASHTO T 19; the gyratory method combines the coarse aggregate fraction and 2 percent asphalt cement which is then compacted by the SGC. Three replicates were completed for each design using each method. As an added investigation, the gyratory VCA was determined for each mixture at three separate compaction levels, 75, 100, and 125 revolutions. The gradations of all VCA specimens were determined before and after the VCA test. Measurement of the VCA for coarse aggregate only and for the mixture is necessary in completing the SMA design.

Moisture susceptibility testing was conducted on each SMA design using AASHTO T 283; no freeze-thaw cycle was employed. In keeping with conventional SMA practice, moisture susceptibility specimens were compacted to 6 ± 1 percent target air voids. The average retained tensile strength (TSR) was determined for each design with and without the inclusion of 1

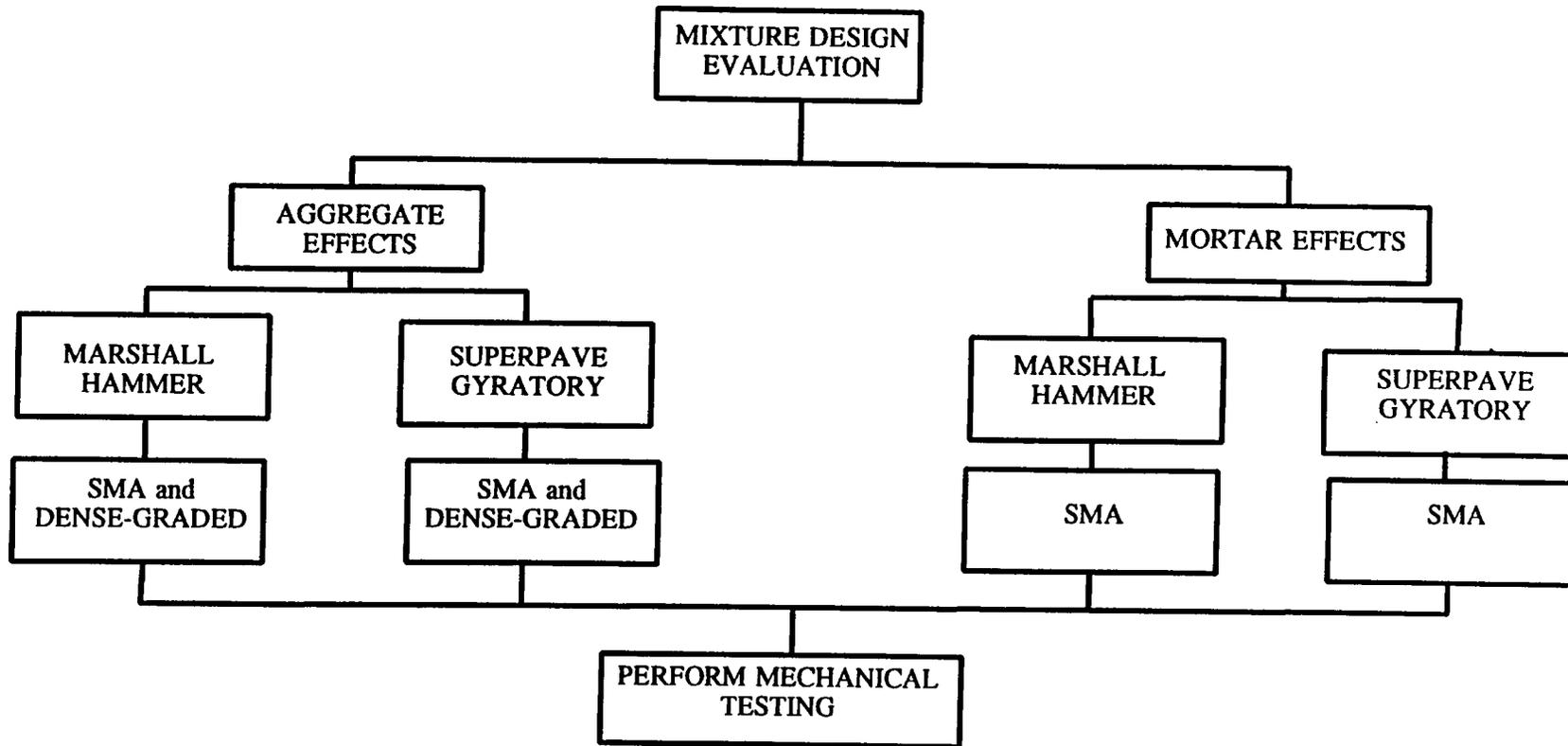


Figure 3.2: Diagram of the Mixture Design Evaluation Subtasks

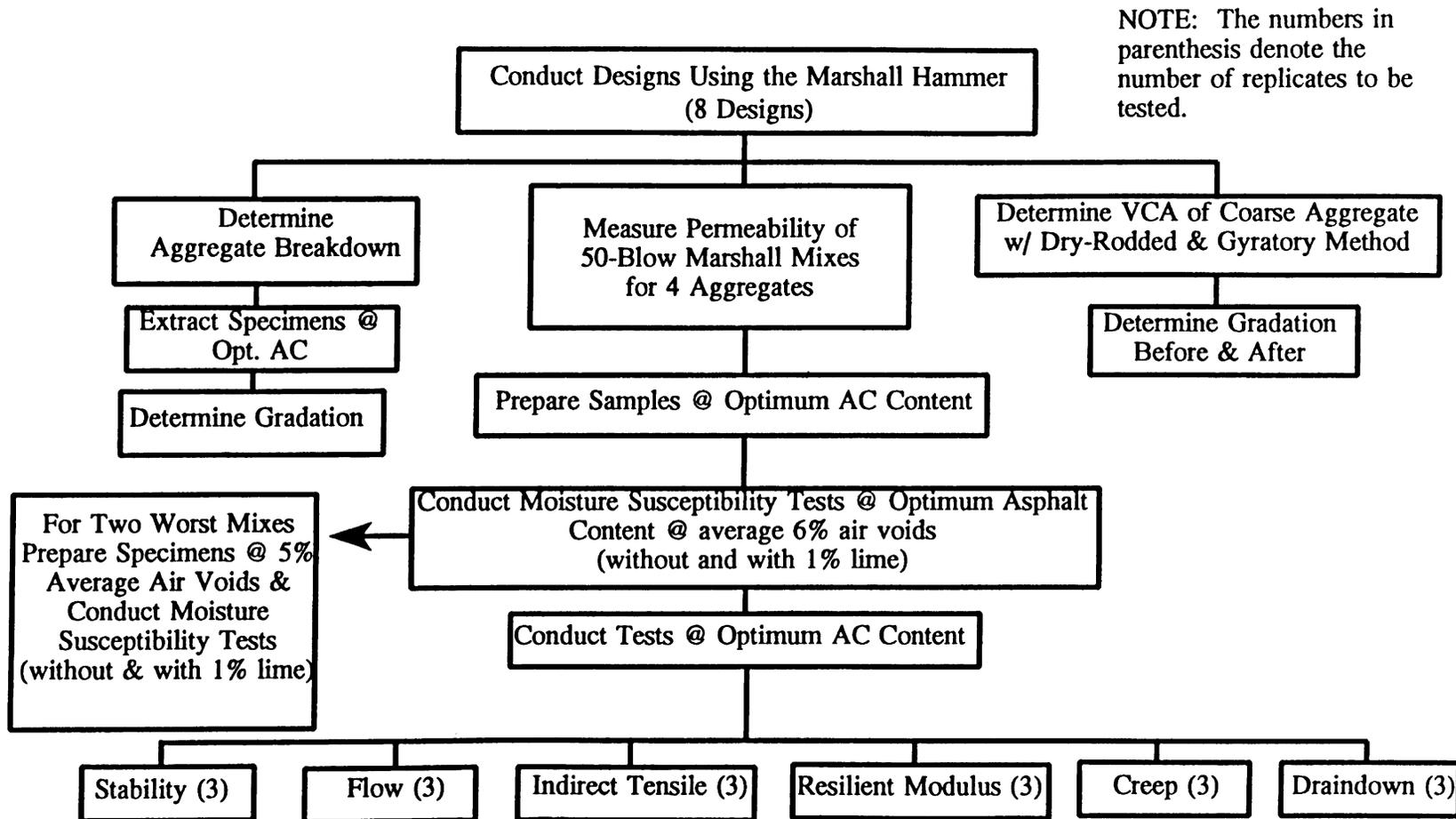


Figure 3.3: Test Plan for SMA Mix Design Evaluation Using a Marshall Hammer for Specimen Compaction

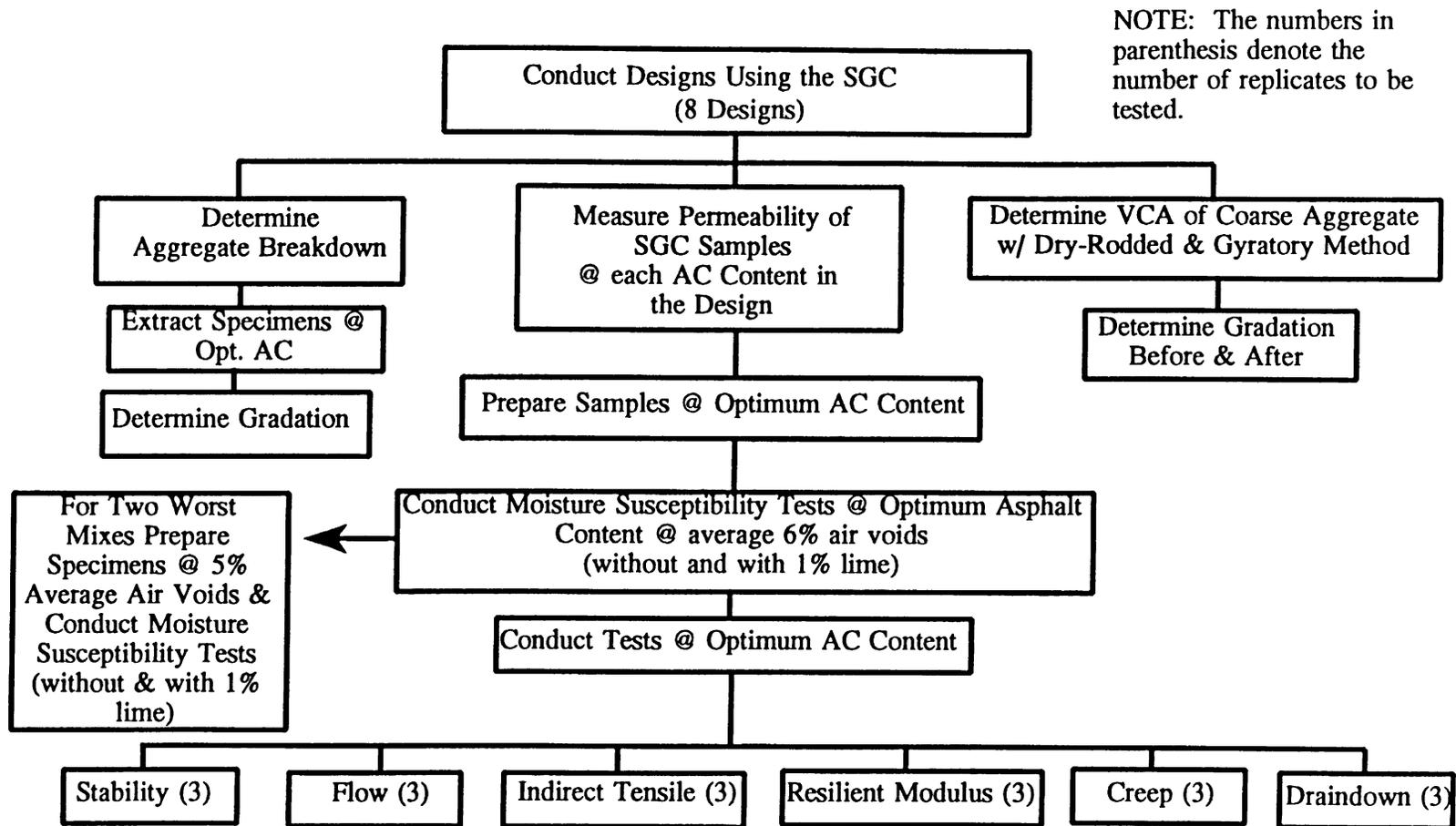


Figure 3.4: Test Plan for SMA Mix Design Evaluation Using the Superpave Gyratory Compactor for Specimen Compaction

percent lime. As seen in Figures 3.3 and 3.4, the two most moisture sensitive mixtures produced by both compaction methods were tested a second time with specimens prepared at 5 ± 1 percent target air voids. These tests were again completed both with and without the inclusion of 1 percent lime.

The mechanical tests used in evaluating the SMA mixture design were all completed using standard test methods. It should be noted that a confined creep test was used and that draindown testing was accomplished according to the NCAT draindown test method.

In addition to the SMA mixture designs previously discussed, four of the aggregates were used in completing SMA mixture designs compacted with various compactive efforts. SMA designs using limestone (1), granite (1), traprock, and granite (2) were completed using 35, 50, and 75 blows of the Marshall hammer. SMA designs with these same 4 aggregates were also completed using 75, 100, and 125 revolutions of the SGC. The amount of aggregate breakdown caused by compactive effort was determined for each mixture design. Figure 3.5 shows a diagram outlining this testing.

For comparison purposes, dense-graded HMA mixtures for each aggregate were also designed using 75 blows of the Marshall hammer and $N_{DES} = 128$ revolutions of the SGC (16 total designs). These mixtures were tested for volumetrics and compared to the SMA mixtures.

The test plan for studying the mortar effects is shown in Figure 3.6. Eight mortars were selected from the mortar testing subtask. For each of these, an SMA design was completed using 50 blows of the Marshall hammer and 100 revolutions of the SGC (16 total designs). As can be seen from Figure 3.6, testing performed during and/or after the mixture design process includes workability, moisture susceptibility, and mechanical testing. The moisture and mechanical testing were completed as previously described under the study of aggregate effects. The workability testing was completed for the workability subtask and is outlined under that heading.

3.2.3 Flat and Elongated Testing

While SMA specifications typically include flat or elongated limits, no data currently exists to quantify the effects that flat or elongated aggregate particles have on SMA mixtures. In an attempt to develop such data, a supply of aggregate was obtained from a producer in Arkansas. This supply was composed of aggregate quarried from the same ledge with one portion being crushed to produce flat or elongated particles and another portion being crushed to produce cubical particles. The test plan for this subtask is shown in Table 3.2. SMA mixture designs using 50-blow Marshall compaction were completed for the various percentage combinations. Once the designs were completed, the aggregate gradations after compaction were determined for each specimen to quantify aggregate breakdown. Each of the designs was also tested for moisture susceptibility using AASHTO T 283. The moisture specimens were produced at a target level of 6 ± 1 percent air voids.

3.2.4 Aggregate Breakdown Testing

This subtask was developed in an attempt to determine how aggregate breakdown affects SMA characteristics and to correlate the amount of aggregate breakdown experienced during laboratory and field compaction. The work involved two parts. First, the amount of aggregate breakdown experienced during the mixture design phase was established for both Marshall

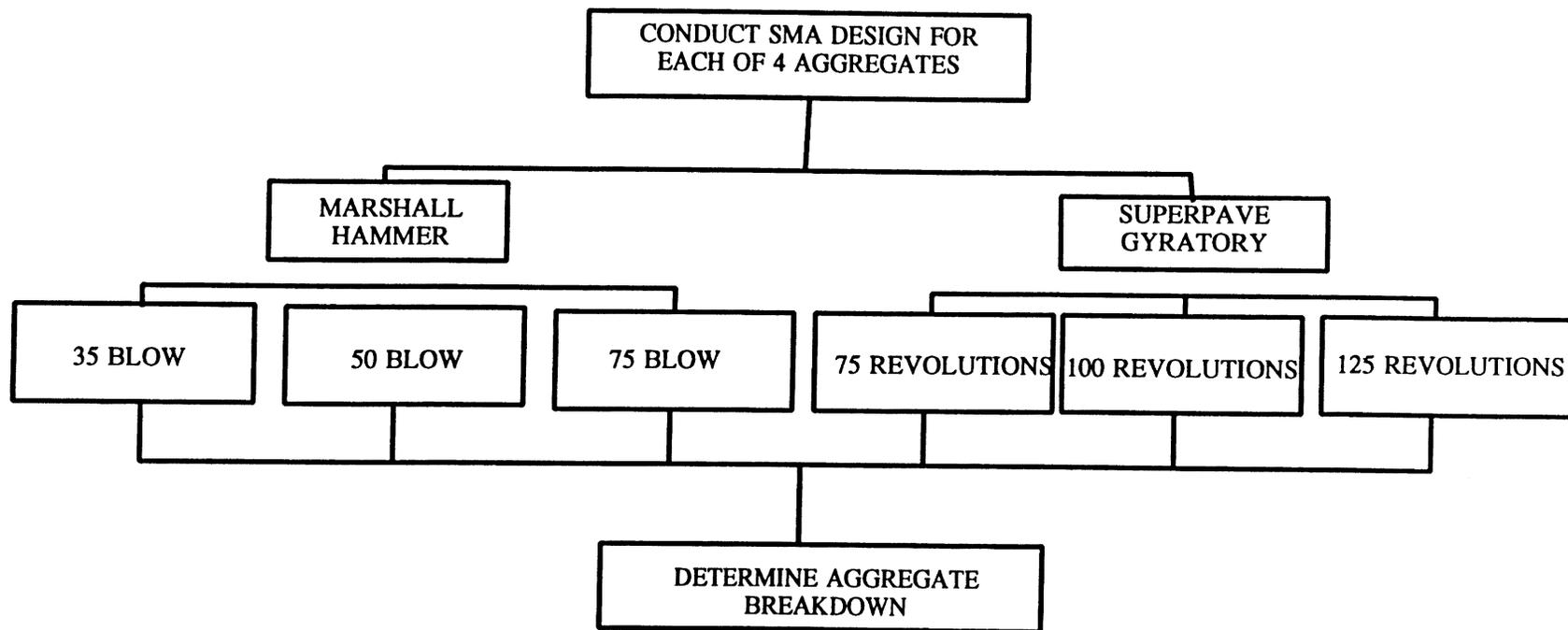


Figure 3.5: Test Plan for Mixture Design Evaluation Using Various Compactive Efforts

NOTE: The numbers in parenthesis denote the number of replicates to be tested.

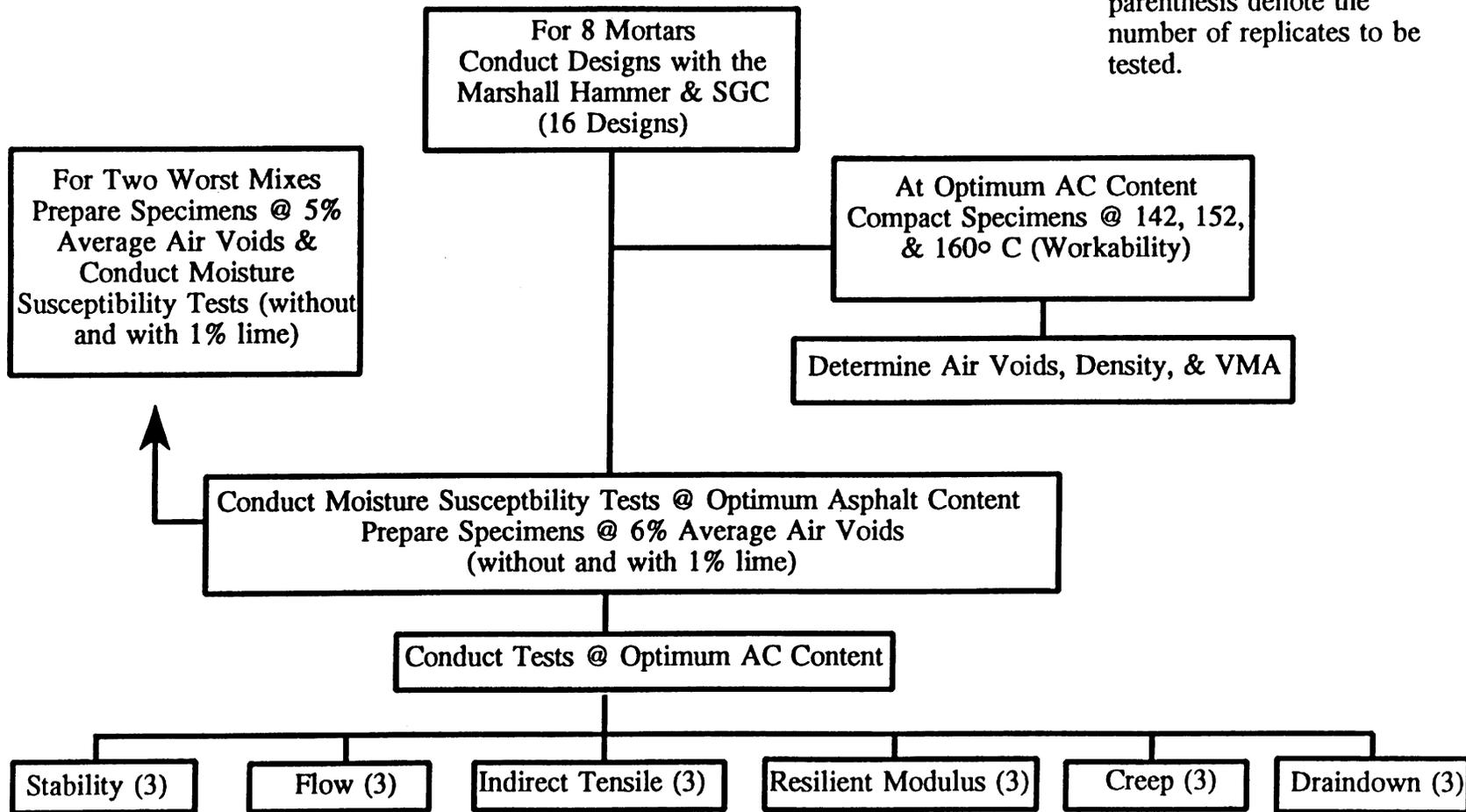


Figure 3.6: Test Plan for Studying Mortar Effects on SMA Mixture Designs

Table 3.2: Test Plan for Flat and Elongated Particles

Aggregate Mixes	SMA Mix Design	Gradations After Compaction	Moisture Susceptibility Tests
100% A1	X	X	X
100% A2	X	X	X
75% A1 - 25% A2	X	X	X
50% A1 - 50% A2	X	X	X
25% A1 - 75% A2	X	X	X

Aggregate A1 - Aggregate containing flat and elongated particles.

Aggregate A2 - Aggregate from same source as A1 but containing no flat and elongated particles.

hammer and SGC compaction for each of the 8 aggregates. This was done by first compacting specimens at optimum asphalt cement content with 50 blows of the Marshall hammer or 100 revolutions of the gyratory. The asphalt cement was then removed from the specimens and their aggregate gradations determined and compared to the gradation prior to compaction. Also, for 4 of these aggregates, the amount of compactive effort was varied to determine how aggregate breakdown varies with compactive effort for both the compaction devices. The two additional Marshall hammer compactive efforts were 35 and 75 blows; the additional SGC compactive efforts were 75 and 125 revolutions. The aggregate breakdown was determined as described for the 8 aggregates above. The amount of aggregate breakdown produced in dense-graded mixtures using 3 of the aggregates was also determined in a similar manner. Dense-graded mixtures were compacted with 75 blows of the Marshall hammer or 128 (N_{design}) revolutions of the SGC.

The second phase of the aggregate breakdown subtask involved gathering field data from SMA projects. The test plan for this part of the subtask is shown in Figure 3.7. A total of 4 field projects were identified (only one submitted complete data). For each project, the data was collected as indicated in the figure. Collection of this data allows for the direct comparison of aggregate breakdown produced by the various stages of SMA design, production, placement, and in-service life.

3.2.5 Workability

This subtask was included to determine if a method could be developed to establish the proper mixing and compaction temperatures for SMA mixtures. Part of this subtask is shown in Figure 3.6. For each of the mortar designs (8 with the Marshall hammer, 8 with the SGC) a compaction temperature-density curve was established by compacting SMA mixtures at optimum asphalt cement at varying temperatures. It is expected that this curve eventually becomes flat as the compaction temperature continues to rise without further increase in mixture density. The temperature at which the curve begins to flatten may be related to the proper SMA mixture compaction temperature.

The mortar from each mixture was tested in a Brookfield viscometer to determine the mortar stiffness at each selected temperature. It is hoped that compaction temperature can be

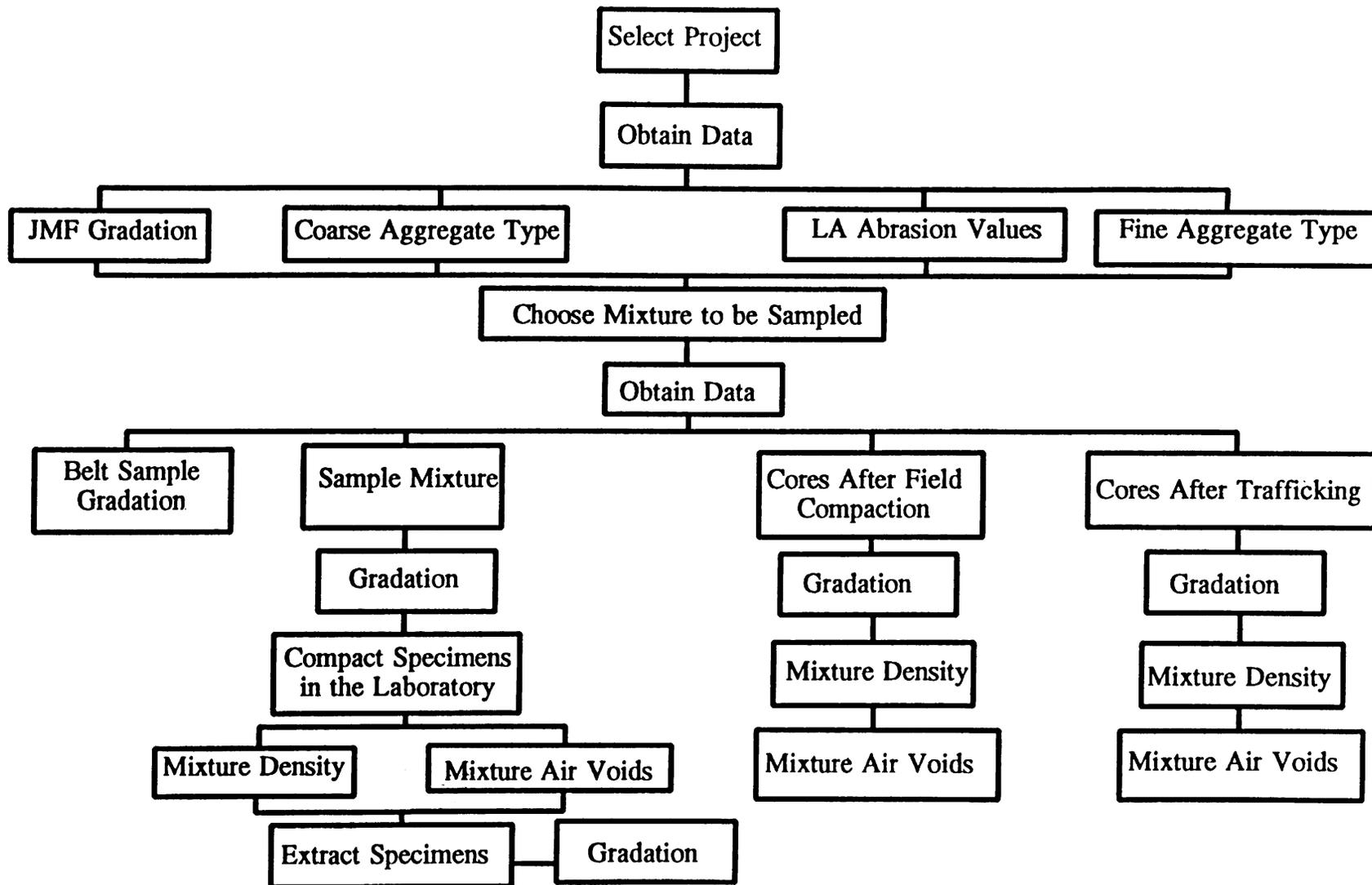


Figure 3.7: Test Plan for SMA Aggregate Breakdown Determination

established based on measured mortar stiffness. Perhaps mixing temperature can be established in a similar way and will likely be 10° to 15°C above compaction temperature.

3.2.6 Permeability Testing

The work in this subtask was undertaken in an effort to establish if SMA mixtures are more or less permeable to water than are conventional dense-graded HMA mixtures. This effort is shown in Figures 3.3 and 3.4 for the Marshall hammer and SGC compacted mixtures, respectively. For 4 of the aggregates, SMA specimens were prepared at optimum asphalt cement content by varying the compactive effort. This yielded compacted specimens having different air void levels. These specimens were tested in a falling head permeometer to determine how permeability varies as a function of air voids. Three specimens were tested at each air void content.

3.3 TASK 6 - MIXTURE ANALYSIS

Task 6 was completed in order to analyze the properties of mixtures produced using the design method established under Task 5. The mixture analyses were done to modify criteria, if necessary, and to further refine the design method. The test plan for this task is shown in Table 3.3. The table shows that two tests were used to analyze the SMA mixtures: Indirect Tensile Creep (ITC), and wheel tracking (WT). As can be seen in Table 3.3, ITC testing was not performed on the SMA mixtures designed using Marshall hammer compaction. This is because there is no way to make ITC test specimens using Marshall hammer compaction. The Superpave Shear Tester (SST) testing was not conducted since an acceptable model for predicting rutting is not available.

Table 3.3: Test Plan for Task 6

Design*		Test			
		Number of Mixture Tests	SST	ITC	WT
Aggregate Effects	Marshall	2	--	--	(3)
	Superpave	2	(3)	(3)	(3)
Mortar Effects	Marshall	2	--	--	(3)
	Superpave	2	(3)	(3)	(3)

* - Refers to compaction method.

NOTE: Numbers in parentheses denote the number of repetition.

3.4 TASK 7 - FINAL REPORT

The requirement of this task was to produce a final report documenting the entire research effort. This report is written in three volumes. Volume I contains a review of all available, pertinent literature at the time the final report was written. The literature was updated based on new information since the interim report. Volume II outlines the research plans, testing, and results obtained during the research program. The Volume II final report provides additional work that was not included in the Volume II interim report. Both Volume II reports are needed to completely understand the research accomplished. Volume III contains the final mixture design method.

CHAPTER 4 - TEST RESULTS AND ANALYSIS

4.1 MATERIAL PROPERTIES

Stone Matrix Asphalt mixtures are made from coarse aggregate, fine aggregate, mineral filler, asphalt cement, and stabilizing additive. In performing the testing reported herein, several different types of each of these materials were included so as to determine the effects of materials on SMA properties. This section details the properties of each of the materials used in the testing.

4.1.1 Coarse Aggregate Properties

Eight different coarse aggregate types were used in the mix design portion of the study. A ninth coarse aggregate, Arkansas limestone, was used for the flat and elongated subtask. The properties of each of these aggregates is shown in Table 4.1. The 8 aggregates used for the mixture design subtask were chosen specifically for their Los Angeles abrasion and absorption characteristics. Note that the aggregates range from very low to very high in Los Angeles abrasion values. The aggregates were selected so that a relatively high and low absorption value is available for each range of L.A. Abrasion values. In addition to the Los Angeles abrasion and absorption values, the aggregate texture is also important. The blast furnace slag is a very rough texture, porous aggregate, while the traprock is a smoother texture, nonporous aggregate. All of the aggregates were 100 percent fractured except for the gravel which had 85 percent of the particles with two or more fractured faces.

The aggregate used in the flat and elongated subtask was chosen because aggregate from the same quarry ledge was crushed in two different manners thus providing two aggregates with identical characteristics with the exception of particle shape. One portion was crushed to provide cubicle particles while another portion was crushed to provide flat or elongated particles.

4.1.2 Fine Aggregate Properties

The fine aggregate properties are shown in Table 4.2 and are similar to the coarse aggregate properties from the corresponding sources. The fractured face count for the gravel fine aggregate was 100 percent. The fine aggregate used for the flat or elongated portion of the study was from the crushing operation that produced cubical coarse aggregate.

4.1.3 Mineral Filler Properties

Eleven different mineral fillers were used in this study. All have been used to some extent in actual SMA production. Their properties are shown in Table 4.3. The BET Surface Area was determined for each of the fillers using the Coulter SA 3100 analyzer. This equipment uses the multi-point BET method to determine surface area. The particle size analysis was completed using the Coulter LS-200 particle size analyzer. Sonic agitation was used in conjunction with this test.

Table 4.1: Properties of the Coarse Aggregate

Property	Test Method	Aggregate Type				
		Traprock	Gravel	Limestone (1)	Dolomite	Granite (1)
Bulk Specific Gravity	AASHTO T85	2.967	2.556	2.752	2.452	2.688
Apparent Specific Gravity	AASHTO T85	3.024	2.689	2.781	2.702	2.735
Absorption, %	AASHTO T85	0.7	1.8	0.4	3.8	0.7
Los Angeles Abrasion, % Loss	AASHTO T96	17	19	24	30	37
Flat and Elongated Particles	ASTM D4791 Section 8.4					
2 to 1		54	56	61	47	55
3 to 1		15	12	23	15	11
5 to 1		1	1	3	1	1
Soundness Loss, %	AASHTO T104	1.1	16.1	0.2	N/A	0.3
Crushed Content, %						
One Face		100	74	100	100	100
Two Faces		100	52	100	100	100

NOTE: Soundness value for gravel is for 10 cycles with Magnesium Sulfate. All other cycles with Sodium Sulfate.

N/A - Not Available

Table 4.1 (continued): Properties of the Coarse Aggregate

Property	Test Method	Aggregate Type				
		Limestone (2)	Granite (2)	Slag	Arkansas Limestone	
					Flat and Elongated	Cubical
Bulk Specific Gravity	AASHTO T85	2.457	2.566	2.263	2.615	2.593
Apparent Specific Gravity	AASHTO T85	2.660	2.668	2.501	2.651	2.638
Absorption, %	AASHTO T85	3.2	1.5	4.2	0.5	0.7
Los Angeles Abrasion, % Loss	AASHTO T96	38	55	46	N/A	N/A
Flat and Elongated Particles	ASTM D4791 Section 8.4					
2 to 1		37	46	15	67	38
3 to 1		4	12	0	25	3
5 to 1		0	0	0	1	0
Soundness Loss, %	AASHTO T104	N/A	0.7	N/A	N/A	N/A
Crushed Content, %						
One Face		100	100	100	100	100
Two Faces		100	100	100	100	100

N/A - Not Available

Table 4.2: Properties of the Fine Aggregate

Property	Test Method	Aggregate Type				
		Traprock	Gravel	Limestone (1)	Dolomite	Granite (1)
Bulk Specific Gravity	AASHTO T84	2.923	2.593	2.648	2.490	2.712
Apparent Specific Gravity	AASHTO T84	3.004	2.695	2.742	2.797	2.736
Absorption, %	AASHTO T84	1.0	1.5	1.3	4.4	0.4
Soundness Loss, %	AASHTO T104	1.1	23.5	0.2	N/A	0.3
Angularity, %	AASHTO TP33	48.3	46.9	44.6	48.0	49.4
Liquid Limit	AASHTO T89	**	**	**	**	**
Plasticity Index	AASHTO T90	NP	NP	NP	NP	NP

NOTE: Soundness value for gravel is Magnesium Sulfate. All other cycles with Sodium Sulfate. All values are 5 cycles

** - Liquid limit could not be determined.

NP- Non-Plastic.

N/A - Not Available

Table 4.2 (continued): Properties of the Fine Aggregate

Property	Test Method	Aggregate Type			
		Limestone (2)	Granite (2)	Slag	Arkansas Limestone
					Cubical
Bulk Specific Gravity	AASHTO T84	2.428	2.687	2.765	2.594
Apparent Specific Gravity	AASHTO T84	2.708	2.690	2.844	2.626
Absorption, %	AASHTO T84	4.3	0.01	1.0	0.5
Soundness Loss, %	AASHTO T104	N/A	0.7	N/A	N/A
Angularity, %	AASHTO TP33	46.1	48.8	49.9	45.3
Liquid Limit	AASHTO T89	**	**	**	**
Plasticity Index	AASHTO T90	NP	NP	NP	NP

** - Liquid limit could not be determined.

NP- Non-Plastic.

N/A - Not Available

Table 4.3: Mineral Filler Properties

Size (μm)	Mineral Filler Type (Cumulative Percent Passing by Volume) ¹										
	Limestone	Marble	Traprock	SE Flyash	GA Flyash	Aglime	Diabase	Wimpey	Dan-kalk	Oyta	Faxekalk
2360	100	100	100	100	100	100	100	100	100	100	100
1180	100	100	98.96	100	99.82	100	100	100	100	98.54	100
600	100	100	95.51	99.16	99.41	100	100	100	100	94.07	100
300	98.22	97.52	88.11	95.21	93.28	97.27	98.30	99.07	97.84	88.62	99.86
150	92.2	84.72	73.00	88.98	81.44	85.51	84.87	91.84	94.19	82.50	98.09
75	79.25	61.43	52.38	77.65	65.92	60.20	53.48	68.56	81.83	74.30	83.45
45	69.82	45.54	38.17	67.03	53.01	40.05	27.33	45.11	70.71	67.04	69.82
20	57.08	28.11	21.93	49.80	34.65	24.08	8.60	17.87	63.90	56.05	56.47
ASG ²	2.883	2.760	2.911	2.303	2.282	2.702	2.864	2.807	2.717	2.692	2.772
RV ³	33.5	40.1	44.1	35.1	46.0	35.8	46.0	43.0	51.7	65.4	38.5
SA ⁴	1.50	0.52	3.36	1.15	1.81	1.31	5.55	1.00	6.23	4.32	1.34

¹ Determinations made using a Coulter LS-200 laser particle size analyzer.

² ASG: Apparent Specific Gravity determined by AASHTO T100

³ RV: Void volume (%) in Dry-Compacted Dust.

⁴ SA: BET Surface area (m^2/g) determined using a Coulter SA 3100 surface area analyzer.

The percentage of material smaller than the 0.020 mm size for these fillers range from 8.6% for the diabase to 63.9% for the dankalk. Only two of these eleven fillers meet the sometimes used requirement that no more than 20 percent by the smaller than the 0.020 mm size.

The void volume for these fillers are determined by a modified Rigdon voids approach; the values vary from 35.5% for the limestone filler to 65.4% for the oyta. It is expected that the fillers with the higher voids will provide a greater stiffening effect when added to the binder.

The surface area for the fillers ranged from 0.52 m²/g for the marble up to 6.23 m²/g for the Dankalk. One would expect that the higher surface area fillers would tend to have a greater stiffening effect on the binder.

4.1.4 Asphalt Cement Properties

The asphalt binders used in the study were tested using both conventional asphalt cement tests and the Superpave binder tests. The designation, as well as the PG grade for each of the asphalt binders are shown in Table 4.4. The complete Superpave binder grading data is shown in Appendix A. From the table it can be seen that the modifiers were added by percent mass of the asphalt cement. At the request of one modifier supplier, the SBS modified AC-20 was from a different crude source than the neat AC-20 used in all other testing. However, the SBS modified asphalt cement was a PG 64-22 before modification just as the neat AC-20 used in this study. The SBS modified asphalt binder was modified by the producer and shipped to the laboratory. The polyolefin modified asphalt binder was produced in the laboratory using the neat AC-20 shown in Table 4.4. The 2 modifiers resulted in a higher grade at the high temperature end and in one case a lower grade at the low end. Thus according to the theory behind PG grades, one of the modified binders should perform better than the neat asphalt cement at high and low temperatures. The other modified binder should perform better than the neat asphalt cement at high temperatures and should provide equal performance to the neat asphalt cement at low temperatures.

Table 4.4: Asphalt Binder Data

Asphalt Binder Designation	Modifier	Percent Modifier by Binder Mass	PG Grade
AC-20	None	0	64-22
AC-20 M1	SBS	4	70-28
AC-20 M2	Polyolefin	8	70-22

4.1.5 Fiber Properties

Cellulose and mineral fiber were selected for inclusion in the test matrix. A rock wool mineral fiber was used. The terms rock wool and mineral fiber are used interchangeably in this report. Both of these fiber types have had extensive use in SMA in the United States and Europe. Typical properties of the fibers are shown in Table 4.5. The surface areas of the fibers were

Table 4.5: Fiber Properties

Property	Cellulose	Rock Wool
Bulk Density (kg/m ³)	28	--
Avg. Fiber Length (mm)	1.1	6.4
Avg. Fiber Thickness (mm)	0.045	0.005
Surface Area (m ² /g)*	1.14	0.23

determined using the multi-point BET method and the Coulter SA 3100 surface analyzer. The bulk density of the mineral fiber was not available.

4.2 MORTAR TEST RESULTS

The mortar in an SMA mixture is designed to hold the aggregate skeleton in place and to provide durability to the mixture. As described in Chapter 3, an SMA mortar is composed of fine aggregate (material passing the 2.36-mm sieve, but retained on the 0.075-mm sieve), mineral filler (material passing the 0.075-mm sieve), asphalt cement, and a stabilizing additive. The tests and results described in this section involve a portion of the mortar that is referred to as the fine mortar. The fine mortar consists of the mineral matter smaller than 0.075 mm, asphalt cement, and stabilizing additive. The fine mortars evaluated in this study are shown in Table 3.1 and their compositions are shown in Table 4.6. The percentages of the components shown in Table 4.6 were determined based on the assumptions that the asphalt content of an SMA mixture was 6.0 percent, the amount of stabilizer was 0.4% for mineral fiber and 0.3% for cellulose, and the amount of mineral filler is as shown.

Each of the fine mortars was tested to determine its characteristics at high, intermediate, and low temperatures. High and intermediate temperature testing was performed using the DSR; low temperature testing was accomplished with the BBR. Asphalt cement aging, when necessary, was done with the RTFO, or with a combination of the RTFO and PAV. The exact aging and testing procedures are described below where relevant.

4.2.1 Specimen Preparation

Mortar testing at high, intermediate, and low temperatures requires unaged, RTFO aged, and PAV aged asphalt cements. Therefore, before mixing the mortars, it was first necessary to age the asphalt binders appropriately. It had been determined earlier that the entire mortar could not be properly aged. Therefore, the asphalt cement had to be aged prior to mixing, and then used in the mortar. Sufficient amounts of the three asphalt binders (AC-20, SBS modified AC-20, and Polyolefin modified AC-20) were aged according to existing Superpave protocol. Thus for each of the three binders, three different aging schemes were completed; no aging, RTFO aging, and

Table 4.6: Fine Mortar Composition

Stabilizer Type	Percent Filler	Percent of Fine Mortar Mass		
		Filler	Asphalt Cement	Stabilizer
None	8	57.1	42.9	0
	10	62.5	37.5	0
	12	66.7	33.3	0
Cellulose Fiber	0	0	95.2	4.8
	8	55.9	42.0	2.1
	10	61.4	36.8	1.8
	12	65.6	32.8	1.6
Mineral Fiber	0	0	93.8	6.2
	10	61.0	36.6	2.4
SBS	0	0	96.0	4.0
	8	57.2	41.1	1.7
	10	62.5	36.0	1.5
	12	66.7	32.0	1.3
Polyolefin	0	0	92.0	8.0
	10	62.5	34.5	3.0

PAV aging. Of course all the material aged in the PAV was first aged in the RTFO according to the Superpave procedures.

To mix the mortars, 100 grams of the given filler was heated in the oven to 175°C while the required amount of asphalt binder was heated to 163°C. The filler and asphalt binder were then removed from the oven and the asphalt stirred into the filler by hand. Once the mixing was completed, the fiber (if used) was added and also stirred by hand until a homogeneous mixture was obtained. For those fine mortars that contained no filler, the asphalt binder was heated as described above and the fiber was then stirred in by hand.

Once a given mortar was mixed, appropriate specimens for the tests to be conducted were made. For high and intermediate temperature testing, DSR samples were molded. For low temperature testing, BBR beams were prepared.

4.2.2 High Temperature Testing

High temperature testing was completed at both 58° and 70°C. Two temperatures were chosen in order to characterize the mortars over a range of temperatures. Superpave binder testing techniques require each mortar to be tested in both its unaged and RTFO aged state at each of the test temperatures using the DSR. Testing was completed according to the protocol of the Superpave binder tests. Two replicates were tested for each mortar at each of the temperatures for both the unaged and RTFO aged mortars.

The average high temperature test results are shown in Tables 4.7-4.11 for the cellulose fiber stabilized, mineral fiber stabilized, SBS stabilized, polyolefin stabilized, and unstabilized

Table 4.7: High Temperature DSR Results for Cellulose Fiber Stabilized Fine Mortars

Filler Type	Percent Filler	Average $G^*/\sin\delta$, kPa			
		No Aging		After RTFO	
		58°C	70°C	58°C	70°C
None	0	7.40	1.72	12.20	2.80
Limestone	8	15.01	3.61	34.21	7.27
	10	17.76	4.00	40.68	8.92
	12	22.01	4.98	47.07	9.24
Marble	8	16.49	4.06	37.12	7.94
	10	20.89	4.57	46.98	9.30
	12	23.36	5.39	55.04	11.12
Traprock	8	14.72	3.48	36.58	7.61
	10	19.25	4.43	46.72	9.62
	12	23.64	4.81	60.71	10.88
Diabase	8	17.42	4.01	38.52	8.34
	10	23.06	5.07	52.26	10.10
	12	26.68	5.71	64.65	11.81
Dankalk	8	20.72	4.86	49.72	10.96
	10	25.16	5.93	73.14	14.36
	12	37.70	8.05	121.98	19.33
Faxekalk	8	16.12	4.01	38.74	8.11
	10	17.47	4.25	45.54	9.27
	12	21.63	5.24	60.33	11.72
SE Flyash	8	15.26	3.74	46.25	8.92
	10	18.59	4.72	54.17	10.92
	12	22.78	5.15	66.32	12.93
GA Flyash	8	21.46	4.95	44.51	9.45
	10	26.06	6.10	59.19	11.73
	12	28.85	6.51	76.05	13.71
Wimpey	8	15.49	3.77	35.82	7.35
	10	19.01	4.08	47.56	9.24
	12	23.55	5.33	53.73	10.35
Aglime	8	17.92	4.35	39.53	8.22
	10	19.96	4.77	44.95	9.16
	12	27.33	5.96	54.99	10.98
Oyta	8	42.93	7.64	469.72	14.28
	10	**	**	**	**
	12	**	**	**	**

** - Mortar too stiff to mold.

Table 4.8: High Temperature DSR Results for Mineral Fiber Stabilized Fine Mortars

Filler Type	Filler Percent	Average $G^*/\sin\delta$, kPa			
		No Aging		After RTFO	
		58°C	70°C	58°C	70°C
None	0	3.86	0.85	7.77	1.60
Limestone	10	14.05	2.95	31.03	6.20
Marble	10	14.02	3.10	33.76	6.33
Traprock	10	15.22	3.25	36.62	6.69
Diabase	10	16.08	3.44	31.68	6.33

Table 4.9: High Temperature DSR Results for SBS Stabilized Fine Mortars

Filler Type	Filler Percent	Average $G^*/\sin\delta$, kPa			
		No Aging		After RTFO	
		58°C	70°C	58°C	70°C
None	0	6.20	1.75	12.08	3.45
Limestone	8	18.33	5.22	37.25	9.47
	10	25.07	6.77	55.11	15.06
	12	35.58	8.59	71.54	18.70
Marble	10	26.57	6.62	57.38	14.12
Traprock	10	33.32	8.28	59.47	15.06
Diabase	10	24.71	6.69	58.12	15.24

Table 4.10: High Temperature DSR Results for Polyolefin Stabilized Fine Mortars

Filler Type	Filler Percent	Average $G^*/\sin\delta$, kPa			
		No Aging		After RTFO	
		58°C	70°C	58°C	70°C
None	0	6.34	1.24	16.00	3.00
Limestone	10	31.81	6.50	87.61	16.22
Marble	10	35.61	7.10	105.84	18.45
Traprock	10	37.54	7.32	97.97	17.07
Diabase	10	35.96	7.11	99.51	17.89

Table 4.11: High Temperature DSR Results for Fine Mortars Without Stabilizers

Filler Type	Percent Filler	Average $G^*/\sin\delta$, kPa			
		No Aging		After RTFO	
		58°C	70°C	58°C	70°C
None	0	2.90	0.59	6.27	1.18
Limestone	8	9.45	1.98	22.77	4.45
	10	11.87	2.50	28.73	5.14
	12	14.91	3.26	35.59	6.92
Marble	8	10.80	2.26	26.61	5.04
	10	15.13	2.99	28.35	5.25
	12	14.44	3.14	44.64	7.83
Traprock	8	11.33	2.35	27.81	5.46
	10	12.12	2.55	28.05	5.26
	12	15.58	3.34	41.89	7.66
Diabase	8	10.28	2.33	25.26	4.92
	10	13.07	2.90	20.09	5.35
	12	16.18	3.57	45.70	8.52

mortars, respectively. To statistically analyze the high temperature data, an analysis of variance (ANOVA) was completed on the cellulose stabilized and unstabilized mortars containing limestone, marble, traprock, and diabase. The ANOVA therefore encompasses two temperatures, two stabilizer types, four filler types, two aging processes, and three filler percentages. The results are shown in Table 4.12. The ANOVA table indicates the significance of each of the variables as well as any significant interaction between them. As can be seen in Table 4.12, none of the four and five way interactions are significant at an α level of 0.05. The three way interactions of temperature, age, and stabilizer type; and temperature, age, and filler percent are significant at the $\alpha = 0.05$ level. Interpretation of the interactions is difficult. The interactions also make it difficult to determine the effect of the individual variables. For this reason, the data was analyzed to establish effects of the variables by looking at trends.

In analyzing individual variable trends, six different variables were examined to determine their effect on the high temperature properties of the fine mortar. These variables are filler type, filler percent, stabilizer type, mineral filler particle shape, the amount of material passing the 0.020-mm sieve in the mineral filler, and the surface area of the mineral filler. The results of each of these examinations are discussed below.

4.2.2.1 Effects of Filler Type

Complete data for each of the 11 filler types exists only for fine mortars stabilized by cellulose fibers. These fine mortars can be compared at the 8, 10, or 12 percent filler levels. The data for the unaged and RTFO aged mortars at 58° and 70°C with 10 percent filler are shown in tabular form in Table 4.7 and plotted in Figures 4.1 and 4.2, respectively. Comparisons at each of the

Table 4.12: ANOVA Table of the High Temperature DSR Fine Mortar Results

SOURCE	Significant @ $\alpha=0.05$
Temperature	Yes
Aging Process	Yes
Filler Type	Yes
Filler Percent	Yes
Stabilizer Type	Yes
Temperature * Aging Process	Yes
Temperature * Filler Type	No
Temperature * Filler Percent	Yes
Temperature * Stabilizer Type	Yes
Aging Process * Filler Type	NO
Aging Process * Filler Percent	Yes
Aging Process * Stabilizer Type	Yes
Filler Type * Filler Percent	No
Filler Type * Stabilizer Type	No
Filler Percent * Stabilizer Type	No
Temperature * Aging Process * Filler Type	No
Temperature * Aging Process * Filler Percent	Yes
Temperature * Aging Process * Stabilizer Type	Yes
Temperature * Filler Type * Filler Percent	No
Temperature * Filler Type * Stabilizer Type	No
Temperature * Filler Percent * Stabilizer Type	No
Aging Process * Filler Type * Filler Percent	No
Aging Process * Filler Type * Stabilizer Type	No
Aging Process * Filler Percent * Stabilizer Type	No
Filler Type * Filler Percent * Stabilizer Type	No
Temperature * Aging Process * Filler Type * Filler Percent	No
Temperature * Aging Process * Filler Type * Stabilizer Type	No
Temperature * Aging Process * Filler Percent * Stabilizer Type	No
Temperature * Filler Type * Filler Percent * Stabilizer Type	No
Temperature * Aging Process * Filler Type * Filler Percent * Stabilizer Type	No

High Temperature DSR Results

10% Filler, Cellulose, Unaged

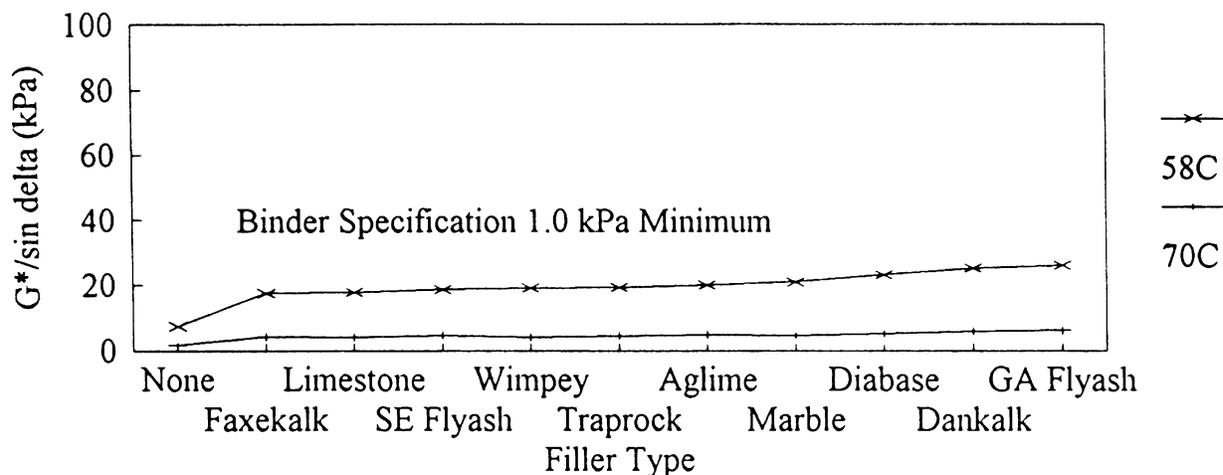


Figure 4.1: Effects of Filler Type (Unaged Fine Mortars)

High Temperature DSR Results

10% Filler, Cellulose, RTFO Aged

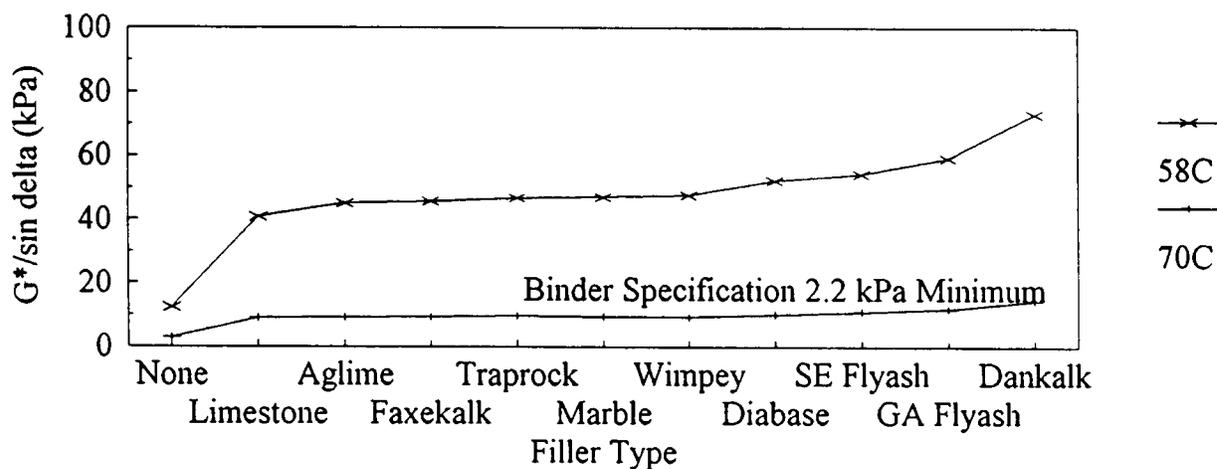


Figure 4.2: Effects of Filler Type (RTFO Aged Fine Mortars)

filler percent levels shows the same general trends. The mortars were compared with 10 percent filler at 58°C prior to aging. The test results show that the mortar with the faxekalk filler had the lowest $G^*/\sin\delta$ with a stiffness of 17.47 kPa. The Georgia flyash had the highest stiffness at 26.06 kPa. Actually the oyta filler provided the mortar with the highest stiffness but it was too stiff to mix at 10 percent and 12 percent filler. So the range from highest to lowest (17.47-26.06) is not that large but the analysis of variance shown in Table 4.12 did show a statistical difference for filler type. The stiffness of the asphalt cement containing only cellulose fiber and no filler was measured to be 7.40 kPa at 58°C. In all cases the addition of filler more than doubled the stiffness of the binder containing asphalt cement and cellulose.

After looking at all of the data in Tables 4.7-4.11, it appears that the addition of filler has a significant effect on the stiffness of the binder but the type of filler appears to have little effect with the exception of oyta which made the binder so stiff in most cases that it could not be blended.

4.2.2.2 Effects of Filler Percent

Complete data for each of the 11 filler types, at each of the filler percent levels, again exists only in fine mortars stabilized by cellulose fibers. These fine mortars contain data for filler percents of 0, 8, 10, and 12 percent. The only exception is for the oyta; the fine mortar with oyta was so stiff it could not be tested at 10 and 12 percent concentrations. The data for the unaged and RTFO aged mortars at 58°C are plotted in Figures 4.3 and 4.4, respectively. These plots readily show that for each filler type, the fine mortar $G^*/\sin\delta$ increases as the percent filler increases. The plots at 70°C show a similar trend so they are not presented here. Thus the addition of filler does act to stiffen the mortar at high temperatures. Increasing the filler from 8 to 12 percent generally results in an increase in stiffness of approximately 50 percent. Also note that Figures 4.3 and 4.4 again indicate, that in general, one filler type does not tend to produce a mortar significantly stiffer than any other (Dankalk appears to be an exception for the RTFO aged mortar).

4.2.2.3 Effects of Stabilizer Type

Data for fine mortars containing each of the stabilizer types present in the experiment is available for four mineral fillers at the 10 percent filler level. These four are limestone, marble, traprock, and diabase. The data for the unaged and RTFO aged mortars at 58°C are shown in Figures 4.5 and 4.6, respectively. In general, the high temperature test results show that the mineral fiber stiffens the least followed by cellulose fiber, SBS, and the polyolefin. For these four stabilizers, the asphalt cement modifiers tend to stiffen the mortars at high temperatures more than do either of the fiber types. This seems to indicate that the polymers will do a better job of preventing rutting. Work under this project has also shown that the fibers do a better job of preventing draindown so the best approach may be to specify a desired PG grade for best resistance to rutting (this may or may not be a modified AC) then use a fiber to prevent draindown.

The data in Table 4.11 shows that the neat asphalt fails to meet the properties of a PG 70. The $G^*/\sin\delta$ as shown in Table 4.7 was measured to be 1.72 for the unaged binder and 2.80 for the aged binder. In this case, the cellulose appeared to improve the higher temperature property of the asphalt. The mineral fiber increases the $G^*/\sin\delta$ to 0.85 and 1.60 for the unaged and aged binder respectively at 70°C (Table 4.8). So, the mineral fiber does not modify the binder sufficiently to meet the PG 70 requirements. From Tables 4.9 and 4.10, it can be seen that the 2 polymers do modify the binder sufficiently to meet the PG 70 requirements.

DSR Results @ 58C

Cellulose Stabilized, Unaged

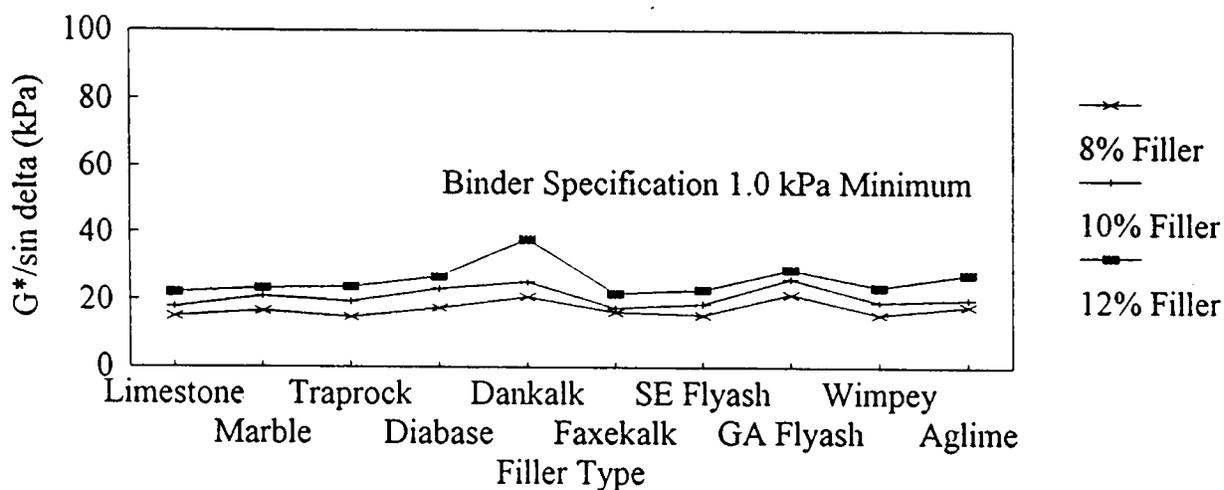


Figure 4.3: Effects of Filler Percent at 58°C (Unaged Fine Mortars)

DSR Results @ 58C

Cellulose Stabilized, RTFO Aged

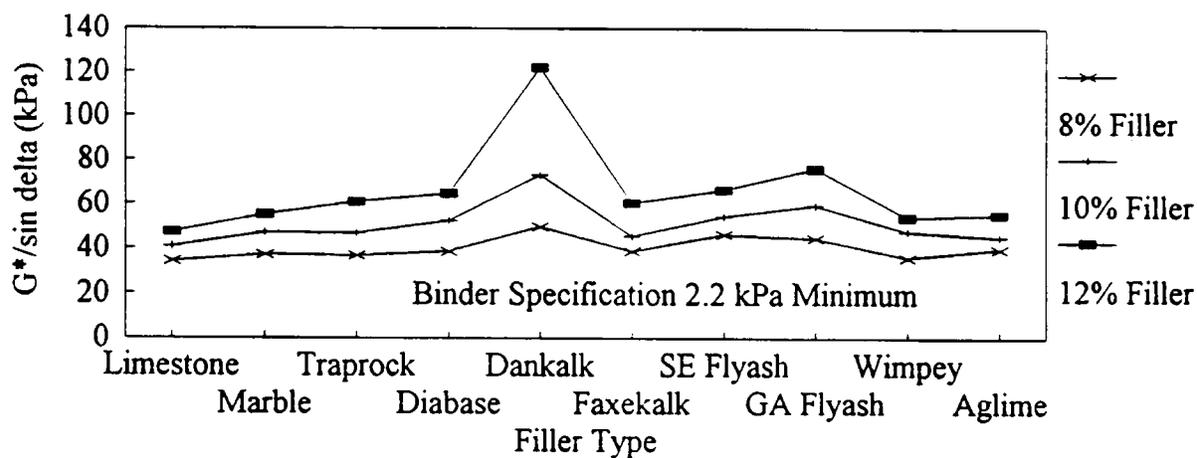


Figure 4.4: Effects of Filler Percent at 58°C (RTFO Aged Fine Mortars)

DSR Results @ 58C

10% Filler, Unaged

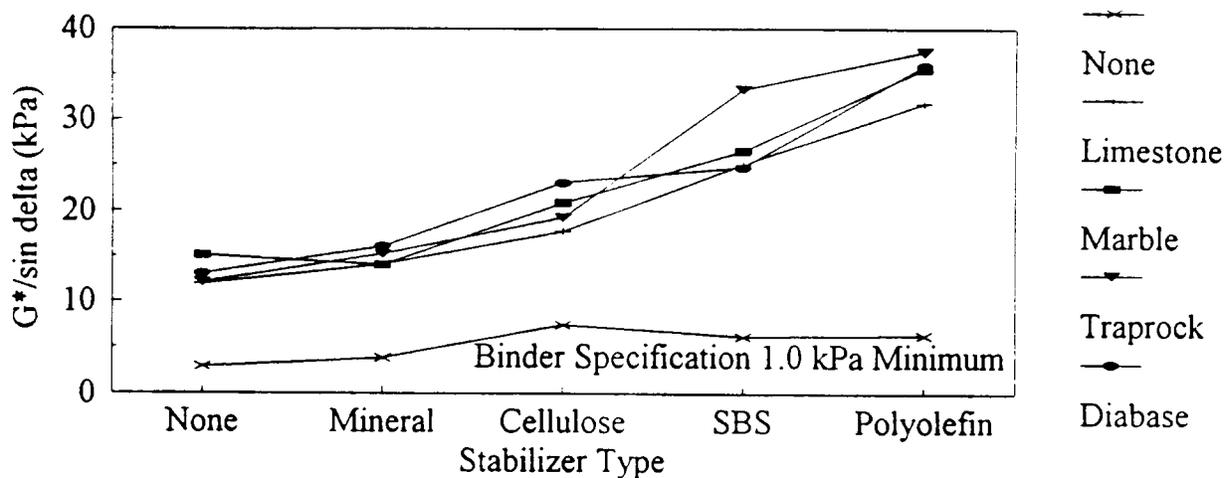


Figure 4.5: Effects of Stabilizer Type at 58°C (Unaged Fine Mortars)

DSR Results @ 58C

10% Filler, RTFO Aged

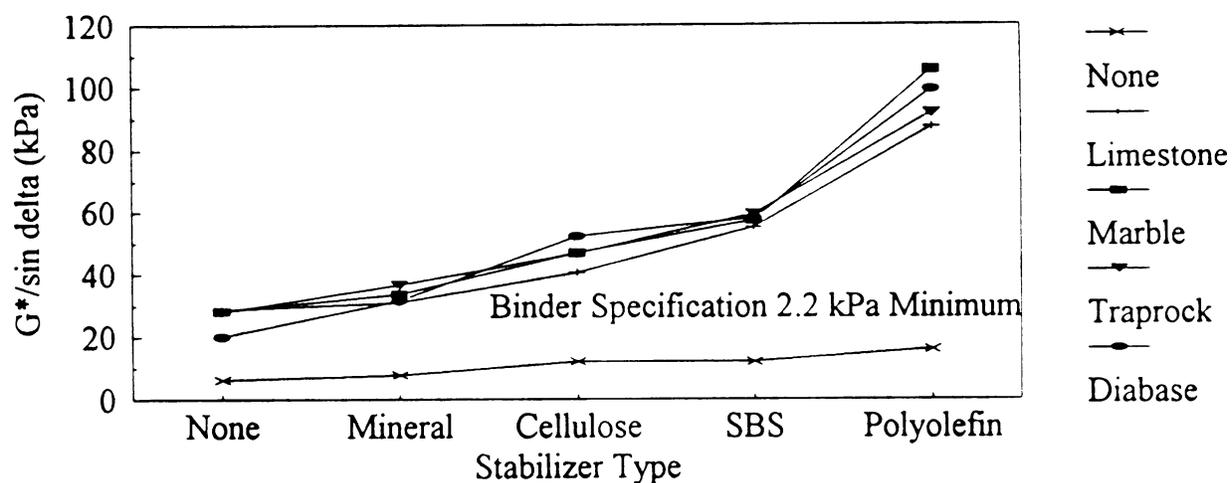


Figure 4.6: Effects of Stabilizer Type at 58°C (RTFO Aged Fine Mortars)

There is an on-going debate about the applicability of testing binders containing fillers, fibers and other discrete particles with the Superpave binder equipment. The authors believe that these tests can be used as a minimum to help rank various binders. The testing of filled systems may not be theoretically correct but it does provide information that can be used to help predict performance of these systems.

4.2.2.4 Effects of Mineral Filler Particle Shape

Since it is not possible to make a direct measurement of the particle shapes in each mineral filler, a surrogate test was used. The Penn State test method (modified Rigden voids) for determining the void volume in dry-compacted dust was chosen because of equipment availability and ease of testing. The test was performed according to the test method found in the National Asphalt Pavement Association (NAPA) Publication IS 101, Appendix B. The method involves packing the mineral filler in a standard cylinder using a specified compactive effort. The mass of the cylinder with the mineral filler inside is then determined. Since the tare mass of the cylinder as well as the cylinder volume are known, the air voids in the mineral filler sample can be determined. It is widely believed that the more angular the particles, the higher the air voids when measured by this test.

To determine what correlation, if any, exists between the fine mortar high temperature characteristics and mineral filler particle shape, linear regression analysis was performed on the data for each test temperature and aging condition. Thus four regression analyses were performed with high temperature fine mortar data (58°C-Unaged, 58°C-RTFO aged, 70°C-Unaged, 70°C-RTFO aged). These results are shown in Table 4.13. As an example, the regression result for the 58°C, unaged fine mortar is shown in Figure 4.7. As can be seen in the figure, the mineral filler particle shape as measured by the Penn State test does correlate well to the $G^*/\sin\delta$ value measured at high temperature. The R^2 values for the four regression analyses ranged from a high of 0.62 to a low of 0.46. Thus, the more angular the particles in a given mineral filler, the more it should stiffen the mortar at high temperatures.

These test results indicate that the void volume of the mineral filler is important to help control the properties of the mortar. Any specification for filler should include the void volume as one of the requirements. Actually the important item to control is the mortar properties but the relationship between filler properties and mortar properties is important to ensure that a filler is selected that will ultimately provide the desired mortar properties.

Table 4.13: Regression Results at High Temperatures for Filler Particle Shape

Aging	Temp., °C	Equation	R ²
Unaged	58	$y = 0.41x + 3.64$	0.618
	70	$y = 0.09x + 1.28$	0.462
RTFO	58	$y = 1.23x + 0.258$	0.579
	70	$y = 0.20x + 1.82$	0.488

DSR Results @ 58C

10% Filler, Cellulose, Unaged

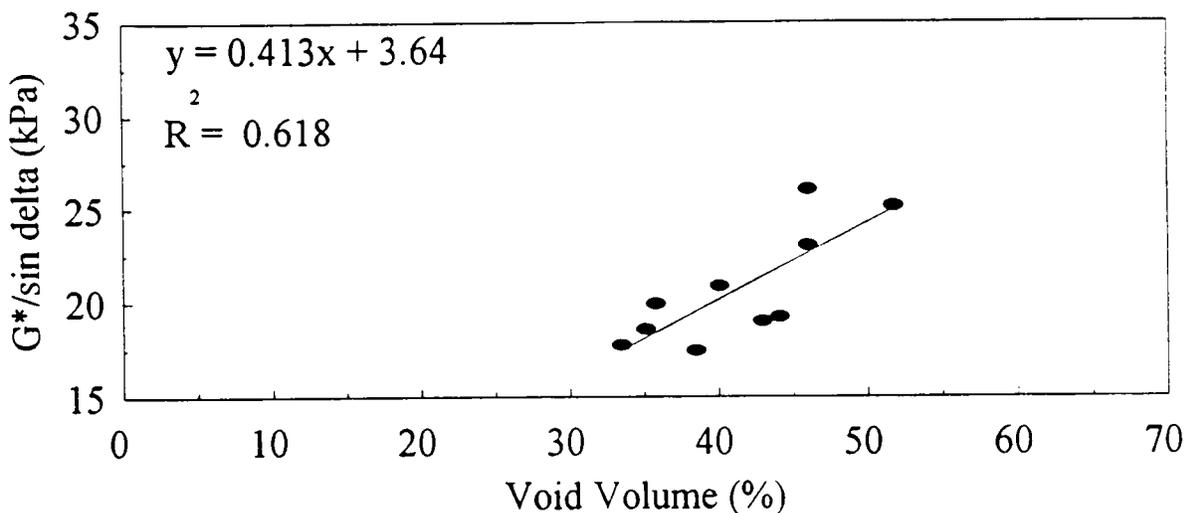


Figure 4.7: Effects of Mineral Filler Particle Shape at 58°C (Unaged Fine Mortars)

4.2.2.5 Effects of Mineral Filler Particle Size

Since the use of SMA began in the United States, there has been an ongoing discussion of the importance to limit the amount of minus 0.020-mm sieve material in the mineral filler. For this reason, the amount of material smaller than the 0.020-mm size was determined for each of the mineral fillers and the high temperature DSR results analyzed as a function of this amount. Regression analyses were again performed for each combination of high temperature and aging. These results are shown in Table 4.14. The result for the unaged fine mortar tested in the DSR at 58°C is shown in Figure 4.8. As can be seen, there appears to be little to no correlation between the $G^*/\sin\delta$ and the percent of the mineral filler passing the 0.02-mm sieve. The R^2 values for the four analyses range from a high of 0.18 to a low of 0.01.

Only 2 of the 10 fillers shown in Figure 4.8 will meet the often used requirement of no more than 20% passing the 0.020 mm size. All of these fillers with the exception of oyta have been used successfully in SMA mixtures. Since there is no correlation between amount passing the 0.020 mm size and mortar properties and since many fillers have been successfully used that don't meet this requirement, it appears that this requirement should be deleted.

4.2.2.6 Effects of Mineral Filler Surface Area

The surface area of a mineral filler is believed to be an important factor that affects the performance of SMA mortar. For this reason, the surface area of each of the mineral fillers was determined and correlated with the high temperature DSR characteristics of the fine mortars. The surface area of each filler was determined using a test method referred to as the BET multi-point

Table 4.14: Regression Results at High Temperatures for Filler Particle Size

Aging	Temp., °C	Equation	R ²
Unaged	58	$y = -0.014x + 21.23$	0.080
	70	$y = 0.004x + 4.64$	0.012
RTFO	58	$y = 0.16x + 45.51$	0.101
	70	$y = 0.04x + 8.89$	0.184

DSR Results @ 58C

10% Filler, Cellulose, Unaged

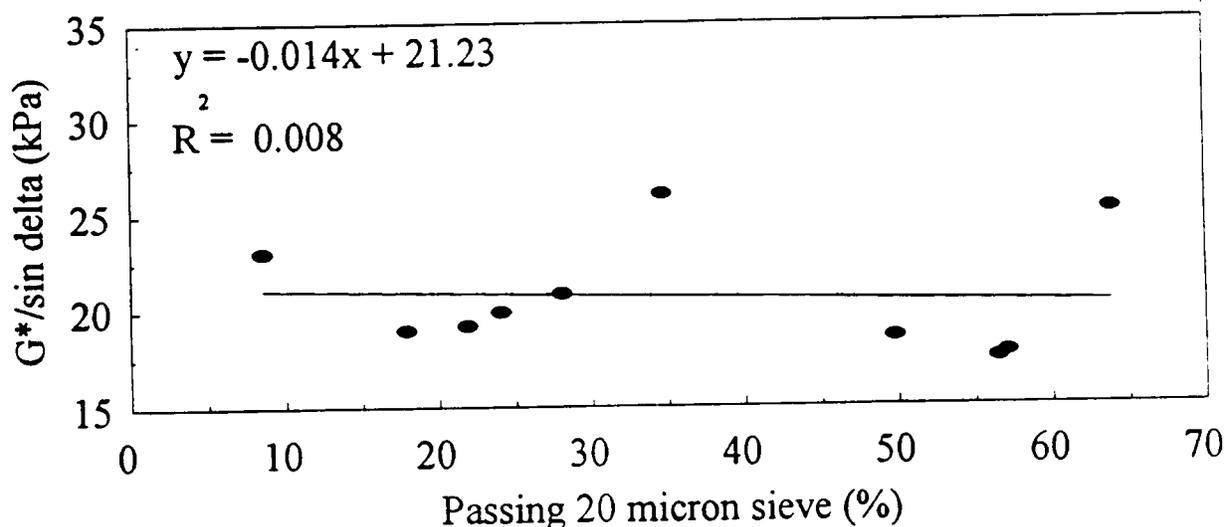


Figure 4.8: Effects of Mineral Filler Particle Sizes at 58°C (Unaged Fine Mortars)

method. The basis of this method is simple in principle. A known mass of any given filler is placed in a small sample chamber of known volume and all the air is evacuated. Next, nitrogen gas is pumped into the sample chamber until the volume is completely occupied. Knowing the size of the nitrogen atoms, the sample chamber volume, and filler mass, the surface area of the filler is determined.

Using the BET surface area results, regression analyses were again completed to determine how $G^*/\sin\delta$ varies as a function of the filler surface area. The results are shown in Table 4.15. Figure 4.9 shows the result for the unaged fine mortar tested at 58°C. This figure indicates that a fair correlation exists between the high temperature DSR characteristics of fine mortars and the surface areas of the filler used in them. The R^2 values for the four high temperature analyses range

from a high of 0.43 to a low of 0.28. In general then, the higher the surface area of the mineral filler, the more it will stiffen the mortar at high temperatures. However, the correlation is not very good.

There is a correlation between surface area and mortar properties but it is not as good as that for void volume. Hence, it is recommended that this test not be considered for specifying fillers.

Table 4.15: Regression Results at High Temperatures for Filler Surface Area

Aging	Temp., °C	Equation	R ²
Unaged	58	$y = 0.87x + 18.65$	0.330
	70	$y = 0.19x + 4.34$	0.284
RTFO	58	$y = 3.05x + 43.87$	0.426
	70	$y = 0.54x + 8.97$	0.413

DSR Results @ 58C

10% Filler, Cellulose, Unaged

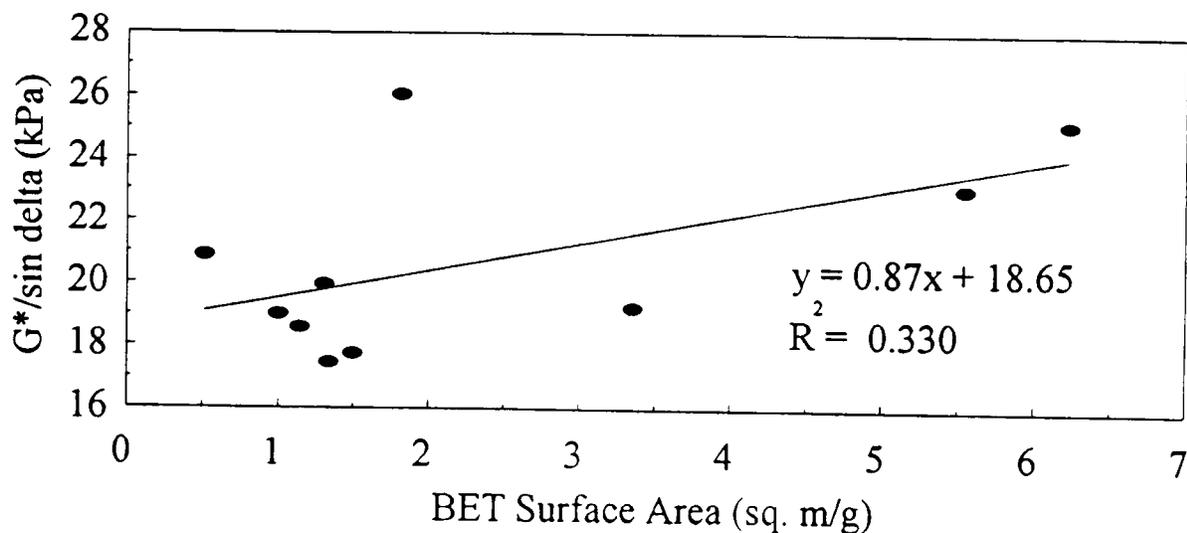


Figure 4.9: Effects of Mineral Filler Surface Area at 58°C (Unaged Fine Mortars)

4.2.3 Intermediate Temperature Testing

Intermediate temperature testing was completed at both 19° and 31 °C. Again, two temperatures were chosen in order to characterize the mortars over a range of temperatures. Superpave binder testing techniques require each mortar to be tested after being aged in the RTFO and the resulting residue further aged in the PAV. Testing was accomplished using the DSR according to the Superpave binder test protocol. Two replicates were tested for each mortar at each of the intermediate test temperatures.

The average intermediate temperature test results are shown in Tables 4.16-4.20 for the cellulose fiber stabilized, mineral fiber stabilized, SBS stabilized, polyolefin stabilized, and unstabilized mortars, respectively. To statistically analyze the data, an analysis of variance (ANOVA) was completed on the cellulose stabilized and unstabilized mortars containing limestone, marble, traprock, and diabase. The ANOVA therefore encompasses two temperatures, four filler types, three filler percentages, and two stabilizer types. The results are shown in Table 4.21. The ANOVA table indicates the significance of each of the variables as well as any significant interaction between them. As can be seen in Table 4.21, only the two way interaction of temperature and filler percent is not significant at an α level of 0.05. The interactions are difficult to interpret, especially when they involve 3 and 4 variables.

In analyzing individual variable trends, six different variables were examined to determine their effect on the intermediate temperature properties of the fine mortar. These variables are filler type, filler percent, stabilizer type, mineral filler particle shape, the amount of material passing the 0.020-mm sieve in the mineral filler, and the surface area of the mineral filler. The results of each of these examinations are discussed below.

4.2.3.1 Effects of Filler Type

Complete data for each of the 11 filler types exists only for fine mortars stabilized by cellulose fibers. These fine mortars can be compared at the 8, 10, or 12 percent filler levels. The data for the PAV aged mortars with 10 percent filler concentration for test temperatures at 19° and 31 °C are shown in Figure 4.10. The figure shows that at 31 °C, there are slight differences in the $G^* \times \sin \delta$ values for fine mortars made with the various mineral fillers. However, at 19 °C, there appears to be more significant differences in $G^* \times \sin \delta$ for fine mortars made with different fillers. At 19 °C, the $G^* \times \sin \delta$ values range from as low as 19000 kPa for the diabase fine mortar to a high of 39,000 kPa for the faxekalk fine mortar. At 31 °C, the $G^* \sin \delta$ values range from 3,000 up to 7,000. These results seem to indicate that the filler type is of some importance in determining the intermediate temperature characteristics of fine mortars. Even though the range of actual stiffness is greater at 19 °C, the percent range is approximately the same for the two temperatures.

It is important to note that none of the cellulose modified mortars meet the Superpave binder specification of 5000 kPa maximum at 19 °C. Most of the cellulose modified mortars meet this specification at 31 °C for both 8 and 10 percent filler concentrations. It appears that only the marble filler meets this specification at 31 °C for the 12 percent filler concentration. It was expected that most of the mortars would fail this requirement since its known that mineral filler will stiffen the binder. The criteria for $G^* \times \sin \delta$ at intermediate temperatures will more than likely have to be modified for mortar testing and evaluation. The stiffness of the mortar at this temperature is typically 4-5 times as large as the stiffness of the asphalt binder.

Table 4.16: Intermediate Temperature DSR Results for Cellulose Fiber Stabilized Fine Mortars

Filler Type	Percent Filler	Average $G^* \times \sin\delta$, kPa	
		19°C	31°C
None	0	9791	1948
Limestone	8	25028	4659
	10	24951	4372
	12	35223	6707
Marble	8	20235	3545
	10	19138	3414
	12	27993	4884
Traprock	8	23476	4568
	10	28284	4974
	12	32413	6588
Diabase	8	25189	4649
	10	19579	3754
	12	28596	6379
Dankalk	8	24260	3778
	10	21087	4867
	12	42838	7733
Faxekalk	8	29395	4940
	10	39137	7344
	12	49302	8186
SE Flyash	8	28689	4966
	10	28431	4748
	12	39025	6765
GA Flyash	8	27977	4803
	10	36689	6797
	12	28295	7171
Wimpey	8	23031	4054
	10	19534	3724
	12	15748	2797
Aglime	8	19926	3102
	10	32876	5549
	12	39168	6732
Oyta	8	33179	6317
	10	**	**
	12	**	**

** Mortar too stiff to mold and test

Table 4.17: Intermediate Temperature DSR Results for Mineral Fiber Stabilized Fine Mortars

Filler Type	Filler Percent	Average $G^* \times \sin\delta$, kPa	
		19°C	31°C
None	0	6460	1159
Limestone	10	20583	4058
Marble	10	27760	4751
Traprock	10	24499	4992
Diabase	10	23688	4570

Table 4.18: Intermediate Temperature DSR Results for SBS Stabilized Fine Mortars

Filler Type	Filler Percent	Average $G^* \times \sin\delta$, kPa	
		19°C	31°C
None	0	4466	850
Limestone	8	17407	2863
	10	14661	2778
	12	19143	3151
Marble	10	16883	2781
Traprock	10	20034	3634
Diabase	10	18128	3356

Table 4.19: Intermediate Temperature DSR Results for Polyolefin Stabilized Fine Mortars

Filler Type	Filler Percent	Average $G^* \times \sin\delta$, kPa	
		19°C	31°C
None	0	6657	1171
Limestone	10	21351	3400
Marble	10	25906	4431
Traprock	10	10183	1753
Diabase	10	13628	2558

Table 4.20: Intermediate Temperature DSR Results for Fine Mortars Without Stabilizers

Filler Type	Percent Filler	Average $G^* \times \sin\delta$, kPa	
		19°C	31°C
None	0	7232	1258
Limestone	8	18207	2999
	10	25730	4409
	12	29243	5021
Marble	8	17423	2546
	10	21742	3592
	12	22242	3593
Traprock	8	25069	4167
	10	29144	5714
	12	27720	5621
Diabase	8	18945	3150
	10	23060	4216
	12	70724	99028

Table 4.21: ANOVA Table of the High Temperature DSR Fine Mortar Results

SOURCE	Significant @ $\alpha=0.05$
Temperature	Yes
Filler Type	Yes
Filler Percent	Yes
Stabilizer Type	Yes
Temperature * Filler Type	Yes
Temperature * Filler Percent	No
Temperature * Stabilizer Type	Yes
Filler Type * Filler Percent	Yes
Filler Type * Stabilizer Type	Yes
Filler Percent * Stabilizer Type	Yes
Temperature * Filler Type * Filler Percent	Yes
Temperature * Filler Type * Stabilizer Type	Yes
Temperature * Filler Percent * Stabilizer Type	Yes
Filler Type * Filler Percent * Stabilizer Type	Yes
Temperature * Filler Type * Filler Percent * Stabilizer Type	Yes

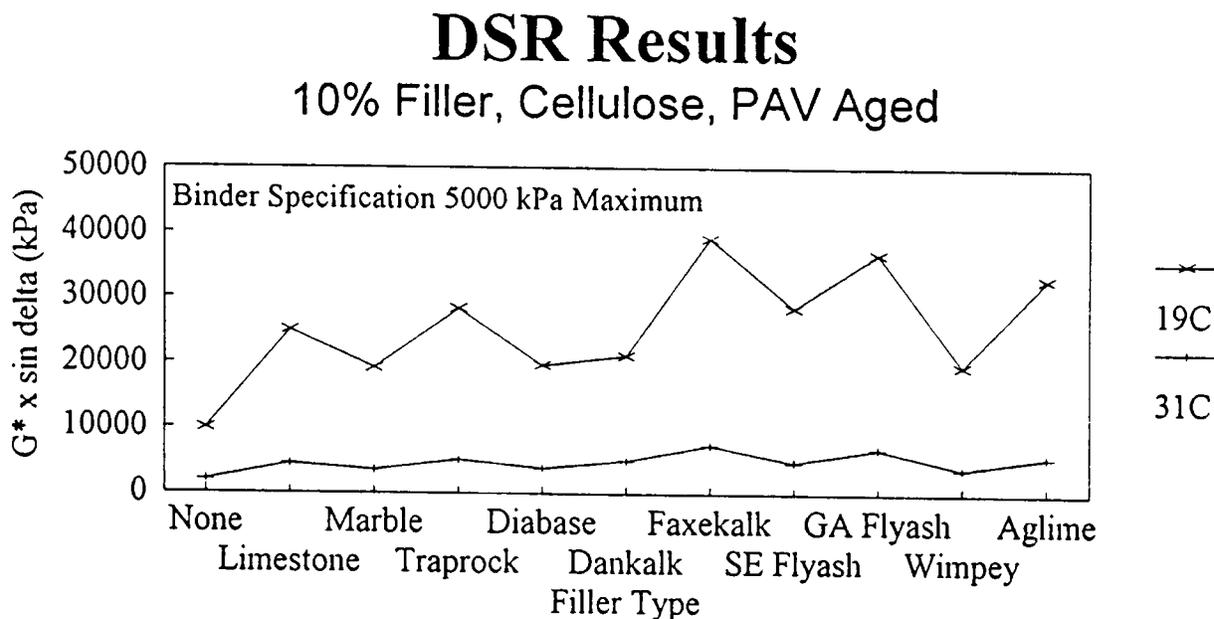


Figure 4.10: Effects of Filler Type at Intermediate Temperatures

4.2.3.2 Effects of Filler Percent

Complete data for each of the 11 filler types, at each of the filler percent levels, again exists only in fine mortars stabilized by cellulose fibers. These fine mortars contain data for filler percents of 0, 8, 10, and 12 percent. The only exception is for the oyta; the fine mortar with oyta was so stiff it could not be tested at 10 and 12 percent filler. The data is plotted in Figures 4.11 and 4.12 for 19° and 31°C, respectively. Both of these plots show some significant variability. These plots indicate that the fine mortar $G^* \times \sin \delta$ is generally increased as the percent filler increases. The differences appear to be larger as the filler percent increases from 10 to 12 percent. On the average, the stiffness of the mortar appears to increase approximately 10 percent from 8-10 percent filler and appears to increase approximately 40% from 8-12 percent filler.

4.2.3.3 Effects of Stabilizer Type

Data for fine mortars containing each of the stabilizer types present in the experiment is available for four mineral fillers at the 10 percent filler level. These four are limestone, marble, traprock, and diabase. The data for the PAV aged mortars at 19° and 31°C are shown in Figures 4.13 and 4.14, respectively. The intermediate temperature test results show that, on average, both the cellulose and mineral fibers stiffen about the same or slightly more than no stabilizer. The polyolefin and SBS modified mortars on the average have about the same stiffness and are less stiff than the average fiber modified mortars. This indicates that the two polymers may be improving the temperature susceptibility of the asphalt cement.

Only the unstabilized SBS modified mortar meets the Superpave binder specification of 5000 kPa maximum at the test temperature of 19°C. All the mortars meet the specification at 31°C. Generally, the fillers tend to increase the mortar stiffness for each stabilizing material from 3-5 percent at each temperature (19°C and 31°C).

DSR Results @ 19C

Cellulose Stabilized, PAV Aged

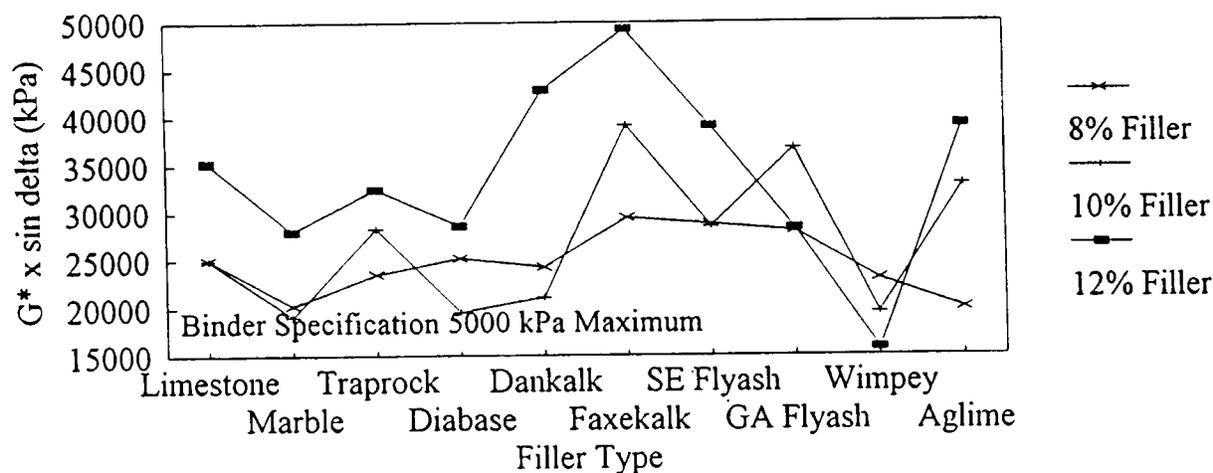


Figure 4.11: Effects of Filler Percent at 19°C

DSR Results @ 31C

Cellulose Stabilized, PAV Aged

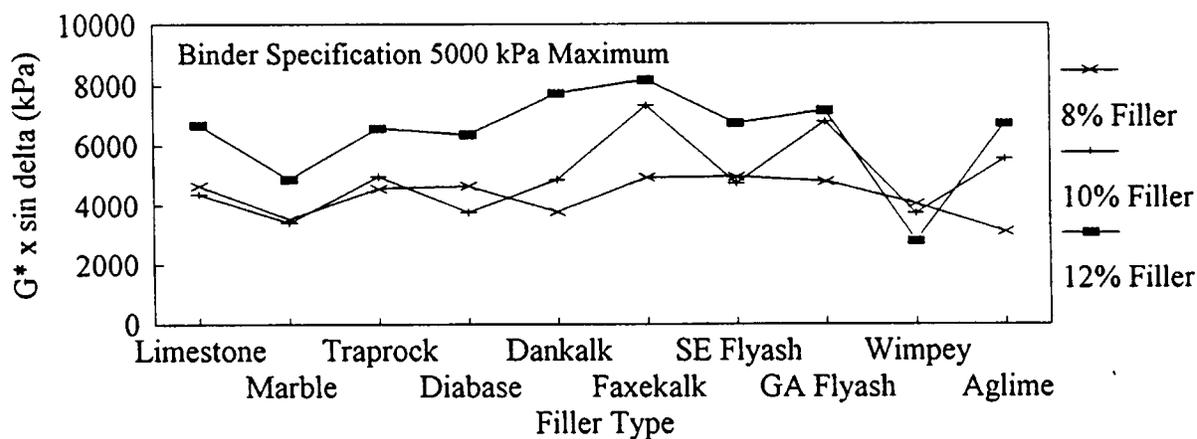


Figure 4.12: Effects of Filler Percent at 31°C

DSR Results @ 19C

10% Filler, PAV Aged

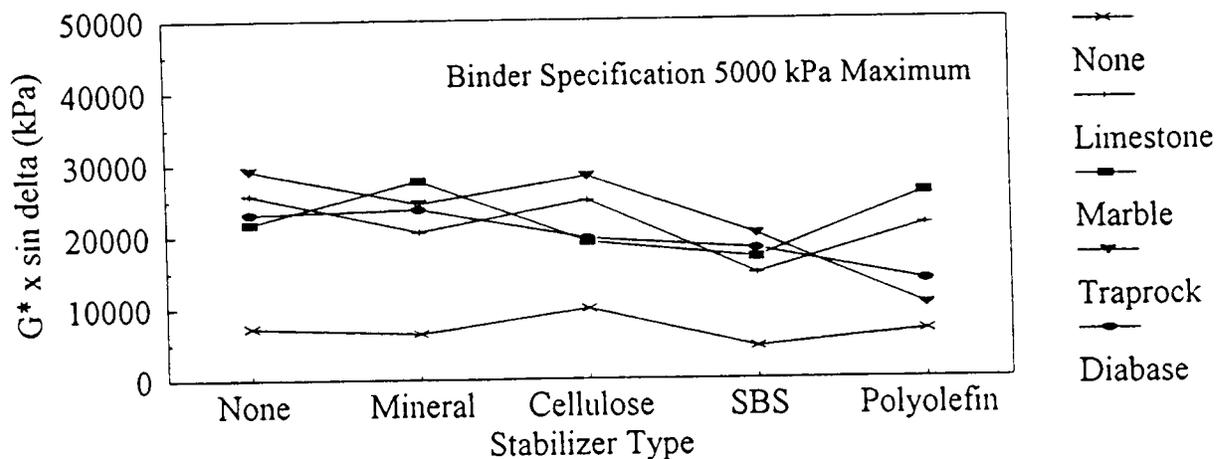


Figure 4.13: Effects of Stabilizer Type at 19°C

DSR Results @ 31C

10% Filler, PAV Aged

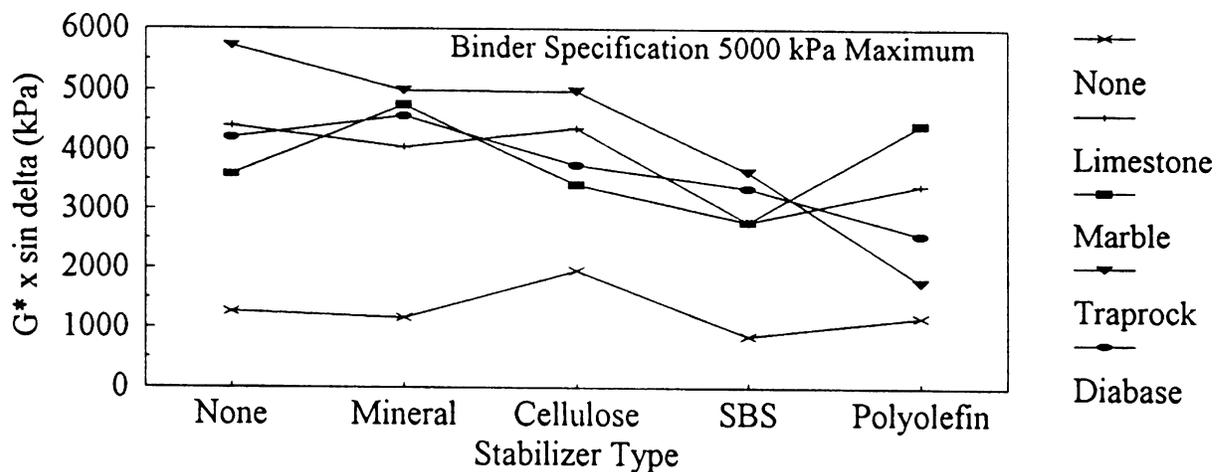


Figure 4.14: Effects of Stabilizer Type at 31°C

4.2.3.4 Effects of Mineral Filler Particle Shape

To determine what correlation, if any, exists between the fine mortar intermediate temperature characteristics and mineral filler particle shape, linear regressions were performed on the data for each intermediate test temperature. The Penn State method was again used as a measure of the particle shape. As an example, the regression result for the 19°C, PAV aged fine mortar is shown in Figure 4.15. As can be seen in the figure, the mineral filler particle shape as measured by this method has no significant correlation to the $G^* \times \sin \delta$ value measured at intermediate temperatures. The R^2 values for the two regression analyses are 0.081 and 0.001 for 19° and 31°C, respectively.

It appears at the intermediate temperatures, mineral filler particle shape is less important to fine mortar characteristics than at the high temperatures. Since asphalt binder becomes stiffer at lower temperatures, it appears that the effect of the binder properties become more important and the aggregate properties less important.

4.2.3.5 Effects of Mineral Filler Particle Sizes

Regression analyses were again performed to determine a correlation between the $G^* \times \sin \delta$ value measured at intermediate temperatures and the percent of the mineral filler passing the 0.020-mm sieve. The result for the PAV aged fine mortar tested in the DSR at 19°C is shown in Figure 4.16. As can be seen, there appears to be no correlation between the $G^* \times \sin \delta$ and the percent of the mineral filler passing the 0.020-mm sieve. The R^2 values for the analyses are 0.08 and 0.157 for 19° and 31°C, respectively. Thus the amount of mineral filler smaller than the 0.020-mm sieve appears to be of little importance to the fine mortar characteristics at intermediate temperatures.

4.2.3.6 Effects of Mineral Filler Surface Area

The surface area of each of the mineral fillers was correlated with the $G^* \times \sin \delta$ value measured at intermediate temperatures to examine their relationship. Figure 4.17 shows the result of the regression analysis for the PAV aged fine mortar tested at 19°C. This figure indicates that no significant correlation exists between the intermediate temperature DSR characteristics of fine mortars and the surface areas of the fillers used in them. The R^2 values are 0.112 and 0.016 for 19° and 31°C, respectively. The intermediate temperature results for mineral filler surface area are in agreement with the other filler properties at this temperature; mineral filler surface area does not appear to be important to the fine mortar properties.

4.2.4 Low Temperature Testing

Low temperature testing was completed at both -18° and -6°C. Two temperatures were chosen in order to characterize the mortars over a range of temperatures. Superpave binder testing techniques required each mortar to be tested after its RTFO residue was aged in the PAV. Testing was performed using the BBR according to the Superpave binder test protocol. Two replicates were tested for each mortar at each of the temperatures.

The average low temperature test results are shown in Tables 4.22-4.26 for the cellulose fiber stabilized, mineral fiber stabilized, SBS stabilized, polyolefin stabilized, and unstabilized mortars, respectively. To statistically analyze the data, an analysis of variance (ANOVA) was completed on the cellulose stabilized and unstabilized mortars containing limestone, marble,

DSR Results @ 19C

10% Filler, Cellulose, PAV Aged

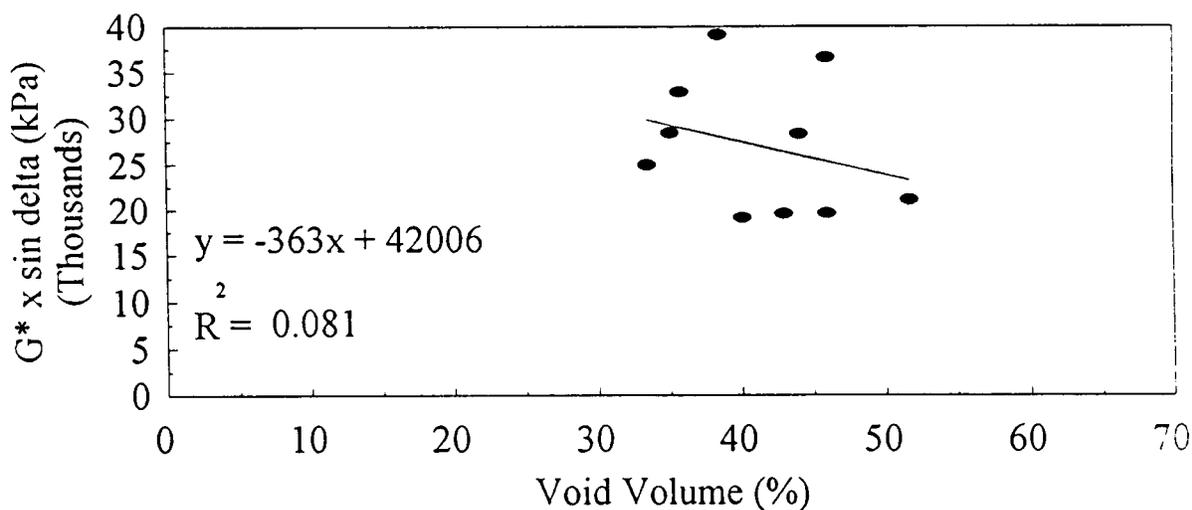


Figure 4.15: Effects of Mineral Filler Particle Shape at 19°C

DSR Results @ 19C

10% Filler, Cellulose, PAV Aged

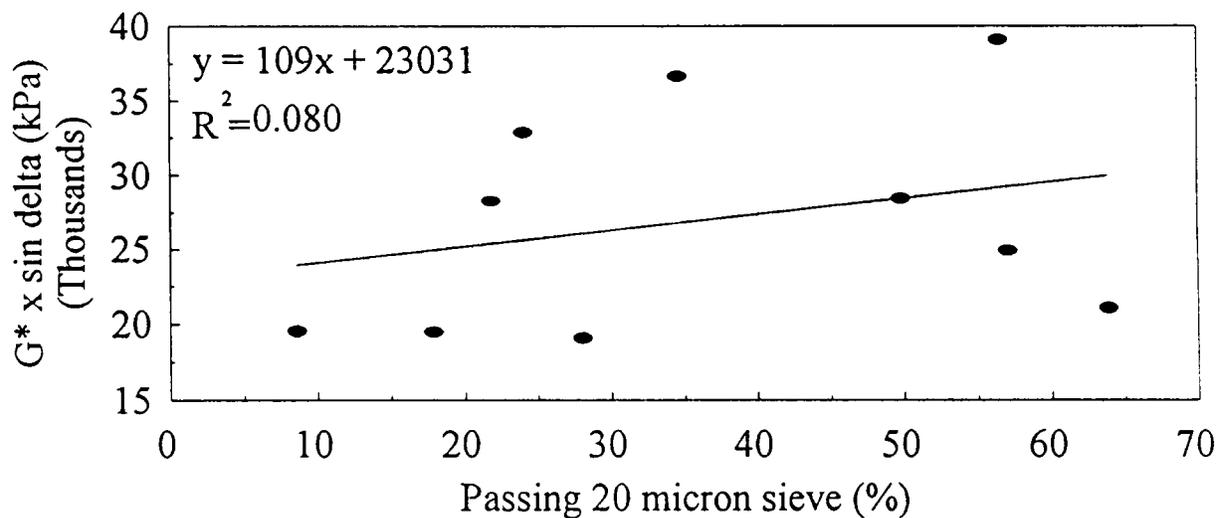


Figure 4.16: Effects of Mineral Filler Particle Sizes at 19°C

DSR Results @ 19C

10% Filler, Cellulose, PAV Aged

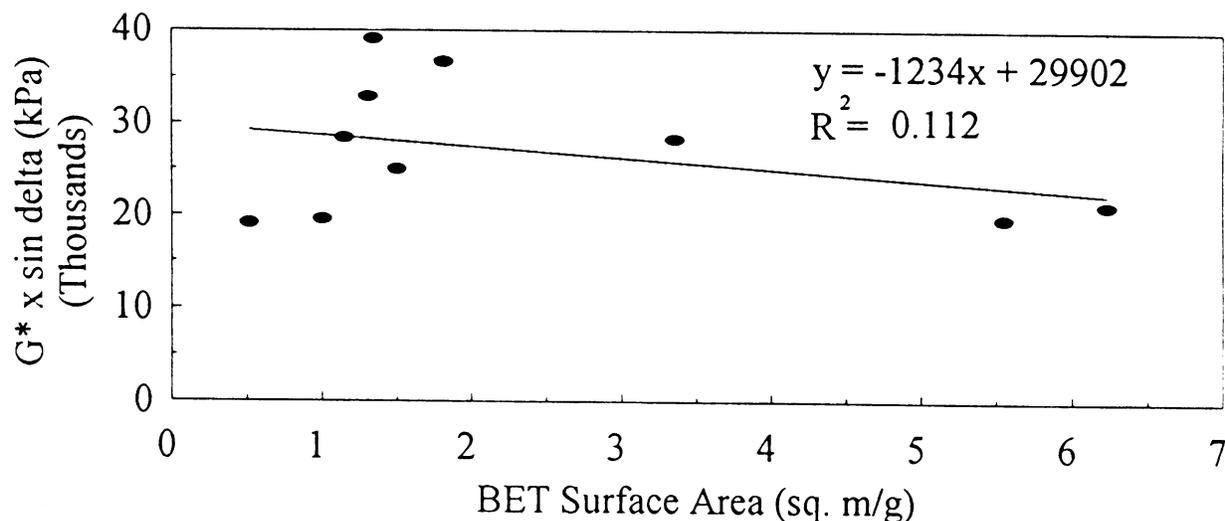


Figure 4.17: Effects of Mineral Filler Surface Area at 19°C

traprock, and diabase. The ANOVA therefore encompasses two temperatures, four filler types, three filler percents, and two stabilizer types. The results are shown in Table 4.27. The ANOVA table indicates the significance of each of the variables as well as any significant interaction between them. As can be seen in Table 4.27, temperature and filler percent are significant as well as the interaction of temperature and filler percent. No other parameter is significant. As temperature decreases and/or filler percent increases, the fine mortar stiffness increases. This seems to indicate that the asphalt binder primarily controls at lower temperatures whereas the filler is more important at higher temperatures.

In addition to the statistical analysis, six different variables were examined to determine their effect on the low temperature properties of the fine mortar. These variables are filler type, filler percent, stabilizer type, mineral filler particle shape, the amount of the filler material smaller than 0.020-mm, and the surface area of the mineral filler. The results of each of these examinations are discussed below.

4.2.4.1 Effects of Filler Type

Complete data for each of the 11 filler types exists only in fine mortars stabilized by cellulose fibers. These fine mortars can be compared at the 8, 10, or 12 percent filler levels. The data for the PAV aged mortars with 10 percent cellulose for tests at -18° and -6°C are shown in Figures 4.18 and 4.19, respectively. All fillers appear to stiffen about the same at these lower temperatures. With the exception of the oya, the differences in the low temperature BBR results in fine mortars made with these different fillers are slight. This is to be expected since the analysis of variance indicated that filler type is insignificant. The m-value does not appear to be significantly affected by the filler type.

Table 4.22: Low Temperature BBR Results for Cellulose Fiber Stabilized Fine Mortars

Filler Type	Percent Filler	Average BBR Results			
		-18°C		-6°C	
		S (MPa)	m-value	S (MPa)	m-value
None	0	379	0.25	93	0.36
Limestone	8	1305	0.26	285	0.38
	10	1419	0.24	423	0.36
	12	1699	0.23	493	0.37
Marble	8	1207	0.26	281	0.38
	10	1628	0.25	331	0.36
	12	1735	0.23	401	0.36
Traprock	8	1394	0.25	351	0.36
	10	1615	0.24	447	0.36
	12	1671	0.23	489	0.34
Diabase	8	1186	0.24	339	0.35
	10	1519	0.24	430	0.34
	12	1645	0.23	596	0.33
Dankalk	8	1138	0.24	469	0.37
	10	1581	0.24	584	0.37
	12	1996	0.23	666	0.37
Faxekalk	8	1229	0.27	364	0.36
	10	1663	0.25	415	0.37
	12	2158	0.25	543	0.36
SE Flyash	8	1253	0.25	365	0.38
	10	1342	0.25	335	0.39
	12	1584	0.24	519	0.36
GA Flyash	8	1266	0.26	399	0.35
	10	1884	0.22	457	0.30
	12	2008	0.22	647	0.33
Wimpey	8	1047	0.25	341	0.38
	10	1525	0.25	356	0.38
	12	2071	0.32	555	0.37
Aglime	8	1195	0.26	318	0.38
	10	1634	0.27	411	0.38
	12	2079	0.26	543	0.36
Oyta	8	2164	0.21	843	0.34
	10	**	**	**	**
	12	**	**	**	**

** - Mortar too stiff to mold.

Table 4.23: Low Temperature BBR Results for Mineral Fiber Stabilized Fine Mortars

Filler Type	Filler Percent	Average BBR Results			
		-18°C		-6°C	
		S (MPa)	m-value	S (MPa)	m-value
None	0	503	0.25	145	0.32
Limestone	10	1954	0.23	587	0.33
Marble	10	2085	0.23	608	0.34
Traprock	10	1707	0.23	547	0.33
Diabase	10	1350	0.23	409	0.35

Table 4.24: Low Temperature BBR Results for SBS Stabilized Fine Mortars

Filler Type	Filler Percent	Average BBR Results			
		-18°C		-6°C	
		S (MPa)	m-value	S (MPa)	m-value
None	0	241	0.32	52	0.41
Limestone	8	735	0.29	143	0.42
	10	1069	0.28	271	0.41
	12	1230	0.26	250	0.39
Marble	10	1183	0.28	261	0.34
Traprock	10	1205	0.26	298	0.39
Diabase	10	1023	0.25	291	0.39

Table 4.25: Low Temperature BBR Results for Polyolefin Stabilized Fine Mortars

Filler Type	Filler Percent	Average BBR Results			
		-18°C		-6°C	
		S (MPa)	m-value	S (MPa)	m-value
None	0	397	0.31	83	0.41
Limestone	10	1562	0.26	426	0.38
Marble	10	1708	0.25	461	0.38
Traprock	10	1827	0.23	493	0.37
Diabase	10	1701	0.24	426	0.34

Table 4.26: High Temperature DSR Results for Fine Mortars Without Stabilizers

Filler Type	Percent Filler	Average BBR Results			
		-18 °C		-6 °C	
		S (MPa)	m-value	S (MPa)	m-value
None	0	383	0.30	87	0.41
Limestone	8	1229	0.26	305	0.41
	10	1360	0.24	400	0.38
	12	1491	0.25	462	0.41
Marble	8	1166	0.27	287	0.40
	10	1660	0.24	429	0.38
	12	1887	0.25	529	0.39
Traprock	8	1310	0.26	342	0.40
	10	1714	0.25	467	0.36
	12	1433	0.25	497	0.38
Diabase	8	1197	0.26	350	0.40
	10	1773	0.25	499	0.35
	12	1741	0.24	446	0.37

Table 4.27: ANOVA Table of the Low Temperature BBR Fine Mortar Results

SOURCE	Significant @ $\alpha=0.05$
Temperature	Yes
Filler Type	NO
Filler Percent	Yes
Stabilizer Type	No
Temperature * Filler Type	No
Temperature * Filler Percent	Yes
Temperature * Stabilizer Type	No
Filler Type * Filler Percent	No
Filler Type * Stabilizer Type	No
Filler Percent * Stabilizer Type	No
Temperature * Filler Type * Filler Percent	No
Temperature * Filler Type * Stabilizer Type	No
Temperature * Filler Percent * Stabilizer Type	No
Filler Type * Filler Percent * Stabilizer Type	No
Temperature * Filler Type * Filler Percent * Stabilizer Type	No

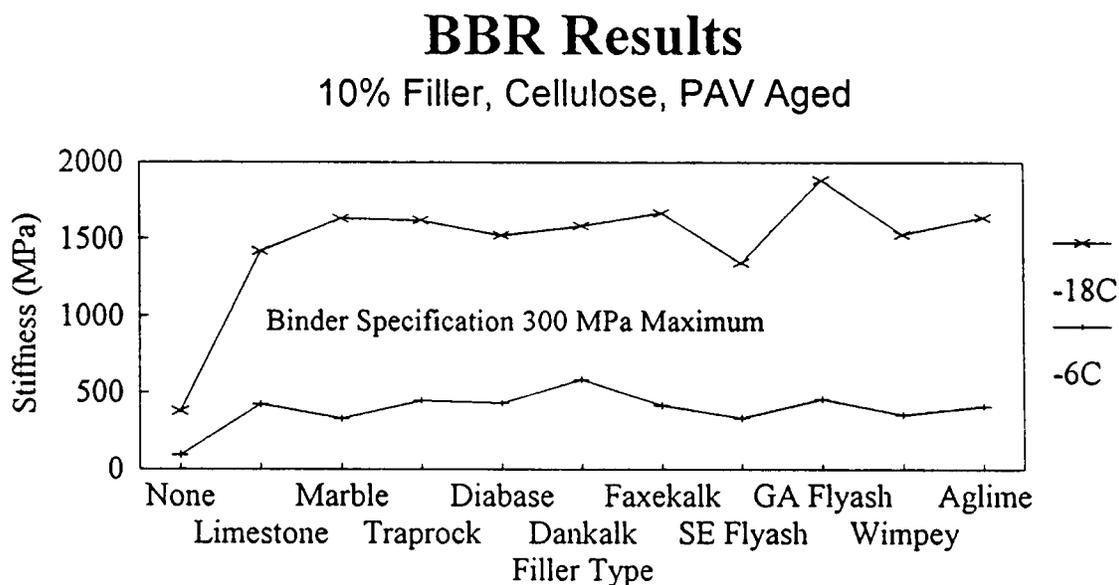


Figure 4.18: Effects of Filler Type on BBR Stiffness at Low Temperatures

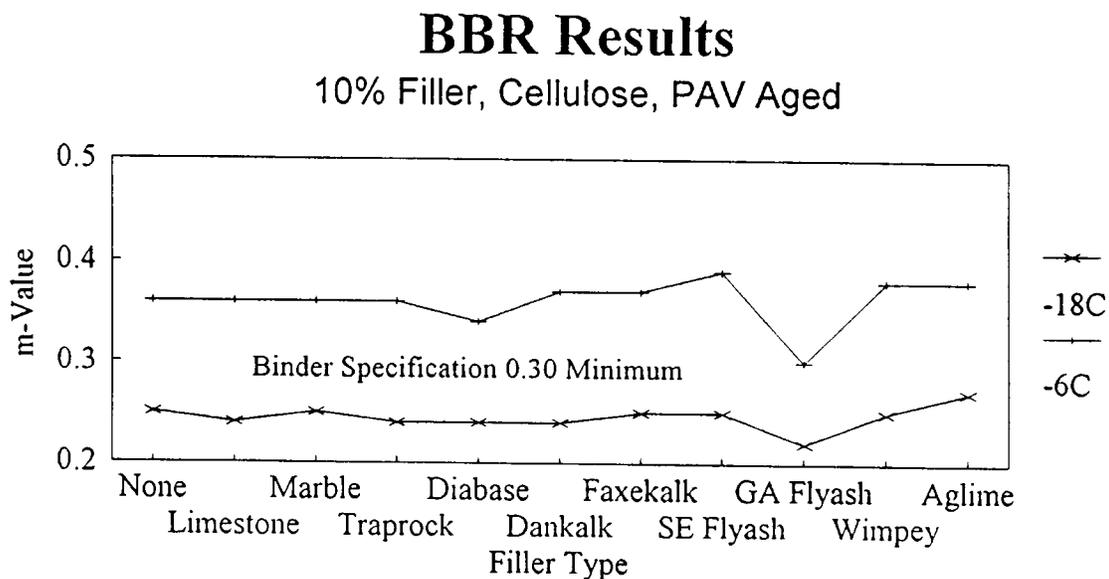


Figure 4.19: Effects of Filler Type on BBR m-values at Low Temperatures

None of the cellulose modified mortars meet the Superpave binder BBR stiffness and m-value specifications of 300 MPa maximum and 0.30 minimum, respectively at -18°C . Only the cellulose modified mortars with 8 percent concentrations of limestone and marble meet these specifications at -6°C .

4.2.4.2 Effects of Filler Percent

Complete low temperature data for each of the 11 filler types, at each of the filler percent levels, again exists only in fine mortars stabilized by cellulose fibers. These fine mortars contain data for filler percents of 0, 8, 10, and 12 percent. The only exception is for the oya; the fine mortar with oya was so stiff it could not be tested at 10 and 12 percent filler. The data is plotted in Figures 4.20 and 4.21 for -18° and -6°C , respectively. These plots indicate that for each of the filler types, the fine mortar BBR stiffness increases as the percent filler increases. The data further shows (Tables 4.22-4.26) that the slope of the creep curve, the m-value, is relatively unaffected by the percent filler in the fine mortar.

4.2.4.3 Effects of Stabilizer Type

Data for fine mortars containing each of the stabilizer types present in the experiment is available for only four mineral fillers at the 10 percent filler level. These four are limestone, marble, traprock, and diabase. The BBR stiffness data for the PAV aged mortars tested at -18° and -6°C are plotted in Figures 4.22 and 4.23, respectively. In general, the low temperature test results show that the mineral fiber stabilized mortars are the most stiff followed by mortars without stabilizers. The cellulose and polyolefin mortars have about the same stiffness; the SBS modified mortars were the least stiff.

Only the SBS modified mortars meet the Superpave binder BBR stiffness and m-value specifications at the test temperature of -6°C . None of the mortars meets the stiffness or m-value specifications at -18°C ; all the mortars meet the m-value specification at -6°C . The results indicate that the m-value may be slightly sensitive to the type of stabilizer. From the results, it can be seen that the SBS modifier plays an important role in keeping the mortar somewhat pliable at the low test temperatures.

4.2.4.4 Effects of Mineral Filler Particle Shape

To determine what correlation, if any, exists between the fine mortar low temperature characteristics and mineral filler particle shape, linear regression was performed on the data for each low test temperature. The Penn State method was again used as a measure of the particle shape. As an example, the regression result for the -18°C , PAV aged fine mortar is shown in Figure 4.24. As can be seen in the figure, the mineral filler particle shape as measured by the test method only slightly correlates to the BBR stiffness value measured at low temperatures. The R^2 values for the two regression analyses are 0.19 and 0.45 for -18° and -6°C , respectively. This result is in reasonable agreement with the low temperature statistical analysis that suggested the filler type was not a significant variable in describing the fine mortar low temperature stiffness.

4.2.4.5 Effects of Mineral Filler Particle Sizes

Regression analyses were again performed to determine a correlation between the BBR stiffness value measured at low temperatures and the percent of the mineral filler passing the 0.020-mm size. The result for the PAV aged fine mortar tested in the BBR at -18°C is shown in Figure

BBR Results @ -18C

Cellulose Stabilized, PAV Aged

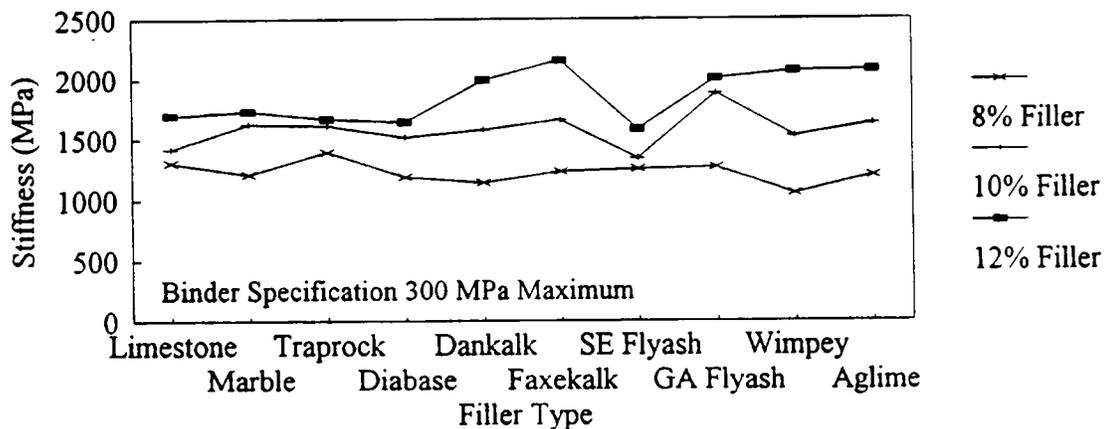


Figure 4.20: Effects of Filler Percent at -18°C

BBR Results @ -6C

Cellulose Stabilized, PAV Aged

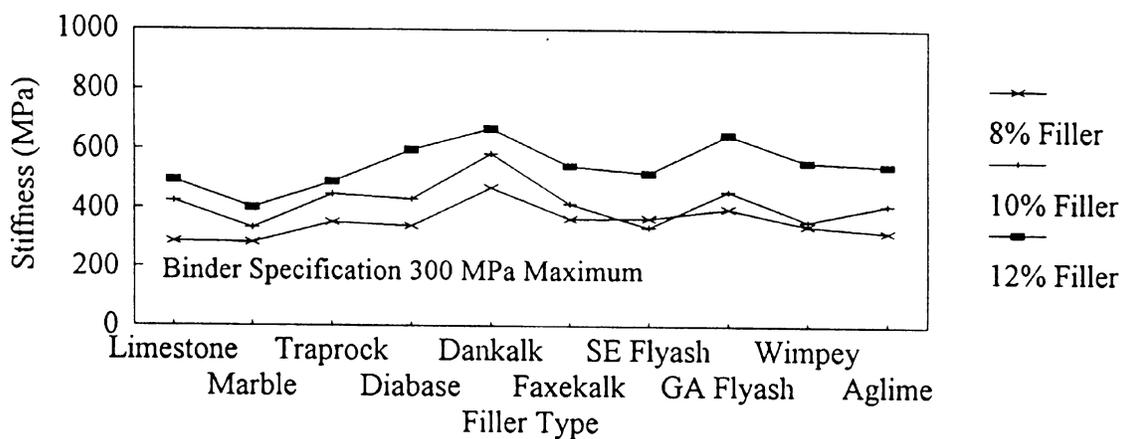


Figure 4.21: Effects of Filler Percent at -6°C

BBR Results @ -18C

10% Filler, PAV Aged

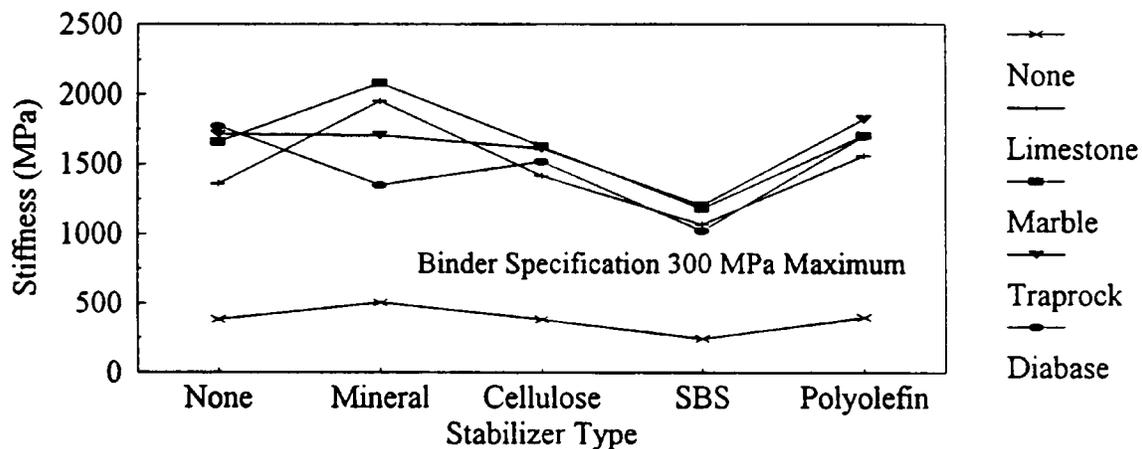


Figure 4.22: Effects of Stabilizer Type at -18°C

BBR Results @ -6C

10% Filler, PAV Aged

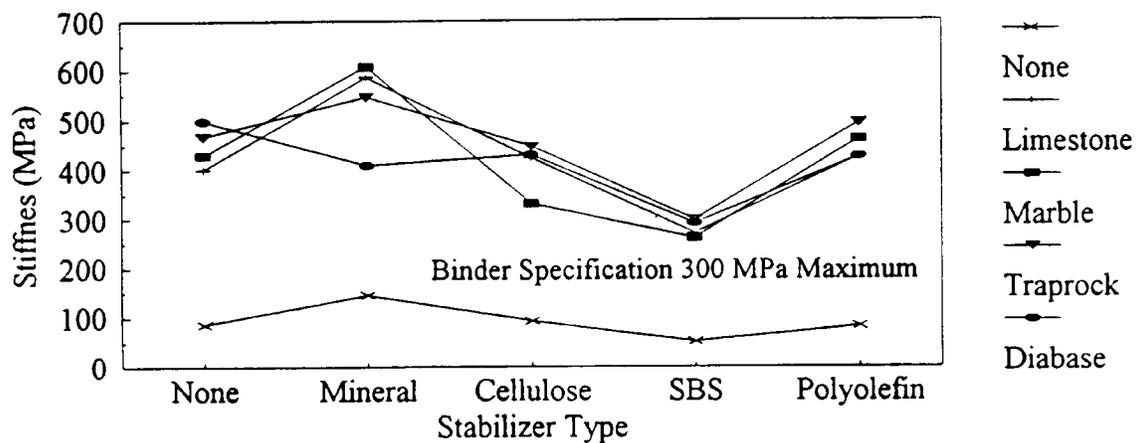


Figure 4.23: Effects of Stabilizer Type at -6°C

BBR Results @ -18C

10% Filler, Cellulose, PAV Aged

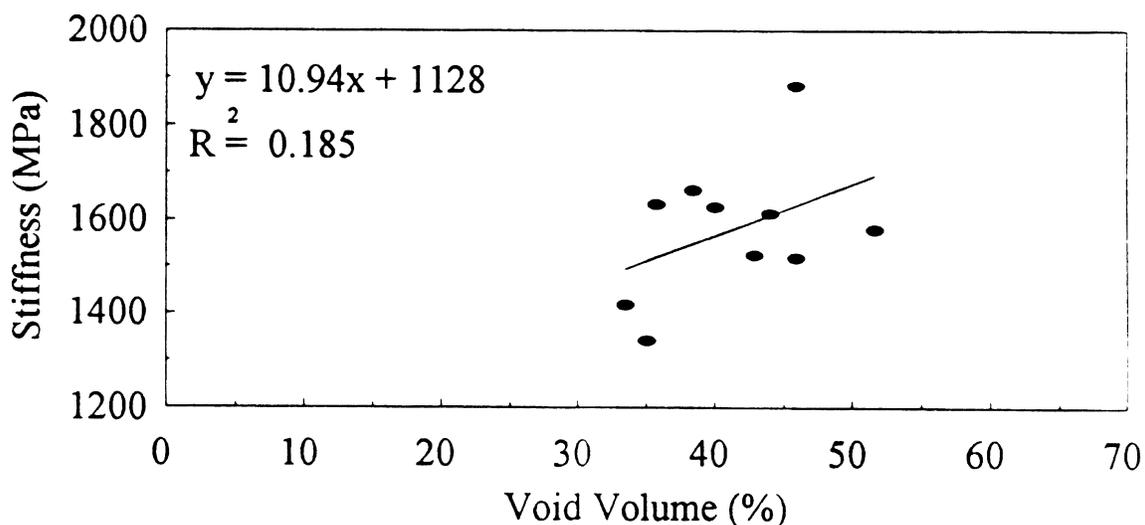


Figure 4.24: Effects of Mineral Filler Particle Shape at -18°C

4.25. As can be seen, there appears to be little to no correlation between the BBR stiffness and the amount of the mineral filler smaller than 0.020-mm. The R^2 values for the analyses are 0.03 and 0.13 for -18° and -6°C, respectively.

4.2.4.6 Effects of Mineral Filler Surface Area

The surface area of each of the mineral fillers was correlated with the BBR stiffness value measured at low temperatures to examine their relationship. The surface areas of the fillers were determined using the multi-point BET method. Figure 4.26 shows the result of the regression analysis for the PAV aged fine mortar tested at -18°C. This figure indicates that no correlation exists ($R^2 = 0.00$) between the BBR characteristics of fine mortars at -18°C and the surface areas of the filler. However, the R^2 value for the -6°C test temperature indicates a good relationship exists ($R^2 = 0.62$).

4.3 MIXTURE DESIGN ANALYSIS

4.3.1 General

Mixture designs were conducted on a number of mixtures to determine the optimum gradation for stone on stone contact, the optimum asphalt content, and the mixture properties at optimum asphalt content. The following designs were conducted:

BBR Results @ -18C

10% Filler, Cellulose, PAV Aged

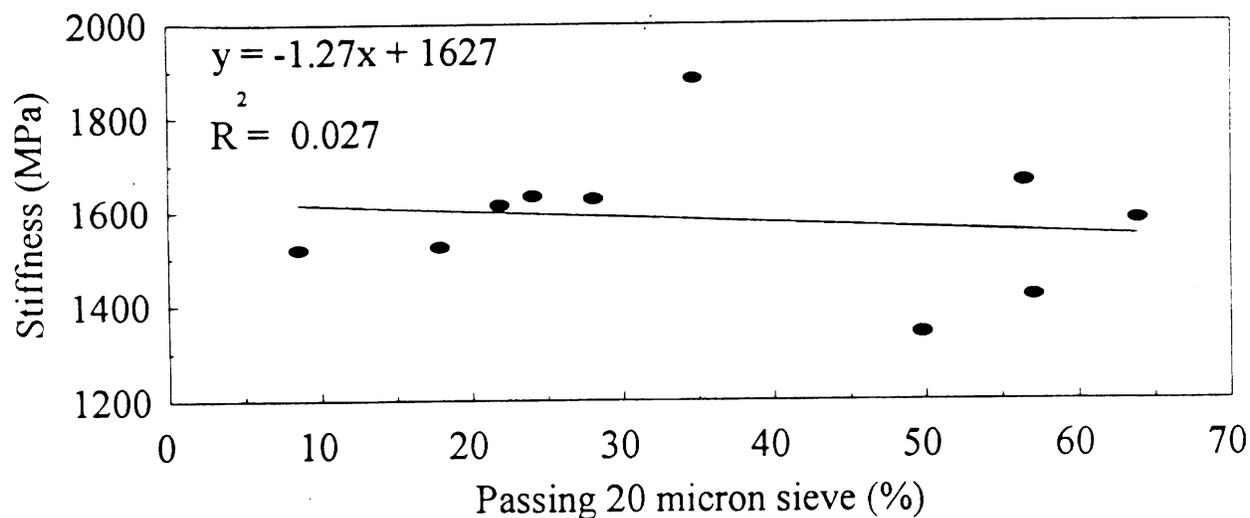


Figure 4.25: Effects of Mineral Filler Particle Sizes at -18°C

BBR Results @ -18C

10% Filler, Cellulose, PAV Aged

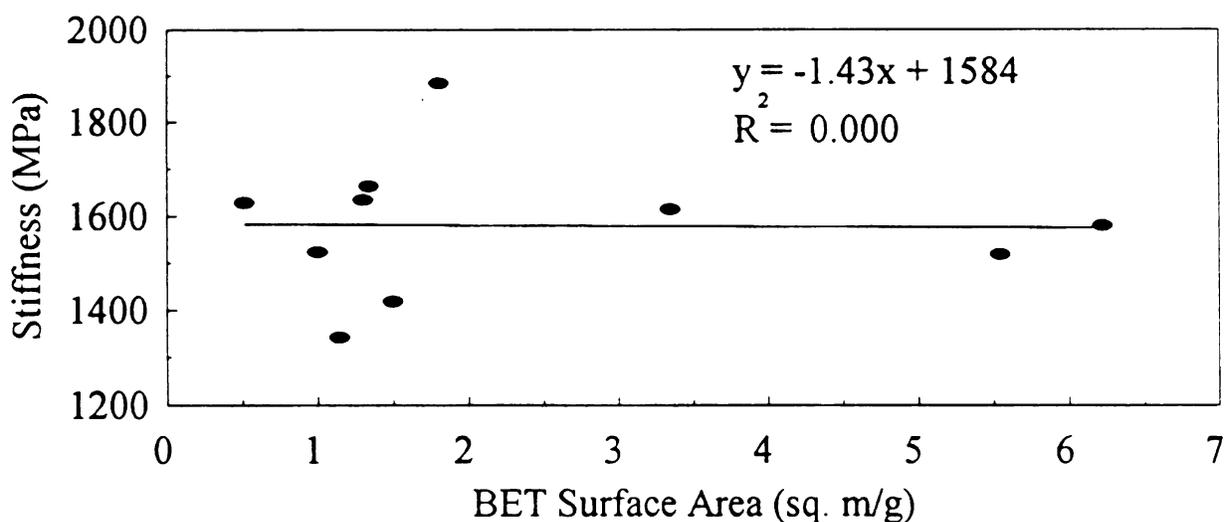


Figure 4.26: Effects of Mineral Filler Surface Area at -18°C

- 1) SMA designs for 8 aggregate types using 50-blow Marshall,
- 2) SMA designs for 4 aggregate types using 35-blow Marshall,
- 3) SMA designs for 4 aggregate types using 75 blow Marshall,
- 4) SMA designs for 8 aggregate types using 100 revolutions of the SGC,
- 5) SMA designs for 4 aggregate types using 75 revolutions of the SGC,
- 6) SMA designs for 4 aggregate types using 125 revolutions of the SGC,
- 7) Dense-graded designs for 8 aggregate types using 75-blow Marshall,
- 8) Dense-graded designs for 8 aggregate types using 128 revolutions of the SGC,
- 9) SMA designs for 8 filler types using 50-blow Marshall, and
- 10) SMA designs for 8 filler types using 100 revolutions of the SGC.

This resulted in a total of 64 designs that allowed for the comparison of various aggregate and fillers for dense-graded and SMA mixtures. The data from these designs is summarized in Tables 4.28 through 4.36. The results will be discussed below and in more detail in Chapter 5.

4.3.2 Effects of Aggregate Type

Eight aggregate types were used to design and evaluate SMA and dense graded mixtures. These eight aggregate types were: limestone(1), granite (1), traprock, granite (2), dolomite, gravel, limestone (2), and blast furnace slag. The properties of these eight aggregates are discussed in Section 4.1. These aggregates were selected because they are widely used and because of the varying aggregate properties.

4.3.2.1 Marshall Hammer Compaction

The SMA mixtures designed with the Marshall hammer are shown in Tables 4.28, 4.29, and 4.30 for 50 blows, 35 blows, and 75 blows, respectively. SMA mixtures are typically designed using a compactive effort of 50 blows per face. The 35 and 75 blow compactive efforts were performed for comparison purposes in order to determine the optimum degree of compaction.

The aggregate gradation was varied from the high side of the gradation band on the 4.75-mm sieve to the low side so that a gradation could be selected to provide minimum VMA (17) and a VCA lower than that in the dry rodded coarse aggregate. As the gradation becomes coarser the VMA increases and the VCA decreases to a point at which both are acceptable. The SMA Technical Working Group recommends that the percentage passing the 4.75-mm sieve be 20-28 percent. The VCA requirement was always met at the lower percentages passing the 4.75-mm sieve but the VMA requirement was not always satisfied. When the VMA was not satisfied the mix design process was continued at 20 percent passing the 4.75-mm sieve to obtain the highest VMA within the gradation band. The optimum asphalt content (that to produce 3.75% air voids) was then selected for that mixture. Test results indicate that those mixes that did not meet the VMA requirements had aggregates that experienced excessive breakdown.

Results for 50-blow Marshall compaction show that the optimum asphalt content, VMA, VCA, and mechanical properties vary considerably for the eight aggregate types. The optimum asphalt content varied from a low of 5.3% for traprock to a high of 7.5% for blast furnace slag.

Table 4.28: Properties of SMA Mixtures Compacted With 50 Blows of the Marshall Hammer

Sieve Size (mm)	Lime-stone (1)	Granite (1)	Trap-rock	Granite (2)	Dolomite	Gravel	Lime-stone (2)	Blast Furnace Slag
19.0	100	100	100	100	100	100	100	100
12.5	90	90	91	90	90	90	90	90
9.5	53	53	55	52	52	53	52	52
4.75	21	21	25	20	20	21	20	20
2.36	18	18	21	17	17	18	17	17
1.18	16	16	19	15	15	16	15	15
0.6	13	13	15	13	13	13	13	13
0.3	12	12	14	12	12	12	12	12
0.15	11	11	12	11	11	11	11	11
0.075	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Opt. AC, %	6.4	6.1	5.3	6.0	6.8	7.2	6.0	7.5
VTM, %	3.8	3.8	3.6	3.6	3.7	3.8	3.8	4.8
VMA, %	17.9	17.3	17.3	15.2	16.7	18.8	15.4	17.4
Voids Filled, %	78.8	78.0	79.2	76.3	78.8	79.8	75.7	72.3
VCA, %	32.2	34.2	35.4	31.1	37.9	37.8	31.0	31.5
Stability, N	5010	7350	7970	8510	7370	6100	7655	9700
Flow, 0.25 mm	13	11	12	12	10	21	13	15
Tensile Strength, kPa	526	668	1050	922	850	885	916	865
Creep Stiffness, 3600S	40.1	68.0	67.4	44.9	58.1	21.1	39.0	33.5
Creep Stiffness, 4500S	41.0	70.1	70.1	46.3	59.5	23.0	39.8	35.4
Draindown @ 140°C	0.02	0.02	0.02	0.00	0.00	0.00	0.03	0.01
Draindown @ 155°C	0.02	0.04	0.02	0.00	0.03	0.07	0.00	0.02
Draindown @ 170°C	0.02	0.00	0.02	0.06	0.04	0.03	0.03	0.01
Conditioned Tensile Strength, kPa ** 5%	591/652	578/687	518/554	359/624/511/665	758/751	295/303/387/391	421/550	654/67
Unconditioned Tensile Strength, kPa ** 5%	630/712	888/916	828/785	902/872/1024/1013	909/905	610/581/662/681	806/911	1025/1002
TSR**, 6% Voids	93.8/91.6	65.1/75.0	62.6/70.6	39.8/71.6/49.6/65.6	83.4/83.0	48.4/52.1/58.4/57.4	52.3/60.4	63.8/67.6

* Not available

** No lime/lime

Table 4.29: Properties of SMA Mixtures Compacted With 35 Blows of the Marshall Hammer

Sieve Size (mm)	Limestone (1)	Granite (1)	Traprock	Granite (2)
19.0	100	100	100	100
12.5	90	90	91	90
9.5	53	53	55	52
4.75	21	21	25	20
2.36	18	18	21	17
1.18	16	16	19	15
0.6	13	13	15	13
0.3	12	12	14	12
0.15	11	11	12	11
0.075	10.0	10.0	10.0	10.0
Opt. AC, %	7.1	6.8	5.5	6.5
VTM, %	3.8	3.7	3.6	3.7
VMA, %	19.4	18.7	17.6	16.2
Voids Filled, %	80.0	80.1	79.5	77.5
VCA, %	31.9	35.2	38.6	32.0

Table 4.30: Properties of SMA Mixtures Compacted With 75 Blows of the Marshall Hammer

Sieve Size (mm)	Limestone (1)	Granite (1)	Traprock	Granite (2)
19.0	100	100	100	100
12.5	90	90	91	90
9.5	53	53	55	52
4.75	21	21	25	20
2.36	18	18	21	17
1.18	16	16	19	15
0.6	13	13	15	13
0.3	12	12	14	12
0.15	11	11	12	11
0.075	10.0	10.0	10.0	10.0
Opt. AC, %	5.8	5.6	4.7	5.2
VTM, %	3.8	3.8	3.8	3.7
VMA, %	16.5	16.2	17.8	13.5
Voids Filled, %	77.0	76.5	78.6	72.5
VCA, %	31.3	33.3	37.8	30.5

Most specifications require a minimum asphalt cement content of 6.0% and seven of these eight mixtures met that requirement. The only mixture that did not meet this requirement is the one containing traprock which has a high specific gravity. When the specific gravity of an aggregate is high, it is more difficult to meet the minimum asphalt content requirement even if the VMA requirement is met. So the minimum asphalt content of 6.0% that many agencies require appears to be a reasonable requirement to meet. But this minimum asphalt content requirement is not needed if a minimum VMA requirement is specified.

All mixtures except the slag mixture had air voids in the range of 3.6-3.8% at optimum asphalt cement content. The blast furnace slag had excess binder running out of the mixture at higher asphalt contents even when more than 4 percent air voids existed in the compacted mixture. The asphalt content was reduced to a point that produced a mixture that appeared not to have excess binder. This resulted in a mixture with 4.8% air voids.

Two of the mixtures had VMA values (15.2% and 15.4%) significantly below the typically recommended 17 percent. The aggregate used in these two mixtures were the granite (2) and the limestone (2). The apparent reason for the low VMA in these two mixtures is the excessive aggregate breakdown (this will be discussed in more detail later). The VMA of the dolomite mixture had a VMA of 16.7 percent. Even though the VMA was low in these two mixtures, they both contained at least 6.0% asphalt cement.

Three of the mixtures (granite (2), limestone (2), and dolomite) met the suggested requirements for at least 6.0 percent asphalt cement but fail to meet the suggested minimum requirement of 17 for VMA. The amount of asphalt cement absorbed into the aggregate in these three mixtures ranged from 0.8% to 1.1% asphalt cement. Therefore, it is not realistic to control the asphalt cement absorption by setting an upper limit on the aggregate absorption. Then there are really two choices for ensuring adequate effective asphalt cement. One would be to set a minimum requirement for “effective” asphalt content and the other would be to set a minimum VMA requirement. The minimum VMA requirement approach appear to be the easiest to specify.

The VCA for the eight mixtures ranged from 31.0 to 37.9 percent. All of these were below the upper limit set by the voids in the dry rodded coarse aggregate except for the gravel which was close (Table 4.31). For gravel, the dry rodded VCA was 36.9 and the VCA in the mixture was 37.8 percent. The coarse aggregate only (with 2% AC) was also compacted in the Superpave gyratory compactor with 75, 100, and 125 gyrations. This provided lower VCA values and was affected by the amount of aggregate breakdown. In most cases, the dry rodded VCA is easily met but the requirement may not be low enough. Those mixtures compacted with the SGC may be too low in some cases.

The Marshall stability values ranged from a low of 5010 N for the limestone (1) to a high of 9700 N for blast furnace slag (Table 4.28). A typical required minimum value is 6200 N. The only two aggregates to fail this criteria were the limestone (1) and the gravel aggregates. The flow values ranged from 10 to 21 (0.25 mm units). The only aggregate to fail the typical requirement of 8-16 was the gravel aggregate. Most specifications do not allow the use of gravel so if this mixture is excluded the only mixture failing to meet both criteria is limestone(1).

The tensile strength of the eight mixtures was determined. There are no typical specifications for tensile strength. The numbers ranged from 610 to 1025 kPa. The limestone (1) and granite (1) mixtures had the two lowest tensile strength results (526 and 668 kPa, respectively).

Moisture susceptibility testing was completed for each of the mixtures for 50-blow

Table 4.31: Dry-Rodded Results for Coarse Aggregates

Aggregate Type	Voids in Coarse Aggregate				
	Coarse Aggregate Only in Gyratory			Dry-Rodded	In Mixture
	75	100	125		
Limestone (1)	35.2	34.8	34.6	44.1	32.2
Granite (1)	32.3	31.2	30.8	39.8	34.2
Traprock	38.0	39.6	37.4	41.5	35.4
Granite (2)	26.2	24.8	24.4	39.9	31.1
Dolomite	30.6	30.0	29.0	40.4	37.9
Limestone (2)	29.7	28.9	27.8	43.6	31.0
Gravel	34.6	33.8	33.3	36.9	37.8
Blast Furnace Slag	32.0	30.0	29.0	43.0	31.5

compaction both with and without hydrated lime (Table 4.28). The samples were compacted to 6 ± 1 percent air voids for testing. Typical retained tensile strength ratio (TSR) requirements are between 70-80 percent. Only 2 of the produced mixtures with the 8 aggregate types without lime exceeded a TSR value of 70 percent. These were the dolomite and limestone (1) mixtures. The TSR of all other mixtures containing no lime were below 65.1 percent. Five of the 8 lime treated SMA mixtures exceeded a TSR value of 70 percent. Two of the mixtures were compacted to 5 percent voids (granite (2) and gravel) and water susceptibility tests conducted to determine if the lower void level would provide improved test results. The results indicate that on the average the retained strength of lime treated SMAs is raised approximately 5 percent while the TSR of the untreated mixture is raised approximately 10 percent. Based on the test results it is recommended that the test be conducted at 6 percent air voids and a limit of 7 percent be established.

Since SMA is a new mixture type with little performance information, no long term performance data for moisture susceptibility is available in the U.S. The limits for sample conditioning or the test itself may not be appropriate for SMA mixtures. At this point there is no reason to believe that moisture susceptibility is a problem with SMA mixtures. It does appear however that in the laboratory the TSR for SMA is somewhat lower than that for dense mixtures.

Four of the 8 aggregates used to design SMA mixtures were compacted with 35 blows and 75 blows of the Marshall hammer (Tables 4.29 and 4.30). This was done to gain a better understanding on how compactive effort affects aggregate breakdown and mixture densification. The aggregate gradations for each of the 4 aggregates were not optimized with 35 and 75 blows of the Marshall hammer. Instead, the optimum aggregate gradations determined with 50 blows of the hammer were used for each of the 4 aggregates. The asphalt cement content was optimized for each mixture by targeting 3.75% air voids. As expected the reduced compactive effort (35 blows) gave significantly higher optimum asphalt contents, higher VMA, and higher VCA. The increased compactive effort (75 blows) gave lower optimum asphalt content, decreased VMA, and decreased VCA. The aggregate breakdown for the various compactive efforts is discussed in section 4.5 of this report.

Dense-graded mixtures were prepared for each aggregate and tested for comparison with the SMA mixtures. All dense-graded mixtures for this part of the study were compacted with 75

blows of the Marshall hammer per face. The optimum asphalt content was selected to yield 4 percent air voids. The asphalt cement contents for the dense-graded mixtures ranged from 4.8 to 6.7% and averaged approximately 1 percent lower than the SMA mixtures (Table 4.32). The VMA of the eight dense-graded mixtures ranged from 10.4 to 16.8 and were lower than the values of the corresponding SMA mixtures at 50-blow compactive effort. It is clear from this comparison that SMA mixtures do contain a significantly higher asphalt content and should therefore be more durable than dense graded mixtures.

4.3.2.2 Superpave Gyrotory Compaction

The same 8 aggregates that were used in the Marshall hammer compaction part of the study were again used to prepare SMA mixtures compacted in the SGC. Based on previous work, 100 revolutions was chosen as the compactive effort to produce a density approximately equal to 50 blows of the Marshall hammer. The results of the SGC compacted mixtures (100 revolutions) are shown in Table 4.33.

A comparison of the optimum asphalt contents for SMA mixtures compacted with 50-blow Marshall and 100 revolutions of the SGC is shown in Figure 4.27. The results indicate that a good correlation exists between the two methods at lower asphalt contents (lower VMA). The SGC typically gives a lower optimum asphalt content than the Marshall hammer. Only one

Table 4.32: Properties of Dense Mixtures Compacted With 75 Blows of the Marshall Hammer

Sieve Size (mm)	Limestone (1)		Granite (1)	Traprock		Granite (2)		Dolomite	Gravel	Limestone (2)	Blast Furnace Slag
	Before **	After	Before	Before	After	Before	After	Before	Before	Before	Before
19.0	100	100	100	100	100	100	100	100	100	100	100
12.5	97	97	97	97	97	97	97	97	97	97	97
9.5	83	86	83	83	84	83	90	83	83	83	83
4.75	56	58	56	56	58	56	63	56	56	56	56
2.36	39	42	39	39	42	39	46	39	39	39	39
1.18	28	30	28	28	30	28	35	28	28	28	28
0.6	19	21	19	19	22	19	25	19	19	19	19
0.3	13	14	13	13	15	13	17	13	13	13	13
0.15	7	9	7	7	9	7	10	7	7	7	7
0.075	4.0	5.7	4.0	4.0	5.6	4.0	5.8	4.0	4.0	4.0	4.0
Opt. A.C., %	4.9	N/A	4.9	4.8	N/A	5.5	N/A	6.8	5.2	4.9	6.7
VTM, %	4.0	N/A	3.9	3.9	N/A	4.0	N/A	3.8	4.0	4.0	4.1
VMA, %	13.9	N/A	15.3	15.6	N/A	15.5	N/A	13.8	14.7	10.4	16.8
Voids Filled, %	71.0	N/A	74.0	75.0	N/A	74.1	N/A	72.4	72.8	61.3	75.6
VCA, %	62.8	N/A	62.5	63.2	N/A	61.7	N/A	65.2	62.0	61.0	59.4

N/A = Not applicable.

*Not available.

**Before compaction/after compaction.

Table 4.33: Properties of SMA Mixtures Compacted With 100 Revolutions of the SGC

Sieve Size (mm)	Limestone (1)	Granite (1)	Traprock	Granite (2)	Dolomite	Gravel	Limestone (2)	Blast Furnace Slag
19.0	100	100	100	100	100	100	100	100
12.5	90	90	90	90	90	90	90	90
9.5	54	52	54	52	52	52	52	52
4.75	23	20	24	20	20	20	20	20
2.36	20	17	20	17	17	17	17	17
1.18	17	15	18	15	15	15	15	15
0.6	14	13	14	13	13	13	13	13
0.3	13	12	13	12	12	12	12	12
0.15	11	11	11	11	11	11	11	11
0.075	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Opt. A.C., %	5.8	5.5	5.6	4.9	7.0	7.1	5.8	8.5
VTM, %	3.7	3.6	3.8	3.8	3.7	3.6	3.7	5.2
VMA, %	16.8	15.7	17.3	12.6	15.8	18.1	13.8	18.1
Voids Filled, %	78.3	77.4	78.2	70.9	76.3	79.5	72.1	71.6
VCA, %	36.2	32.1	36.5	29.7	30.8	33.5	34.8	31.9
Stability, N	5628	8635	7102	12876	9997	*	9146	8439
Flow, 0.25 mm	16	18	18	17	18	*	25	20
Tensile Strength, kPa	841	1080	915	1409	1220	*	1213	*
Creep Stiffness 3600S	49.8	40.7	*	40.1	25.4	20.5	27.0	*
Creep Stiffness, 4500S	46.9	42.3	*	42.5	26.3	21.7	28.2	*
Draindown @ 140°C	0.01	0.01	0.01	0.02	0.01	0.02	0.00	0.01
Draindown @ 155°C	0.02	0.02	0.03	0.06	0.03	0.04	0.01	0.00
Draindown @ 170°C	0.02	0.02	0.02	0.01	0.02	0.03	0.02	0.02
Conditioned Tensile Strength, kPa	643/648	454/699	547/605	453/566	/681	476/382	441/488	568/610
Unconditioned Tensile Strength, kPa	707/737	737/793	746/725	1040/1063	/813	647/685	811/877	662/664
TSR, %	91.0/89.3	61.6/88.1	73.3/83.4	43.6/53.2	/83.8	73.6/55.8	54.4/55.6	85.8/91.9

*Not available.

mixture had less than 6 percent asphalt when compacted with 50 blows of the Marshall hammer while five mixtures had less than 6 percent asphalt when compacted with 100 revolutions of the SGC. This would seem to indicate that the SGC is forcing the aggregate closer together than the Marshall hammer, or that it may be causing more aggregate breakdown.

The VMA of the samples compacted with 100 revolutions of the SGC varied from 12.6 to 18.1 percent. As expected, the softer aggregates generally had the lower VMA results.

The effect of compactive effort was again determined by compacting SMA mixtures for 4 of the aggregates using 75 and 125 revolutions of the SGC (Tables 4.34 and 4.35). As before, the

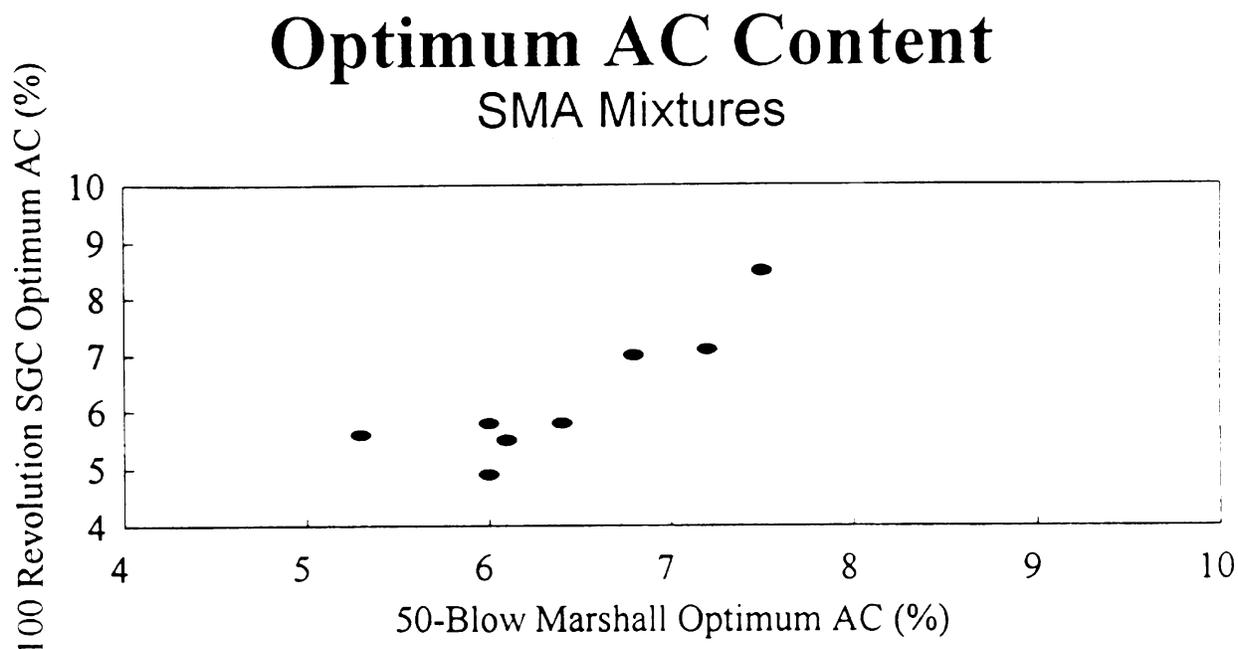


Figure 4.27: Comparison of Optimum Asphalt Content for SMA Mixture With 50 Blow Marshall and 100 Gyration With SGC

optimum aggregate gradation determined with 100 revolutions for each aggregate was used. Optimum asphalt cement contents were then established for each of the 4 aggregates. The results are shown in Tables 4.34 and 4.35 for 75 and 125 revolutions, respectively. As expected, these tables show that the higher compactive effort gave lower optimum asphalt contents and lower VMA. The harder aggregates had less change in optimum asphalt content which seems to indicate that the change in asphalt content may be due to aggregate breakdown.

For comparison purposes, dense-graded mixtures were prepared and compacted with $N_{\text{design}} = 128$ revolutions of the SGC. The results are shown in Table 4.36. The optimum asphalt content for the dense-graded mixtures varied from 4.6 to 7.4 percent. The optimum asphalt content for the SMA mixtures designed with 100 revolutions with the SGC were typically 0.5 to 1.0% higher than the dense-graded mixtures. The VMA of the dense graded mixtures averaged 2.4% lower than the VMA of the SMA mixtures. This supports the findings with the Marshall which indicates that the SMA mixtures should be more durable due to the higher asphalt content.

4.3.3 Effects of Mortar

Since the mortar in SMA mixtures plays an important role in the performance of SMA, several mortars were evaluated to look at their effects on mixture properties. Eight different mortars were evaluated. The traprock was selected as the coarse and fine aggregate for use in the mortar mixtures. The combinations of mineral filler, asphalt cement, and stabilizer for the eight mortar mixtures were as shown below:

- Mortar A - 10% Traprock filler, AC-20, no stabilizer
- Mortar B - 10% Traprock filler, SBS modified AC-20, no fiber
- Mortar C - 10% Traprock filler, polyolefin modified AC-20, no fiber

Table 4.34: Properties of SMA Mixtures Compacted With 75 Revolutions of the SGC

Sieve Size (mm)	Limestone (1)	Granite (1)	Traprock	Granite (2)
19.0	100	100	100	100
12.5	90	90	90	90
9.5	54	52	54	52
4.75	23	20	24	20
2.36	20	17	20	17
1.18	17	15	18	15
0.6	14	13	14	13
0.3	13	12	13	12
0.15	11	11	12	11
0.075	10.0	10.0	10.0	10.0
Opt. AC, %	6.2	6.2	5.7	5.3
VTM, %	3.7	3.6	3.8	3.7
VMA, %	17.6	17.3	17.8	13.3
Voids Filled, %	79.0	79.5	78.2	72.0
VCA, %	37.0	33.3	38.2	26.9

Table 4.35: Properties of SMA Mixtures Compacted With 125 Revolutions of the SGC

Sieve Size (mm)	Limestone (1)	Granite (1)	Traprock	Granite (2)
19.0	100	100	100	100
12.5	90	90	91	90
9.5	54	52	54	52
4.75	23	20	24	20
2.36	20	17	20	17
1.18	17	15	18	15
0.6	14	13	14	13
0.3	13	12	13	12
0.15	11	11	12	11
0.075	10.0	10.0	10.0	10.0
Opt. AC, %	5.5	5.3	5.1	4.8
VTM, %	3.7	3.8	3.8	3.7
VMA, %	16.2	15.5	16.4	12.2
Voids Filled, %	76.9	75.5	76.9	69.2
VCA, %	35.3	32.2	34.3	26.1

Table 4.36: Properties of Dense Mixtures Compacted With 128 Revolutions of the SGC

Sieve Size (mm)	Limestone (1)	Granite (1)	Traprock	Granite (2)	Dolomite	Gravel	Limestone (2)	Blast Furnace Slag
19.0	100	100	100	100	100	100	100	100
12.5	97	97	97	97	97	97	97	97
9.5	83	83	83	83	83	83	83	83
4.75	56	56	56	56	56	56	56	56
2.36	39	39	39	39	39	39	39	39
1.18	28	28	28	28	28	28	28	28
0.6	19	19	19	19	19	19	19	19
0.3	13	13	13	13	13	13	13	13
0.15	7	7	7	7	7	7	7	7
0.075	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Opt. A.C., %	4.6	5.0	4.9	5.0	7.3	5.2	5.7	7.4
VTM, %	4.0	3.9	3.9	4.0	3.9	3.9	4.1	3.9
VMA, %	13.2	14.8	15.3	14.3	13.0	13.7	10.8	17.1
Voids Filled, %	70.0	73.7	74.9	72.5	69.9	72.0	62.0	77.1
VCA, %	62.5	62.2	63.1	61.2	64.0	61.6	59.3	58.4

N/A = Not applicable.

*Not available.

Mortar D - 10% Traprock filler, AC-20, cellulose fiber

Mortar E - 10% Traprock filler, AC-20, mineral fiber

Mortar F - 8% Wimpey filler, AC-20, cellulose fiber

Mortar G - 12% Dankalk filler, AC-20, cellulose fiber

Mortar H - 10% SE flyash filler, AC-20, cellulose fiber

The results of the mortar mixtures compacted with 50 blows of the Marshall hammer are shown in Table 4.37. The results show that mortar B and C (the two polymer mortars) provided the highest optimum asphalt content and the highest VMA. Mortars F and H produced the lowest optimum asphalt content and the lowest VMA. As expected, the VCA was approximately the same for all mortar mixtures. The optimum asphalt contents ranged from 5.7 to 7.0 percent. The VMA ranged from 17.1 to 19.1 percent.

The results of the mortar mixtures compacted with 100 revolutions of the SGC are shown in Table 4.38. Mortars B and C provided the highest optimum asphalt content and mortars G and H provided the lowest optimum asphalt contents. The VCA was again approximately the same for all mixtures indicating that a similar aggregate structure was developed. The optimum asphalt content ranged from 5.0 to 6.4 percent. The VMA ranged from 13.8 to 17.6 percent. The SGC typically produced SMA mixtures having approximately 0.5% less asphalt cement at optimum than the Marshall hammer. The correlation between the Marshall hammer and gyratory compactor results is shown in Figure 4.28.

Table 4.37: Properties of SMA Mortar Mixtures Compacted With 50 Blows of the Marshall Hammer

Sieve Size (mm)	A	B	C	D	E	F	G	H
19.0	100	100	100	100	100	100	100	100
12.5	90	90	90	90	90	90	90	90
9.5	52	52	52	52	52	52	52	52
4.75	20	20	20	20	20	20	20	20
2.36	18	18	18	18	18	18	19	18
1.18	17	17	17	17	17	16	18	17
0.6	16	16	16	16	16	15	17	16
0.3	15	15	15	15	15	14	16	15
0.15	13	13	13	13	13	11	14	13
0.075	10.0	10.0	10.0	10.0	10.0	8.0	12.0	10.0
Opt. A.C., %	6.2	6.8	7.0	6.1	6.2	5.8	6.4	5.7
VTM, %	3.7	3.8	3.7	3.8	3.7	3.8	3.8	3.6
VMA, %	17.6	18.9	19.1	17.8	17.5	17.1	18.1	17.2
Voids Filled, %	79.4	79.3	80.5	79.1	79.0	78.2	79.3	71.0
VCA, %	33.3	34.3	34.5	33.0	33.1	33.3	34.4	35.0
Stability, N	8874	*	9261	9236	8173	9665	8652	9786
Flow, 0.25 mm	12	16	13	15	13	10	11	12
Tensile Strength, kPa	*	780	949	882	774	894	859	881
Creep Stiffness 3600S	34.3	28.2	19.9	41.9	36.8	33.8	26.1	34.4
Creep Stiffness, 4500S	36.7	29.1	21.2	43.6	38.4	36.8	27.3	35.8
Draindown @ 140°C	2.5	3.0	5.5	0.0	0.0	0.0	0.0	0.0
Draindown @ 155°C	5.3	6.0	7.3	0.0	0.0	0.0	0.0	0.0
Draindown @ 170°C	7.2	6.0	7.0	0.0	0.1	0.0	0.0	0.0
Conditioned Tensile Strength, kPa	437/572	477/511	474/569	453/502	467/487	441/647	587/635	670/795
Unconditioned Tensile Strength, kPa	688/619	657/615	629/686	886/752	589/651	797/782	745/794	905/919
TSR, %	63.5/92.4	72.6/83.1	75.4/82.9	51.1/66.8	79.3/74.8	55.3/82.7	78.8/80.0	74.0/86.5

*Not available.

4.4 FLAT OR ELONGATED PARTICLES

4.4.1 Mixture Designs

Mixture designs having varying amounts of flat or elongated particles were performed as prescribed in the test plan. The properties of the materials used in this phase of the study were given in section 4.1. Only the coarse aggregate fraction of the SMA mixture was varied. The fine

Table 4.38: Properties of SMA Mortar Mixtures Compacted With 100 Revolutions of the SGC

Sieve Size (mm)	A	B	C	D	E	F	G	H
19.0	100	100	100	100	100	100	100	100
12.5	90	90	90	90	90	90	90	90
9.5	52	52	52	52	52	52	52	52
4.75	20	20	20	20	20	20	20	20
2.36	18	18	18	18	18	18	19	18
1.18	17	17	17	17	17	16	18	17
0.6	16	16	16	16	16	15	17	16
0.3	15	15	15	15	15	14	16	15
0.15	13	13	13	13	13	11	14	13
0.075	10.0	10.0	10.0	10.0	10.0	8.0	12.0	10.0
Opt. A.C., %	6.2	6.4	6.4	6.1	5.8	5.9	5.5	5.0
VTM, %	3.7	3.8	3.8	3.7	3.7	3.7	3.8	3.6
VMA, %	17.1	17.4	17.6	17.0	16.2	17.5	15.7	13.8
Voids Filled, %	78.2	78.5	78.5	78.0	77.0	78.6	75.8	74.0
VCA, %	32.8	33.1	33.2	32.7	32.1	34.4	32.4	32.4
Stability, N	7885	9299	7950	8377	*	20802	*	*
Flow, 0.25 mm	21	25	19	18	16	9	21	*
Tensile Strength, kPa	811	709	1045	1092	1100	833	1260	*
Creep Stiffness 3600S	31.6	24.3	33.0	35.5	20.1	32.8	25.0	*
Creep Stiffness, 4500S	34.9	25.2	37.8	39.3	20.7	35.1	25.3	*
Draindown @ 140°C	2.4	2.0	1.8	0.0	0.0	0.0	0.0	*
Draindown @ 155°C	5.0	2.6	2.4	0.0	0.1	0.0	0.0	*
Draindown @ 170°C	7.2	5.6	2.6	0.0	0.1	0.0	0.0	*
Conditioned Tensile Strength, kPa	494/465	472/577	466/520	566/622	485/432	522/658	609/809	*
Unconditioned Tensile Strength, kPa	601/646	621/629	643/577	728/838	780/716	815/760	930/885	*
TSR, %	81.0/72.0	76.0/91.7	72.5/90.1	77.7/74.2	62.2/60.3	64.0/86.6	65.5/91.4	*

*Not available.

aggregate used in all the mixes was from the material designated as Arkansas “cubical” (Tables 4.1 and 4.2). The coarse aggregate percentage were varied from 100 percent A1 aggregate to 100 percent A2. A1 and A2 came from the same source. A1 contained a high flat and elongated count and A2 was a more cubical aggregate. Compaction was achieved using 50 blows of the Marshall hammer.

The optimum gradations determined for the blends are shown in Table 4.39. However, the 100 percent A2 blend was selected for all five mix designs in order to eliminate gradation as a variable. This particular gradation was chosen since it had the lowest percent passing the 4.75-

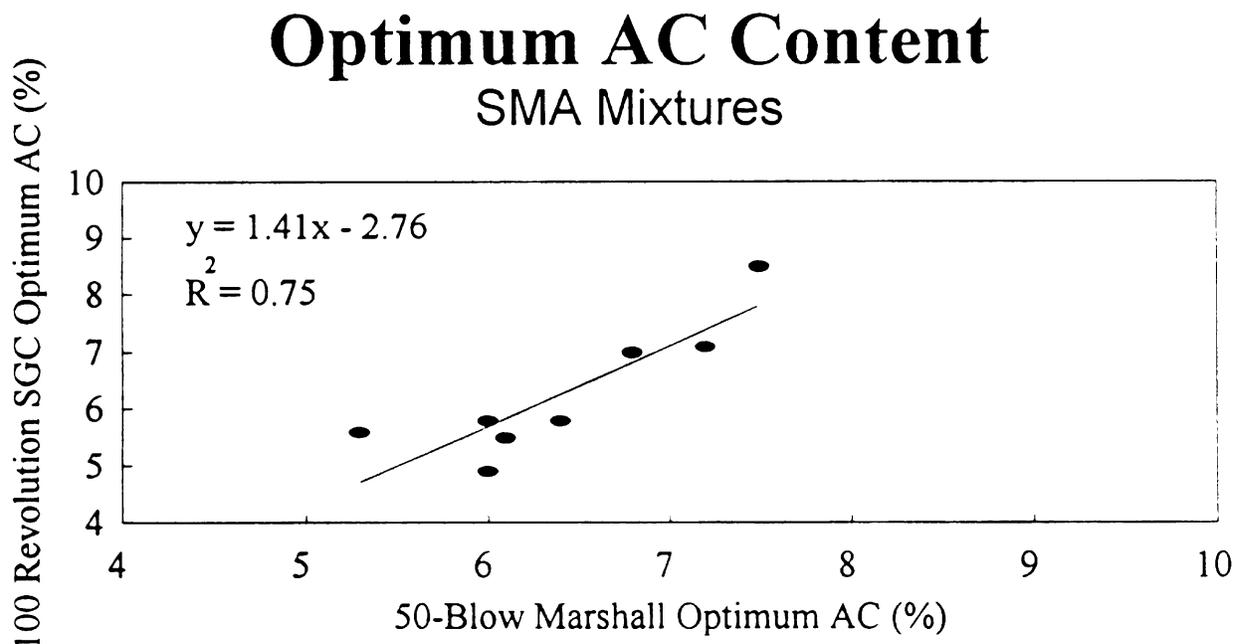


Figure 4.28: Correlation Between the Marshall Hammer and SGC Optimum Asphalt Cement Contents

mm sieve and would thus meet VMA and VCA requirements for all mixtures. The fractured face count for these 5 aggregate blends is shown in Table 4.40.

Table 4.40 shows the optimum asphalt contents and the volumetric properties at the optimum asphalt content for the five mixes. As with the other SMA mixtures, 3.75% was targeted as the optimum air voids. Table 4.41 shows optimum asphalt contents that ranged from 6.8% to 7.2%. The VFA and VCA were approximately 79.0% and 35.0% respectively. The VMA as well as the aggregate breakdown and tensile strength ratio were more closely examined and evaluated below to determine the effect of flat or elongated particles on mixture properties.

4.4.2 Voids in the Mineral Aggregate (VMA)

The VMA values of the five mixtures are presented in Table 4.41. This data was analyzed using a one-way analysis of variance (ANOVA). This method employed an F -test at a significance level of five percent ($\alpha=0.05$) to determine if any differences existed between the mean VMA values of the five mixtures. The test determines if one or more means is significantly different from the other means. This method was appropriate since determination of any differences would permit the conclusion that these particles had an impact on the SMA mixes. The results of the statistical analysis showed a significant difference between one or more of the mean VMA values. This was also demonstrated by the VMA plot in Figure 4.29. The data showed a trend of increasing VMA as the percent flat or elongated particles in the mix was increased.

Table 4.39: Optimum Gradations

Sieve Size (mm)	Aggregate Mixes				
	100% A1	100% A2	75% A1 - 25% A2	50% A1 - 50% A2	25% A1 - 75% A2
19.0	100	100	100	100	100
12.5	90.4	90.1	90.3	90.3	90.3
9.5	53.8	52.6	54.5	53.2	53.2
4.75	23.0	21.0	24.0	22.0	22.0
2.36	19.6	17.9	20.5	18.8	18.8
1.18	17.3	15.8	18.0	16.6	16.6
0.6	14.1	13.4	14.5	13.8	13.8
0.3	13.1	12.4	13.5	12.8	12.8
0.15	11.4	11.1	11.5	11.3	11.3
0.075	10.0	10.0	10.0	10.0	10.0

Aggregate A1 - Aggregate containing flat or elongated particles

Aggregate A2 - Aggregate from same source as A1 but containing less flat or elongated particles (more cubical particles) relative to aggregate A1

Table 4.40: Fractured Face Count for Coarse Aggregates

Aggregate	Percent Flat or Elongated		
	2 to 1	3 to 1	5 to 1
100% A1	67	25	1
100% A2	38	3	0
75% A1 25% A2	64	25	2
50% A1 50% A2	50	14	1
25% A1 75% A2	55	15	0

Table 4.41: Optimum Mixture Properties

Mix Property	Aggregate Mixes				
	100% A1	100% A2	75% A1 - 25% A2	50% A1 - 50% A2	25% A1 - 75% A2
AC, %	7.2	6.9	7.0	6.8	6.8
VTM, %	3.8	3.8	3.7	3.8	3.7
VMA, %	19.2	18.4	18.9	18.3	18.1
VFA, %	80.4	78.1	79.1	79.3	79.4
VCA, %	35.4	34.7	35.2	34.4	34.3

Table 4.42: Aggregate Breakdown Sieve Analysis Results

Sieve Size, mm	Optimum Gradation	Aggregate Mixes				
		100% A1	100% A2	75% A1 - 25% A2	50% A1 - 50% A2	25% A1 - 75% A2
19.0	100	100	100	100	100	100
12.5	90.1	90.4	90.1	90.3	90.3	90.3
9.5	52.6	63.6	61.4	64.8	63.9	64.1
4.75	21.0	30.4	26.0	29.3	28.7	28.4
2.36	17.9	22.0	19.9	21.8	21.6	21.3
1.18	15.8	18.1	16.9	18.1	18.0	17.8
0.6	13.4	15.0	14.1	14.8	14.9	14.8
0.3	12.4	13.4	12.7	13.3	13.4	13.3
0.15	11.1	11.9	11.4	11.8	11.9	11.8
0.075	10.0	10.0	9.5	9.8	9.9	9.9

Aggregate A1 - Aggregate containing flat or elongated particles

Aggregate A2 - Aggregate from same source as A1 but containing less flat or elongated particles (more cubical particles) relative to aggregate A1

Voids in the Mineral Aggregate (VMA) at Optimum Asphalt Content

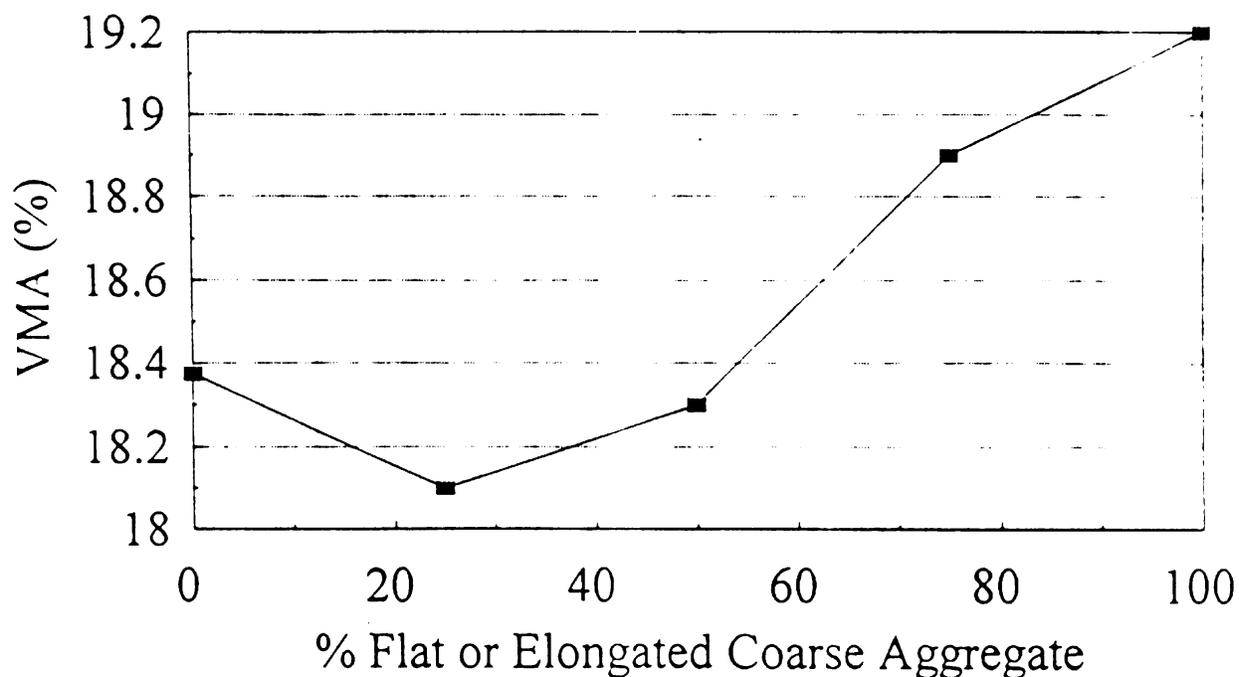


Figure 4.29: VMA Results for the Flat or Elongated Mixtures

4.4.3 Aggregate Breakdown

After completion of the mixture designs, specimens were compacted at optimum asphalt content for each of the five mixtures. The volumetric properties were determined to verify the design, and the asphalt cement was then removed using the Ignition Furnace Method (Method A, ASTM Draft). Gradation analyses were conducted according to AASHTO T 27 and T 11 to determine the aggregate breakdown of each mixture after compaction. Three test replicates were done. Table 4.42 shows the mean gradation analysis results for each mixture along with the optimum gradation that was prepared.

For the statistical analysis, only the percents passing the 4.75-mm and 0.075-mm sieves were examined. Again, the one-way analysis of variance with a significance level of five percent was employed. The statistics showed that there was a significant difference in the gradation results of the five mixtures. Figures 4.30 and 4.31 demonstrate graphically and confirm that the aggregate breakdown increases as the percent flat or elongated particles in the mixture increases. However, both Figures 4.30 and 4.31 also showed that the effect is very similar for all the mixtures containing the flat or elongated particles. This is shown by the relative flatness of both the 4.75- and 0.075-mm curves after introduction of flat or elongated particles. This prompted a second statistical analysis to determine if the four mixes containing flat or elongated particles differed with respect to aggregate breakdown. The analysis indicated no statistical difference at the five percent significance level, for either sieve examined, between the four mixes having flat or elongated particles. This suggests, as did the curves of Figures 4.30 and 4.31, that after some percentage of flat or elongated particles in the mix is obtained an increase in aggregate breakdown occurs.

4.4.4 Moisture Susceptibility Testing

It was thought that flat or elongated aggregates, and particularly the breakdown of those aggregates during compaction, would increase the susceptibility of the mix to moisture induced damage. Thus, AASHTO T 283 was conducted on the five mixtures. The tensile strength ratios (TSR) of each mix along with the average unconditioned and conditioned tensile strengths are given in Table 4.43.

Since only one replication of the test method was completed, a statistical analysis was not possible. However, a generalized observation of the data can be made. Figure 4.32 shows the plot of the data which facilitated the analysis. The graph of the data suggests that the TSR is not

Table 4.43: Moisture susceptibility (AASHTO T-283) Results

Aggregate Mix	Unconditioned Tensile Strength (kPa)	Conditioned Tensile Strength (kPa)	Tensile Strength Ratio (%)
100% A1	412	829	49.7
100% A2	434	804	54.0
75% A1 - 25% A2	400	757	52.8
50% A1 - 50% A2	343	748	45.9
25% A1 - 75% A2	368	779	47.2

% Passing 4.75-mm Sieve After Compaction of Flat or Elongated Mixes

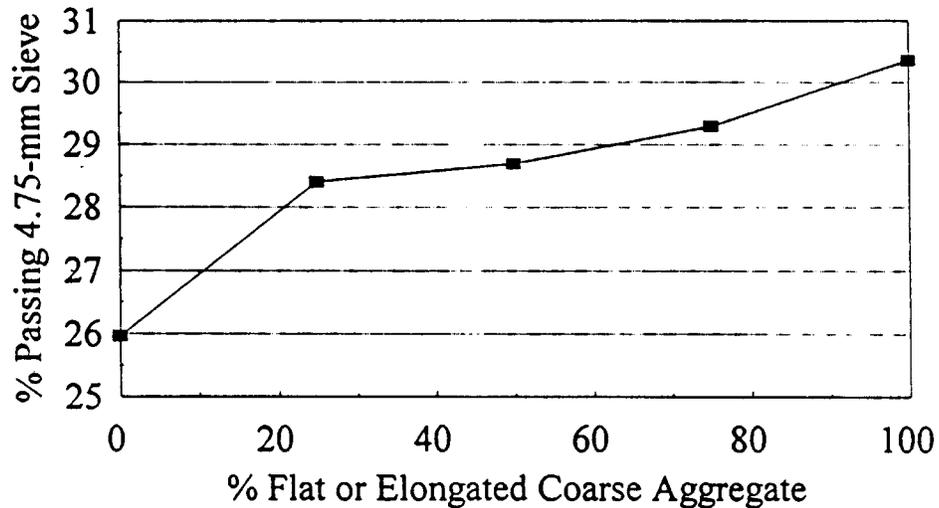


Figure 4.30: Aggregate Breakdown on the 4.75-mm Sieve as a Function of Percent Flat or Elongated Particles

% Passing 0.075-mm Sieve After Compaction of Flat or Elongated Mixes

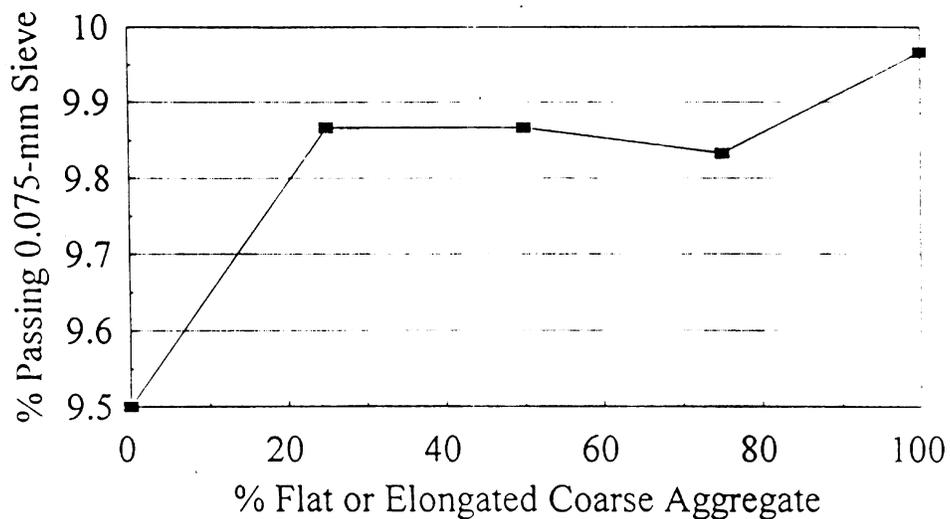


Figure 4.31: Aggregate Breakdown on the 0.075-mm Sieve as a Function of Percent Flat or Elongated Particles

Moisture Susceptibility (AASHTO T-283) of Flat or Elongated Mixes

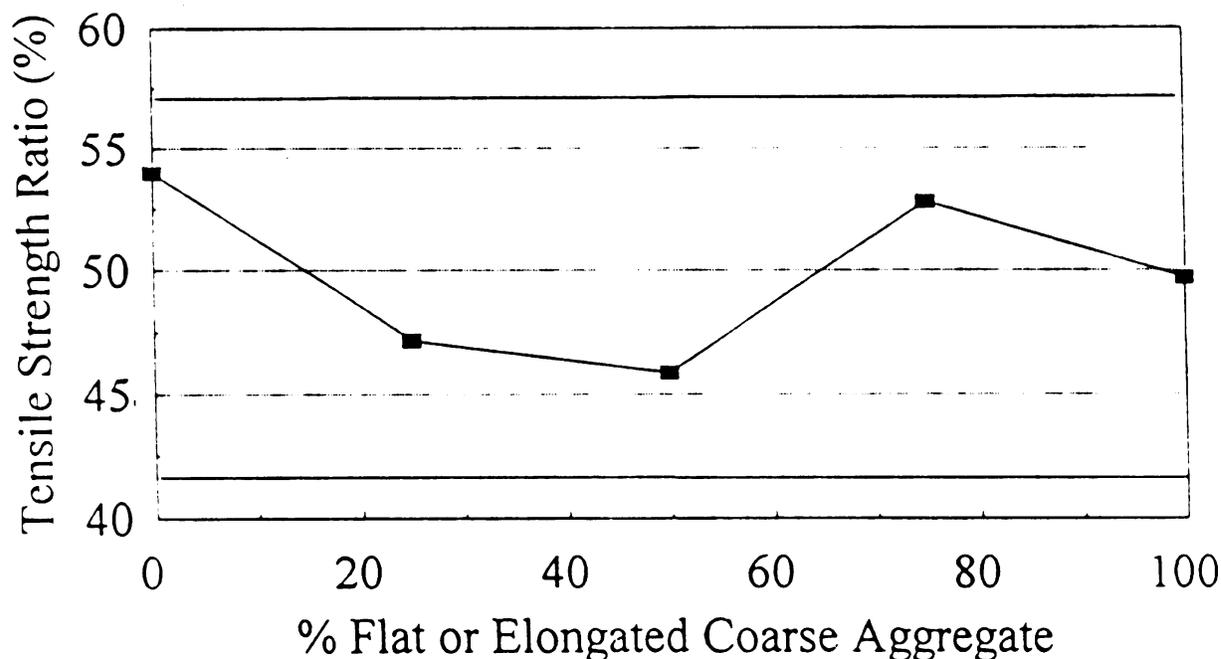


Figure 4.32: Moisture Susceptibility Results for the Flat or Elongated Subtask

influenced by the presence of flat or elongated particles in the mix. This conclusion is further supported by examination of the precision statement of ASTM D 4867. This method of determining the effect of moisture induced damage was consulted since no precision statement is available with the AASHTO standard. ASTM D 4867 gives a multi-laboratory standard deviation for TSR of the same mix of 8 percent. This standard deviation was applied to the flat or elongated TSR data even though all of the stated conditions of the test standard were not met. The TSR data exhibited a difference between the two extreme values of 8.1% as shown by Table 4.43. This is well within the allowable difference between 2 test results given in ASTM D 4867. Thus, it is concluded that flat or elongated particles do not affect the TSR of the five SMA mixtures investigated. This may not be true for other mixtures but it does provide some indication that flat and elongated particles do not affect the TSR value.

In summary, for the aggregate source evaluated, it appears that flat and elongated particles affect the VMA and affect the aggregate breakdown during compaction but does not affect the moisture susceptibility.

4.5 AGGREGATE BREAKDOWN TEST RESULTS

This subtask was completed in an attempt to determine how aggregate breakdown produced during compaction of SMA mixtures affects their ability to perform. The subtask involves two

phases; a laboratory study was conducted to determine the amount of breakdown due to laboratory compaction during the mixture design process; the second phase involved a field study combined with work in the laboratory. The results from each of these phases is reported below.

4.5.1 Laboratory Aggregate Breakdown

The laboratory aggregate breakdown phase was discussed previously in Sections 3.2.2 and 3.2.4. This work used the same 8 aggregates employed in the mixture design subtask. The properties of these aggregates are shown in Tables 4.1 and 4.2. The mixture designs resulting for these aggregates were presented and discussed in Section 4.3.

The amount of aggregate breakdown for each of the 8 aggregates was determined for the optimum gradation at optimum asphalt cement content for each of the designs compacted with 50 blows of the Marshall hammer (see Figure 3.3) and 100 revolutions of the SGC (see Figure 3.4). Additionally, for 4 of the aggregates, the optimum gradation determined by the 50-blow and 100-revolution designs was used to determine the optimum asphalt cement content at two additional levels of compaction; 35 and 75 blows with the Marshall hammer; 75 and 125 revolutions with the SGC (see Figure 3.5). The amount of aggregate breakdown for these additional compactive efforts was determined in an effort to determine how aggregate breakdown varies with compactive effort for each of the compaction devices employed. In addition, the aggregate breakdown caused by the two compaction methods was also determined for dense-graded mixtures designed using 3 of the aggregates.

The amount of aggregate breakdown was determined by removing the asphalt cement from the compacted specimens using the Ignition Furnace Method (Method A, ASTM Draft) and then completing a gradation analysis according to AASHTO T 27 and T 11. For each combination of aggregate type, compaction type, and compactive effort, the aggregate breakdown was determined for three specimens. The results for SMA mixtures compacted with the Marshall hammer and SGC are shown in Tables 4.44 and 4.45, respectively. Table 4.46 shows the aggregate breakdown results from the dense-graded mixtures compacted with the Marshall hammer. Note that these tables show the percents passing the 4.75- and 0.075-mm sieves after compaction. The initial, pre-compaction percentages passing these sieves are also listed for comparison purposes.

4.5.1.1 Marshall Hammer vs. Superpave Gyratory

SMA mixture aggregate breakdown produced by 50 blows of the Marshall hammer and by 100 revolutions of the SGC were compared for each of the 8 aggregates. The results for the 4.75- and 0.075-mm sieves are shown in Figures 4.33 and 4.34, respectively. The plots show that in general, the SGC produces less aggregate breakdown on both these sieves than does the Marshall hammer. Figures 4.33 and 4.34 also clearly show that the amount of breakdown produced depends on the type of aggregate used. In an attempt to be more precise, an analysis of variance (ANOVA) was performed on the data. At an α level of 0.05, it shows that the aggregate type and compactor type are both significant to the amount of aggregate breakdown experienced for both the 4.75- and 0.075-mm sieves. Additionally, the ANOVA suggests that the interaction between aggregate type and compactor type is significant for the 4.75-mm sieve ($\alpha = 0.05$). The interaction term was not found to be significant for the 0.075-mm sieve.

Table 4.44: Aggregate Breakdown Experienced During SMA Designs Compacted With the Marshall Hammer

Aggregate	Average Passing 4.75-mm (%)				Average Passing 0.075-mm (%)			
	35	50	75	Prior to Compaction	35	50	75	Prior to Compaction
Limestone (1)	30.2	30.0	31.0	21.0	10.3	10.3	10.2	10.0
Granite (1)	31.7	31.9	33.7	21.0	10.4	10.8	11.2	10.0
Traprock	30.6	31.2	32.1	25.0	10.3	10.5	10.6	10.0
Granite (2)	40.5	42.2	43.6	20.0	10.8	11.1	11.0	10.0
Dolomite	--	38.5	--	20.0	--	11.1	--	10.0
Limestone (2)	--	31.1	--	20.0	--	11.1	--	10.0
Slag	--	33.3	--	20.0	--	10.0	--	10.0
Gravel	--	26.8	--	21.0	--	10.3	--	10.0

Table 4.45: Aggregate Breakdown Experienced During SMA Designs Compacted With SGC

Aggregate	Average Passing 4.75-mm (%)				Average Passing 0.075-mm (%)			
	75	100	125	Prior to Compaction	75	100	125	Prior to Compaction
Limestone (1)	27.5	27.4	27.8	23.0	10.1	10.1	10.1	10.0
Granite (1)	28.0	29.7	29.9	20.0	10.0	10.4	10.5	10.0
Traprock	27.6	28.0	27.6	24.0	10.2	9.9	10.2	10.0
Granite (2)	39.2	40.0	40.2	20.0	10.6	10.7	10.9	10.0
Dolomite	--	29.7	--	20.0	--	11.0	--	10.0
Limestone (2)	--	31.1	--	20.0	--	11.1	--	10.0
Slag	--	29.7	--	20.0	--	9.8	--	10.0
Gravel	--	24.2	--	20.0	--	10.1	--	10.0

Table 4.46: Aggregate Breakdown Experienced During Design of Dense-Graded Mixtures

Aggregate	Average Passing 4.75-mm (%)		75 Blows	Specification
	75 Blows	Prior to Compaction		
Limestone (1)	58.5	56.0	5.7	4.0
Traprock	57.8	56.0	5.6	4.0
Granite (2)	63.2	56.0	5.8	4.0

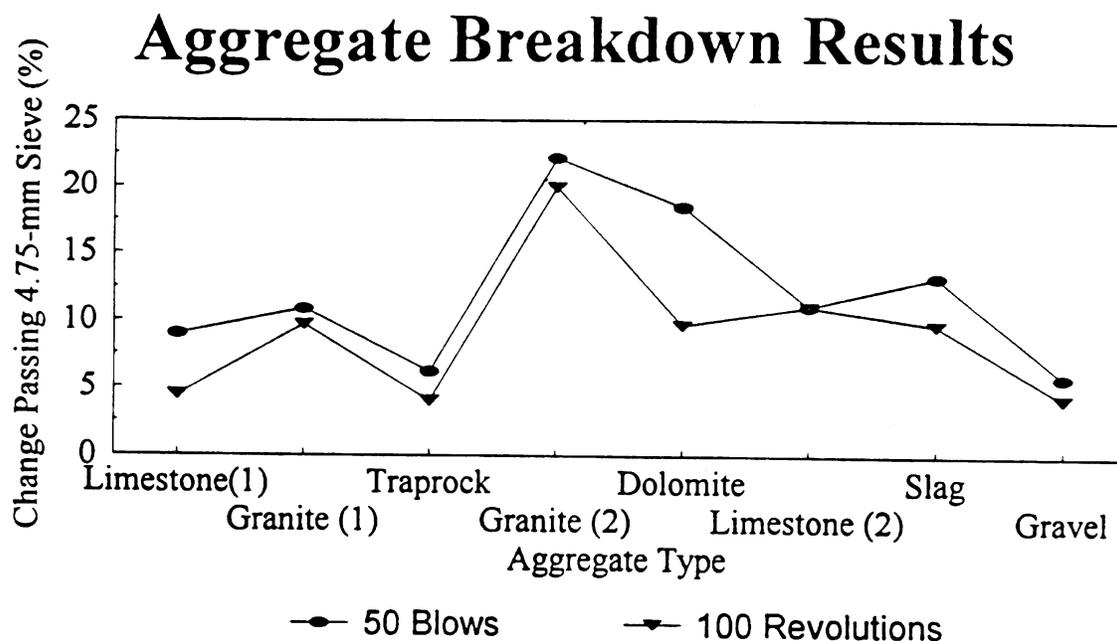


Figure 4.33: Aggregate Breakdown on the 4.75-mm Sieve for 50-Blow Marshall Compaction and 100 Revolutions of the SGC

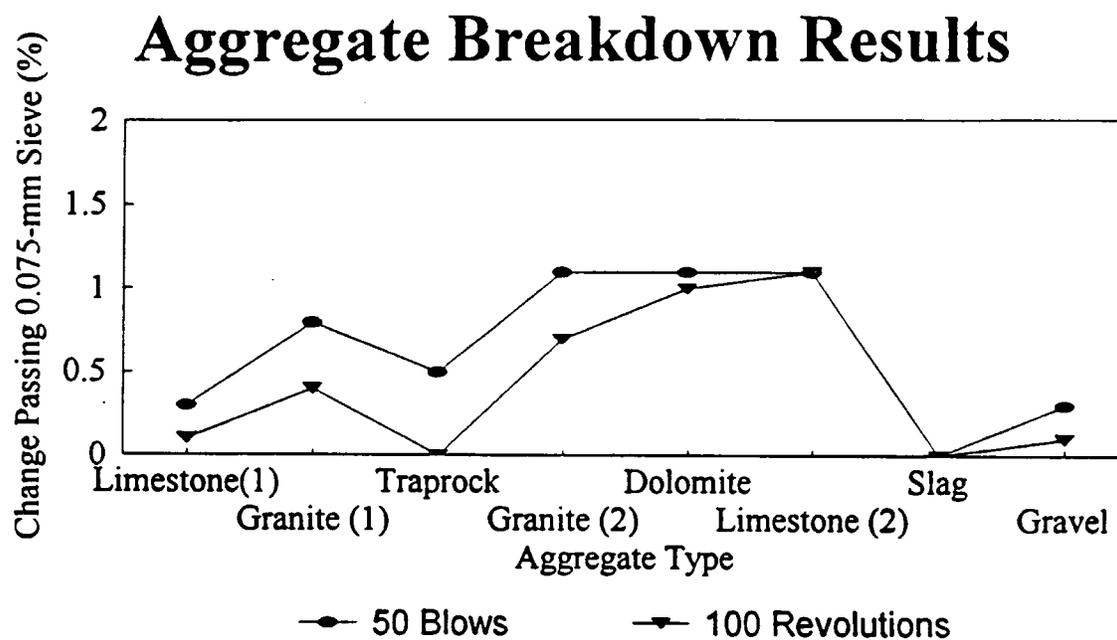


Figure 4.34: Aggregate Breakdown on the 0.075-mm Sieve for 50-Blow Marshall Compaction and 100 Revolutions of the SGC

Since the aggregate type was found to be significant to the amount of aggregate breakdown experienced in both types of compaction, an attempt to correlate one or more aggregate properties to the amount of breakdown experienced seems logical. In the United States, the Los Angeles Abrasion Loss Value (LA value) is normally thought to be an indicator of an aggregate's ability to withstand degradation. Linear regression analyses were therefore completed for each of the compaction methods in order to correlate the amount of breakdown with the LA values for each aggregate. The results of the 4.75-mm sieve are shown in Figures 4.35 and 4.36 for the Marshall hammer and SGC, respectively. Note that the R^2 values indicate a good correlation between aggregate breakdown and LA values for both compaction types. This would seem to indicate that the LA value may be valuable in excluding aggregates that may experience excessive breakdown from use in SMA mixtures. It appears from the data that an L.A. Abrasion requirement of 30 which is often used is reasonable. Increasing this requirement will result in excessive aggregate breakdown in some cases.

4.5.1.2 Analysis of Marshall Compaction

Mixture designs compacted with 35, and 75 blows of the Marshall hammer were completed for the limestone(1), granite(1), traprock, and granite(2) aggregates. Dense-graded HMA mixtures were also designed using 75 blows of the Marshall hammer for the limestone(1), traprock, and granite(2) aggregates for comparative purposes. The results are plotted in Figures 4.37 and 4.38 for the 4.75- and 0.075-mm sieves, respectively. An immediate observation from these figures is that while the dense-graded mixtures experience less breakdown on the 4.75-mm sieve, they show an increase in the percent passing the 0.075-mm sieve. One plausible explanation for this is that since the dense-graded mixtures have a graded aggregate structure, the amount of breakdown over each of the sieves is minor, but when added together yields a significant increase in the amount passing the 0.075-mm sieve. The SMA mixtures are gap-graded and the majority of breakdown occurs in the coarse aggregate sizes. Thus the amount passing the 4.75-mm sieve increases significantly, but the resulting particles are mostly in the mid-size range of sieve sizes. Thus the percent passing the 0.075-mm sieve does not change as much for SMA mixtures as for dense graded mixtures.

To further analyze the data, an ANOVA was completed on the data from mixtures compacted with 35, 50, and 75 blows of the Marshall hammer. At an α level of 0.05, the results show that for SMA, the aggregate type and compactive effort is significant to the amount of aggregate breakdown for both the 4.75- and 0.075-mm sieves. The interaction of these two variables was not significant. Also, the analysis indicates a linear trend in the amount of aggregate breakdown produced by the varying compactive efforts; 35 blows produces the least, while 50 blows shows the next highest followed by 75 blows. It can be seen from Figures 4.37 and 4.38 that the difference between the aggregate breakdown produced by 35 and 50 blows is slight. Also, the statistical analysis did confirm that there is a difference between aggregate breakdown in SMA mixtures compacted at each of the three levels and dense-graded HMA mixtures compacted with 75 blows.

4.5.1.3 Analysis of Superpave Gyrotory Compaction

Mixture designs compacted with 75, and 125 revolutions of the SGC were completed for the limestone(1), granite(1), traprock, and granite(2) aggregates. The results are plotted in Figures 4.39 and 4.40 for the 4.75- and 0.075-mm sieves, respectively. As can be seen from the figures,

Aggregate Breakdown Results

Marshall Hammer, 50 Blows

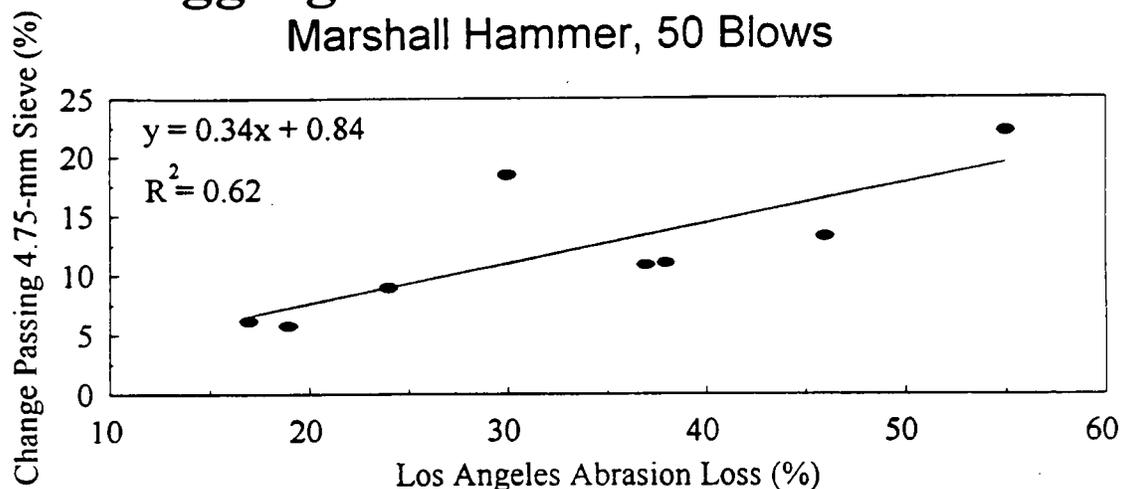


Figure 4.35: Correlation of Aggregate Breakdown and Los Angeles Abrasion for 50-Blow Marshall Compaction

Aggregate Breakdown Results

SGC, 100 Revolutions

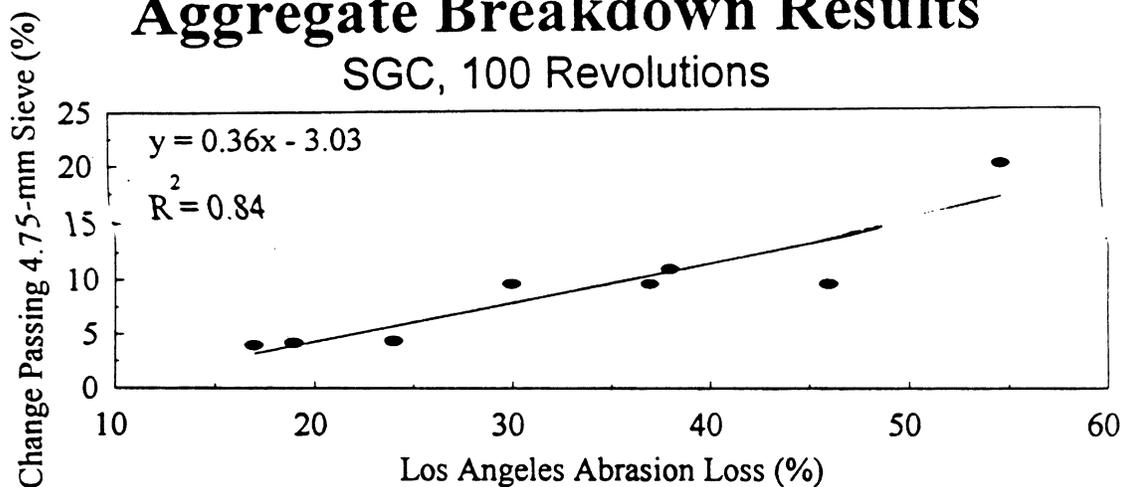


Figure 4.36: Correlation of Aggregate Breakdown and Los Angeles Abrasion for 100 Revolutions SGC Compaction

Aggregate Breakdown Results

Marshall Hammer

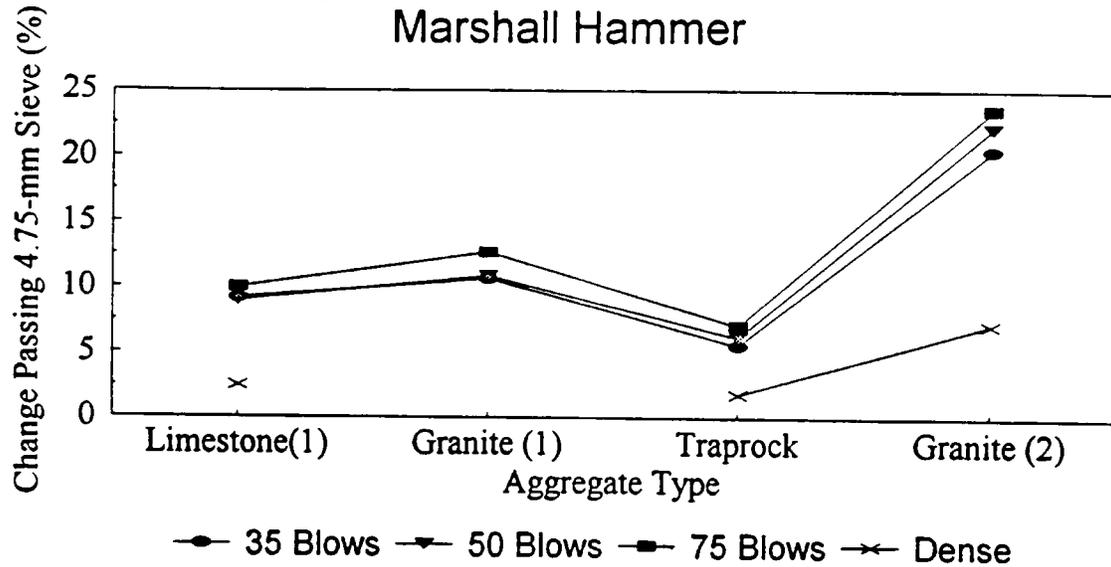


Figure 4.37: Aggregate Breakdown on the 4.75-mm Sieve for Various Levels of Marshall Compaction

Aggregate Breakdown Results

Marshall Hammer

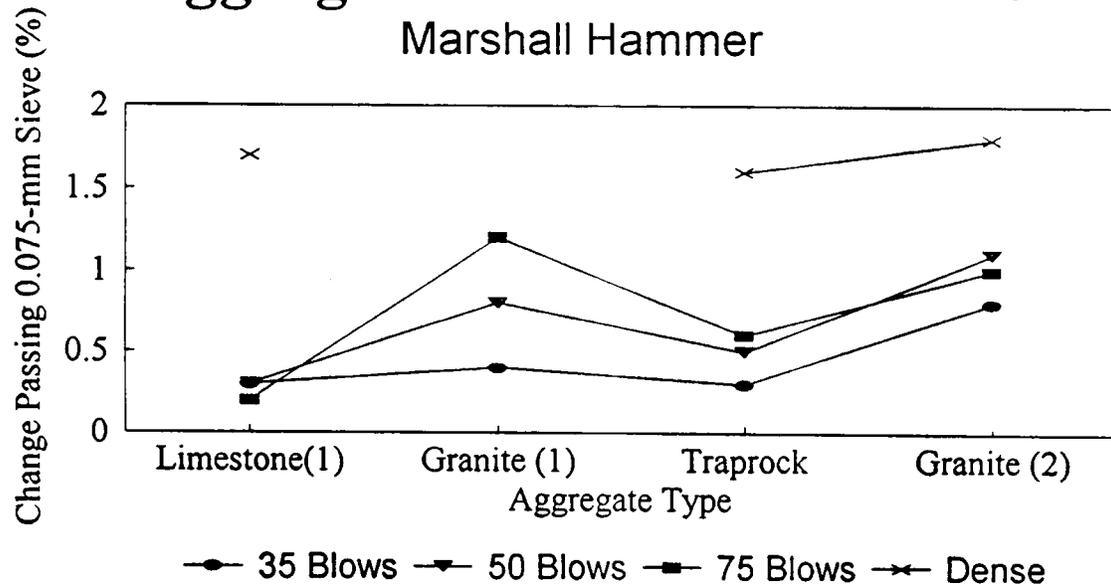


Figure 4.38: Aggregate Breakdown on the 0.075-mm Sieve for Various Levels of Marshall Compaction

Aggregate Breakdown Results

Superpave Gyrotory Compactor

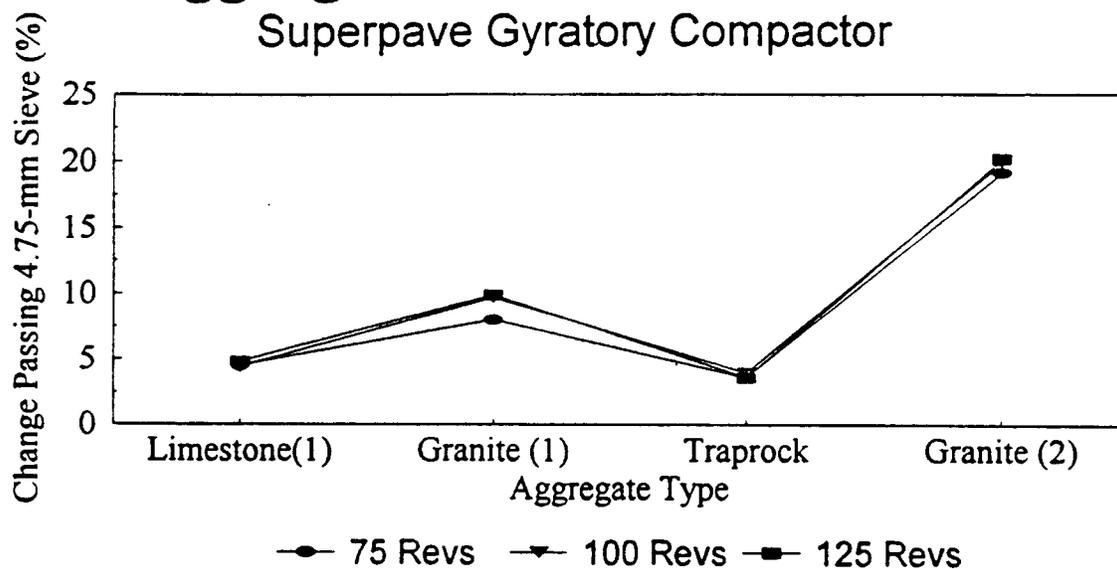


Figure 4.39: Aggregate Breakdown on the 4.75-mm Sieve for Various Levels of SGC Compaction

Aggregate Breakdown Results

Superpave Gyrotory Compactor

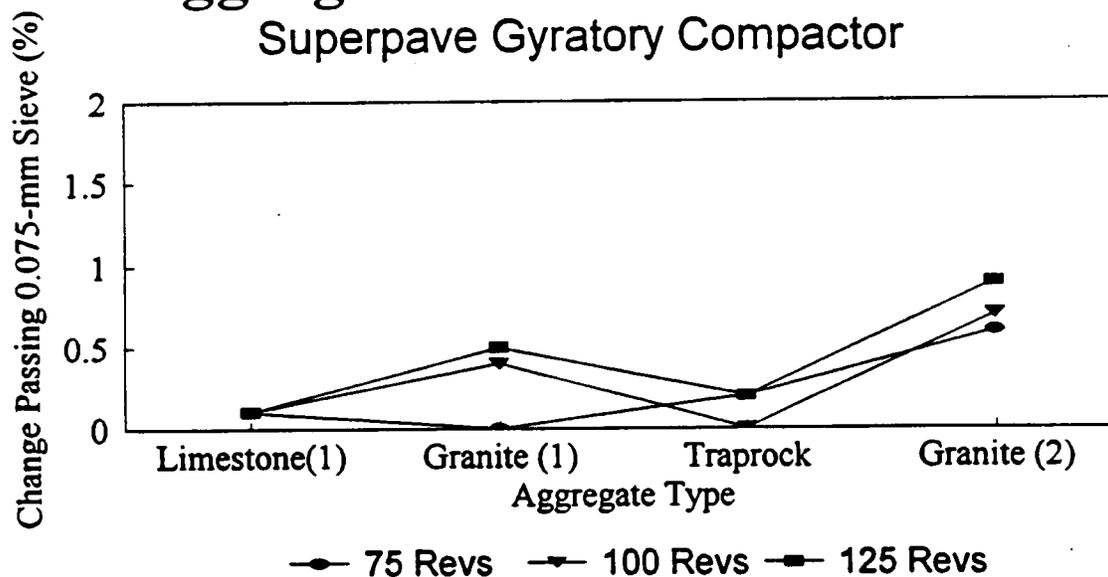


Figure 4.40: Aggregate Breakdown on the 0.075-mm Sieve for Various Levels of SGC Compaction

there appears to be very little difference in the amount of breakdown produced by the three compaction levels.

An ANOVA was also completed for the data from SMA mixtures compacted with 75, 100, and 125 revolutions of the SGC. The results indicate that at an α level of 0.05, the type of aggregate as well as the compactive level are significant to the amount of aggregate breakdown produced on both the 4.75- and 0.075-mm sieves. The results further suggest that while the interaction of these two variables is not significant for the 4.75-mm sieve, it is significant for the 0.075-mm sieve. The results again indicated a linear trend in the amount of breakdown produced as a function of compaction level; the least amount of breakdown occurs with 75 revolutions, followed by 100 and 125. However, in looking at the data in Table 4.45, the differences in breakdown does appear to be slight for the three compaction levels.

4.5.2 Aggregate Breakdown Field Study

The laboratory breakdown study showed that many of the SMA mixtures had a lot of aggregate breakdown during compaction. To be realistic the laboratory compaction method should result in breakdown that is similar to breakdown during field compaction. If the breakdown between the field and laboratory is significantly different the laboratory volumetrics may have little meaning.

To evaluate field breakdown, the Missouri DOT compared the field breakdown to laboratory breakdown on an SMA project. The LA abrasion of the aggregate used on this project was 25. To evaluate breakdown, samples were taken and sieve analysis conducted for belt samples, aggregate extracted from loose mixture, aggregate extracted from laboratory compacted mixture, and aggregate extracted from field compacted mixture. The results are shown in Table 4.47.

Even though this is a limited amount of data it does indicate for this aggregate that the breakdown is similar after compaction with the Marshall hammer and compaction in the field. For example observation of the 4.75-mm sieve indicates that the average percent passing from belt sample is 24, loose mix is 26, lab compacted mix is 36, and field compacted mix is 34. Additional data is needed before definitive conclusions can be made about the comparison of breakdown of aggregates, in the laboratory and in-place.

4.6 WORKABILITY - MIXING & COMPACTION TEMPERATURES

Two methods were investigated for evaluating the mixture workability: the Brookfield viscometer and high speed asphalt cement blender. The equipment used for these tests allow the torque to be measured as the sample is tested. The entire SMA mixture could not be evaluated using these techniques but the fine mortar was evaluated. The Brookfield viscometer proved to be the best approach of the two methods.

The eight mortars investigated in this study were evaluated with the Brookfield viscometer using a number 29 spindle. The stiffness of mortar was measured at 135° and 175°C. The results are shown in Table 4.48. The mortars were evaluated at 2 different asphalt contents that were representative of the two mix designs (Marshall and Superpave). In some cases, these two asphalt contents were equal.

In almost every case the higher asphalt content for a given mortar provided the lower stiffness. There is a wide range of stiffnesses between the various mortars. Mortar G is by far the

Table 4.47: Aggregate Breakdown Measured by Missouri DOT

Sample Identification	Sample No.	Percent Passing					
		19-mm	12.5-mm	9.5-mm	4.75-mm	2.36-mm	0.075-mm
Belt	1	100	85	62	23	15	8.6
	2	100	87	67	25	16	8.6
	3	100	86	65	22	15	8.4
	4	100	85	65	24	17	9.2
	5	100	86	65	25	17	9.1
	Average	100	86	65	24	16	8.8
Loose Mix	1	100	88	67	24	14	7.6
	2	100	88	72	29	18	8.9
	3	100	87	69	25	16	8.2
	4	100	89	67	26	17	8.6
	5	100	89	70	27	18	9.0
	Average	100	88	69	26	17	8.5
Lab Mix	1	100	87	68	33	20	8.0
	2	100	91	74	38	23	9.1
	3	100	88	72	34	21	8.8
	4	100	93	78	39	24	8.6
	5	100	90	74	38	24	8.9
	Average	100	90	73	36	22	8.7
Field Mix	1	100	91	74	33	20	8.7
	2	100	86	69	30	19	8.0
	3	100	91	72	34	22	10.0
	4	100	91	72	35	22	9.4
	5	100	91	75	36	23	10.7
	Average	100	90	72	34	21	9.4

Table 4.48: Stiffness of Fine Mortars at Approximate Mixing and Compaction Temperatures

Mortar	Brookfield Viscosity, cP		
	AC, %	135 °C	175 °C
A	6.2	6,450	1,180
B	6.8	17,800	3,000
	6.4	22,600	3,500
C	7.0	10,100	1,620
	6.4	17,770	2,620
D	6.1	85,550	14,600
	6.2	23,400	3,080
E	5.8	29,800	4,040
	5.8	36,400	5,000
F	5.9	44,800	7,500
	6.4	690,000	72,000
G	5.5	1,300,000	128,000
	6.0	171,250	23,300

highest stiffness. One reason for the highest stiffness in mortar G is the higher amount of filler in this mixture (12 percent). The mortars without fiber, (mortar A, B and C) generally had the lowest overall stiffness.

The data clearly shows the effect of temperature on the stiffness. The stiffness increased by a factor of 5-10 as the temperature was decreased from 175° to 135°C.

The use of the Brookfield viscometer to measure the stiffness of loose mortar appears to be reasonable. All the test results generally follow the expected trend. Field verification is needed prior to developing and adopting a standard for this test procedure. The field verification should determine if this method can be used to rank mix stiffnesses for various SMA mixtures and to establish a maximum stiffness that is acceptable. This limiting stiffness should be useful in establishing mixing and compaction temperatures.

The mortar stiffness in the laboratory was evaluated to determine what effect it had on compaction of mixes. All of the mortar mixes were compacted with the SGC and the Marshall hammer at optimum asphalt content. The temperature was varied from 143° to 160°C. The effect of temperature on VCA is shown in Table 4.49. The VCA is used to evaluate the compactibility because all of the mortar mixes had the same coarse aggregate and should have similar VCA values when compacted in the laboratory. Using the VCA would allow for comparison between all mixtures as well as the effect of variations in temperature for a particular mixture.

The data clearly shows the effect of temperature on the stiffness. The stiffness increased by a factor of 5-10 as the temperature was decreased from 175°C to 135°C.

Table 4.49: Effect of Mixture Compaction Temperatures on VCA of SMA Mortar Mixtures

Mortar Type	Compaction Method	AC, %	VCA at 143°C	VCA at 152°C	VCA at 160°C
A	M	6.2	33.0	33.0	33.2
	S	6.2	33.1	34.0	33.8
B	M	6.8	34.2	34.5	34.0
	S	6.4	34.0	33.6	34.1
C	M	7.0	34.2	33.9	33.9
	S	6.4	33.9	33.8	33.5
D	M	6.1	33.2	33.1	32.8
	S	6.1	33.2	33.8	33.8
E	M	6.2	33.0	32.8	32.9
	S	5.8	32.7	33.3	33.3
F	M	5.8	33.0	33.2	32.7
	S	5.9	33.7	33.4	33.6
G	M	6.4	34.4	33.4	33.4
	S	5.5	33.0	33.0	32.7
H	M	6.0	----	----	----
	S	5.7	----	----	----

M - Marshall

S - SGC

The test results indicate that there is very little change in VCA (inverse of density) over the range of temperatures evaluated. Mortar mixes B and C which contained the 2 polymers appeared to be the most difficult to compact at all 3 temperatures. This may indicate that a temperature higher than 160°C (320°F) is needed for the 2 polymers. The data tends to show in general that the test variability is too high (even though it appears to be reasonable) to determine the effect of temperature variations over the range of temperatures. In other words, the normal variability in density exceeds the variability that is caused by changes in temperature within the range of temperatures investigated.

4.7 PERMEABILITY EVALUATION

Testing during some of the early SMA projects indicated that mixture permeability may be a problem if the air voids in the SMA mixture are slightly high. With dense mixtures the permeability begins to become significant somewhere between 8 and 10 percent air voids. Some test results seemed to indicate that permeability may become a problem with SMA mixtures somewhere between 6 and 8 percent air voids.

A test plan was set up to evaluate the permeability of the SMA mixture over a range of air void contents. The air voids were varied by varying the compaction effort. The permeability test results are shown in Table 4.50. The table shows the measured permeability, as well as percentage of absorbed water during SSD test, for each mixture. The percentage of absorbed water is a rough measure of permeability and provides some measure of the problem.

The permeability of the SMA mixture is very sensitive to the air void content and may change by a factor of 10 with very little change in air void content. On the other hand the percentage of absorbed water during the SSD test may provide the best guide for determining the critical void level. It appears from Figures 4.41 and 4.42 that the percentage of absorbed water and the permeability start to increase rapidly at approximately 6-6.5 % air voids. This seems to indicate that when the air void level of SMA mixtures is 6 percent or higher permeability may tend to be a problem.

Based on the data presented in this section every effort should be made to compact SMA mixtures in-place to approximately 6 percent air voids or less.

4.8 MIXTURE PERFORMANCE EVALUATION RESULTS

Several parameters were evaluated to help estimate the potential performance of SMA mixtures. The two primary tests that may provide some correlation with performance include the low temperature indirect tensile test and wheel tracking tests.

The laboratory wheel tracking test is becoming widely used to estimate the rutting potential of asphalt mixtures. This test involves running a small loaded wheel back and forth across a sample for a specified number of passes then determining the rut depth and the rutting rate. Several machines are available for doing these tests but there is no one test that is nationally accepted as being better than the rest. For this study the test equipment owned by Couch Construction was used. This equipment was built by Couch and is very similar to the Hamburg equipment. The loads are applied under water.

Eight mixtures were evaluated in the wheel tracking device. Each mix was tracked at 55°C with up to 20,000 passes unless failure occurred earlier. The test results are shown in Table 4.51.

The test results clearly show a difference between the 4 aggregate types and between the 4 mortar types. The limestone (1) aggregate had an average rutting rate of 5.02 which is very high. A rutting rate of 0.30 is considered to be too high. The rutting rates for slag, traprock, and granite, were 0.31, 0.22, and 0.21 mm/hr respectively. So all of the aggregate types did well except for the limestone (1).

There is no clear reason why the limestone(1) coarse aggregate performed so poorly in the wheel tracking device. Limestone(1) does have a much lower stability (5010 N) than the other aggregates (6100-9700 N); it also has a much lower tensile strength (526 kPa) than do the other aggregates (668-1050 kPa). These results can be seen in Table 4.28. The information in Table 4.33 for SGC compacted mixtures shows a similar trend. Apparently there is some problem with this mixture as a result of aggregate type, gradation, or a combination of the two; the result is poor performance. It also appears that the Marshall stability and indirect tensile strength test identified that a problem existed.

Four of the mortar mixes were also evaluated. Mortar A which contained no stabilizer had a high rate of rutting (1.45). The rutting rate for SMA mortar mixtures B and F (0.19 and

Table 4.50: Permeability Test Results

Mixture Type	Compaction Method	Air Voids, %	Permeability, cm/s	Absorbed Water %
Limestone (2)	Marshall	7.0	0.600	1.2
		6.5	0.030	0.7
		5.3	0.060	0.3
		4.1	0.005	0.2
		3.7	0.002	0.2
	SGC	7.6	1.400	1.5
		6.5	0.400	0.8
		5.3	0.200	0.5
		4.6	0.040	0.4
		4.2	0.040	0.2
Gravel	Marshall	5.3	0.600	0.4
		4.2	0.300	0.2
		3.6	0.030	0.2
		2.7	0.040	0.1
		2.8	0.003	0.2
	SGC	7.0	0.600	0.8
		5.8	0.600	0.6
		5.3	0.200	0.3
		4.6	0.100	0.4
		4.0	0.002	0.2
Granite (2)	Marshall	7.1	0.500	0.8
		5.4	0.010	0.3
		4.8	0.070	0.2
		3.2	0.0002	0.2
		3.4	0.00008	0.2
	SGC	8.1	0.600	1.3
		7.3	0.200	1.0
		6.2	0.100	0.6
		5.4	0.070	0.3
		4.1	0.009	0.2

Table 4.50: Permeability Test Results (continued)

Mixture Type	Compaction Method	Air Voids, %	Permeability, cm/s	Absorbed Water %
Traprock	Marshall	6.2	0.500	0.8
		5.7	0.030	0.3
		3.9	0.100	0.2
		3.6	0.020	0.2
		3.5	0.100	0.2
	SGC	6.9	0.600	0.8
		5.2	0.300	0.3
		4.7	0.400	0.3
		4.6	0.100	0.2
		4.0	0.040	0.2

Table 4.51: Results of Wheel Tracking Tests

SMA Mix Identification	Average Rutting Rate (mm/hr)
Slag	0.31
Limestone (1)	5.02
Traprock	0.22
Granite (2)	0.21
Mortar A	1.45
Mortar B	0.19
Mortar E	0.61
Mortar F	0.30

0.30 respectively) were satisfactory and A and E (1.45 and 0.61 respectively) were not satisfactory.

The DSR results at 58° for mortar mixtures A, B, E, and F are 28.05, 59.47, 36.62, and 35.82, respectively. It is expected that the DSR value for the mortar at 58°C should correlate to the wheel tracking tests for the same mixture at 55°. Figure 4.43 shows the correlation between DSR at 58°C and wheel tracking at 55°. There is a reasonable correlation between DSR and rutting rate. Based on this limited amount of data, a $G^*/\sin\delta$ after RTFO of approximately 30 or more at the design temperature will provide a rutting rate of 1.0 mm/hr or less. Since the rutting and the DSR testing were done at different temperatures, additional testing needs to be completed before a specification can be established using rutting data.

Tests were also conducted to evaluate the low temperature properties of the mixture. Tests were conducted at -10°C to determine the tensile strength and strain at failure for the 4 aggregate variations and the 4 mortar variations. The test results are shown in Table 4.52.

SMA Mixture Permeability

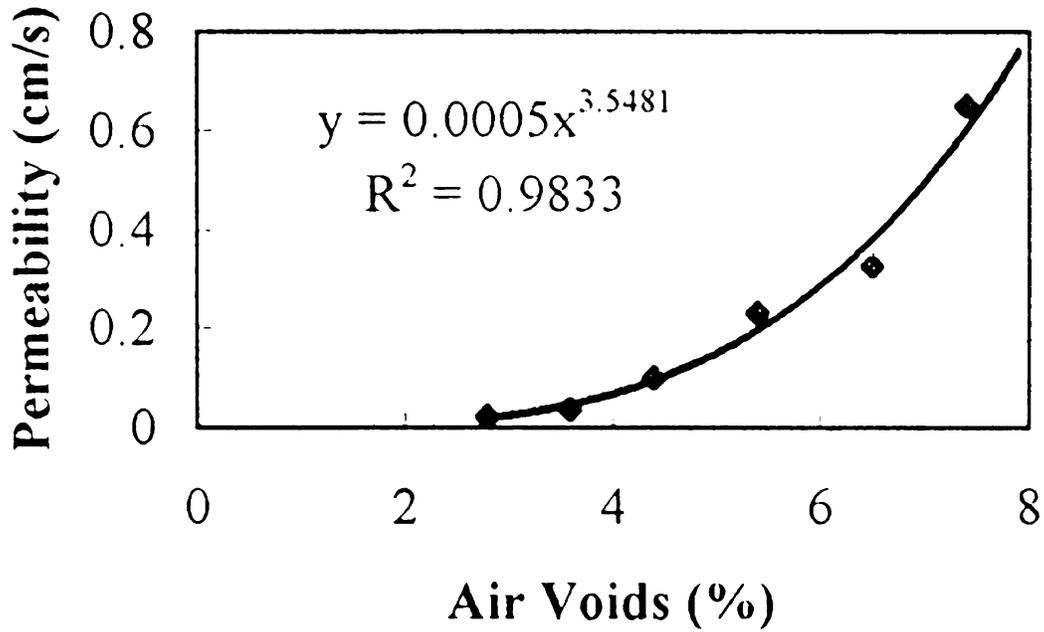


Figure 4.41: SMA Mixture Permeability as a Function of Air Voids

Absorbed Water

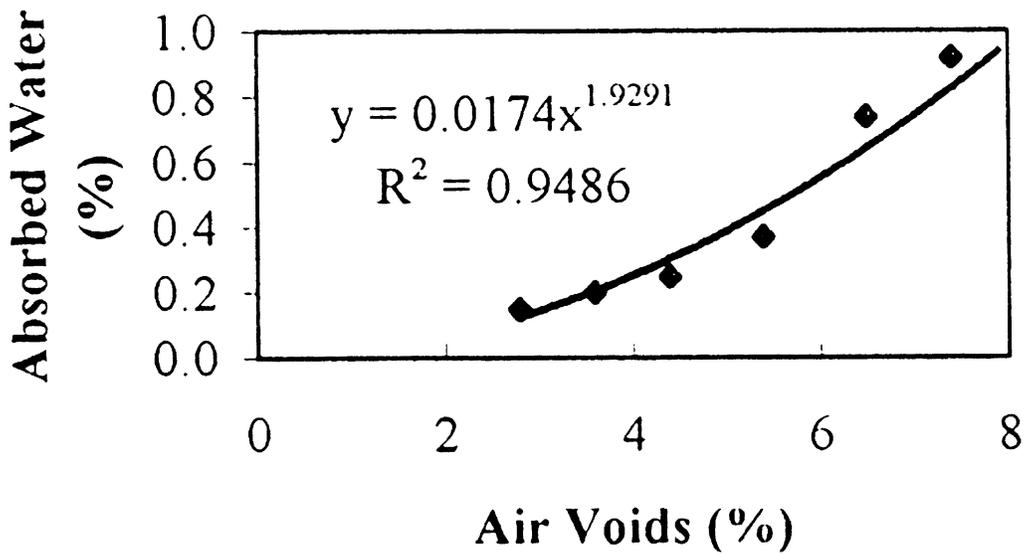


Figure 4.42: SMA Mixture Absorbed Water as a Function of Air Voids

It is expected that the tensile strain at failure is related to the stiffness of the mortar at low temperature. As shown in Table 4.47 the tensile strains at failure for mortars A, B, E, and F are 0.00193, 0.00102, 0.00158, and 0.00119 respectively. The stiffnesses of these mortars as determined by the bending beam rheometer and shown in Tables 4.22-4.26 are 467, 298, 547, and 341 respectively. There does not appear to be a good correlation between the bending beam rheometer test results and strain at failure. The tensile test was not conducted on the mortar. The strain at failure of the mixture is much more likely to be related to the tensile properties of the binder. This is being evaluated under additional work for this project.

Table 4.52: Indirect Tensile Test Results at -10°C

Mix Identification	Tensile Strength, kPa	Tensile Strain at Failure, mm/mm
Mortar A	2625	0.00193
Mortar B	2281	0.00102
Mortar E	2715	0.00158
Mortar F	2522	0.00119
Limestone (1)	2260	0.00130
Slag	2467	0.00099
Traprock	4202	0.00081
Granite (2)	2811	0.00120

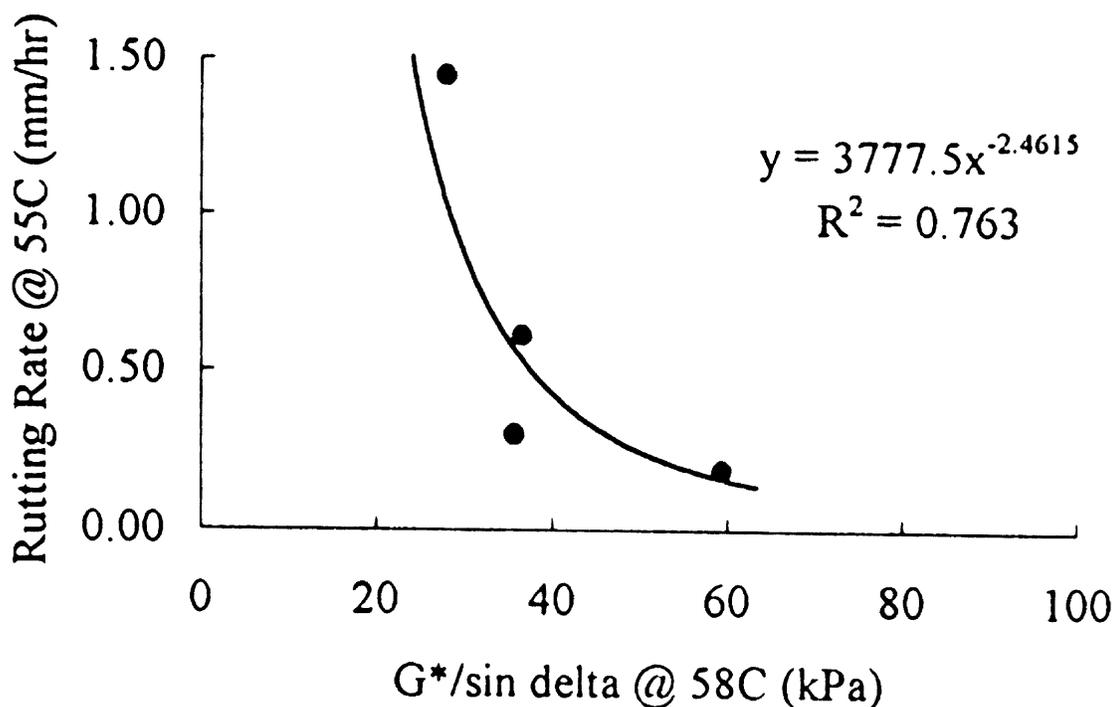


Figure 4.43: Wheel Tracking Results

CHAPTER 5 - DISCUSSION OF RESULTS

The results from this study will be used to develop a mix design procedure for SMA, to identify tests to evaluate material and mixture properties, and to establish criteria for these tests. A tremendous amount of data has been collected to help provide the background information to satisfy these objectives. A discussion of the various test results provided in Section 4 will be performed with the ultimate objectives in mind: How is this data going to provide information that can be used in designing SMA mixtures?

5.1 MATERIAL PROPERTIES

The materials properties are provided for the aggregate, mineral fillers, asphalt binders, and fibers. When possible test results should be specified on the final SMA mixture or mortar to provide more flexibility in selecting the materials to be used. However in some cases specifications will be required for the component materials.

The materials selected for this study were chosen to provide a wide range of properties. Some of these materials may not be acceptable to be used in SMA mixtures but they must be evaluated to allow identification of desirable properties.

The aggregate properties shown in Tables 4.1 and 4.2 are believed to be important to the performance of SMA. The bulk specific gravity of the coarse aggregate varied from 2.263 to 2.967 and the fine aggregate varied from 2.490 to 2.923. The apparent specific gravity of the coarse aggregate varied from 2.501 to 3.024 and the fine aggregate varied from 2.626 to 3.004. The absorption of the coarse aggregate varied from 0.4 to 4.2 and the fine aggregate from 0.0 to 4.4. The LA Abrasion value ranged from 17 to 55 for the coarse aggregates. The range of the test results for all of these properties would include most aggregates used in the U.S.

The soundness loss was reported for each of the aggregates if the information was provided by the supplier. There was no analysis of the soundness results.

The flat or elongated particles were measured using the 5 to 1 ratio as suggested by Superpave. Even though some of the aggregates were definitely flat or elongated, the worst aggregate only had 3 percent of the particles failing to meet the 5 to 1 ratio. A 3 to 1, and a 2 to 1 ratio were also evaluated. Two of the aggregates had more than 20 percent flat and elongated particles, thus failing to meet the 3 to 1 ratio suggested criterion of 20 percent, maximum. The 3 to 1 ratio seems to separate the aggregates even better than the 2 to 1 ratio. It appears from this part of the study that a 3 to 1 or 2 to 1 ratio must be specified instead of, or along with, the 5 to 1. A reasonable flat and elongated specification for 3 to 1 is 20 percent maximum; a reasonable ratio for 2 to 1 seems to be 60 percent maximum.

All of the coarse aggregate except one evaluated in this study had 100 percent of the particles with 2 or more fractured faces. The crushed gravel had 52 percent with two or more fractured faces and 74 percent with one or more fractured faces. This allowed for some evaluation of the effect of fractured faces but very little. Present guidance for SMA suggests that all crushed stone should be used and that appears to be a good approach to ensuring satisfactory aggregate properties. The gravel aggregate generally did not do well in most of the SMA mixture tests. If gravel is used in SMA mixtures it should have 100 percent with 2 or more fractured faces.

The fine aggregate angularity was evaluated by the NAA flow test as recommended by Superpave. It was determined prior to starting this study that natural sands would not be evaluated so all fine aggregates have reasonably good uncompacted void results. The test results for the fine aggregates ranged from 44.6 to 49.9. For the highest volume roads Superpave recommends that the minimum value be 45. Only one of the nine fine aggregates failed to meet this criteria; when rounded off, this aggregate would also meet the 45 percent angularity requirement. A value of 45 seems reasonable for the fine aggregate angularity requirement.

The mineral filler properties as shown in Table 4.3 cover the range of mineral fillers that are normally used. The Oyta and Dankalk fillers have been used in Denmark. These fillers can not be used alone because they tend to stiffen the mortar excessively so they have to be blended with other fillers. The Faxekalk filler is also from Denmark and is one that is often used to produce satisfactory SMA mixtures. The remaining eight fillers are from the U.S. and have been used successfully to produce SMA mixtures.

Three properties were determined for each filler to evaluate the filler's effect on mortar properties. These properties were particle size, particle shape, and surface area. The particle size of primary interest was 0.020 mm since there has been some effort to limit the amount smaller than this size to 20 percent. Two of the eleven fillers, diabase and wimpey, met this requirement of 20 percent while the remaining nine fillers failed to meet the requirement. Based on the findings of this study, 0.020 mm particle size limitation should be deleted from SMA specifications.

The particle shape measurements resulted in dry-compacted voids ranging from 33.5 for limestone filler to 65.4 for Oyta filler. The surface area ranged from 0.52 for marble filler to 6.23 for Dankalk filler. These ranges should include most fillers that are used to produce SMA mixtures.

The effect of asphalt binder was not a major part of this study. However, three binder types were selected: AC-20, AC-20M1 (SBS modified) and AC-20M2 (polyolefin modified). The three binder grades (Table 4.4) were 64-22 for non-modified, 70-28 for SBS modified, and 70-22 for polyolefin modified. The performance grading system for selecting binders for dense-graded HMA should also be used for SMA. Consideration should be given to increasing the grade on the high end by one grade to improve rutting resistance for high volume roads.

The fibers selected for this study were two typical fibers that have been used in many SMA projects (cellulose and mineral fiber). The properties shown in Table 4.5 are typical of these 2 fibers. Both fiber types appeared to give good SMA mixtures.

5.2 MORTAR PROPERTIES

Mortars were evaluated using the Superpave binder tests. Tests were conducted at high intermediate, and low temperatures just as one would do for performance graded (PG) asphalt cement. The mortar consisted of mineral filler, asphalt cement, and stabilizer mixed in the approximate proportions that they would be used in SMA mixture.

There tests indicated that the Superpave binder tests could be conducted on the mortar and reasonable results obtained. It appears that the DSR, BBR, tensile test, and Brookfield viscometer tests can be conducted on the mortar with little problem. When it is required to age the binder in the thin film over test and/ or pressure aging vessel the binder is aged first then mixed with the other mortar components.

As shown in Table 4.7, the DSR results at higher temperatures (58° and 70°C) are affected by the type of filler and the amount of filler. The primary concern at higher temperatures is resistance to permanent deformation so an increase in $G^*/\sin\delta$ values is a benefit. Therefore, from a high temperature standpoint the stiffer binder is better however the low temperature properties must also remain satisfactory.

Figures 4.3 to 4.4 show that the amount of filler affects the $G^*/\sin\delta$ at high temperatures. Increasing the filler from 8-12 percent appears to increase the $G^*/\sin\delta$ by about 30 percent. The $G^*/\sin\delta$ at high temperatures is also affected by the type of modifier used in the mortar (Figures 4.5 and 4.6). The mineral fiber provides some stiffening to the mortar with no modification. The cellulose provides a stiffer mortar than the mineral fiber followed by SBS and polyolefin with the greatest increase in stiffness. The effect of polyolefin on stiffness appears to be increased after the RTFO.

The filler property that relates best to mortar performance is the modified Rigdon voids. There is a reasonably good correlation between modified Rigdon voids and stiffening effect on the mortar. The modified Rigdon voids should therefore be a good screening test to evaluate fillers for possible use in SMA mixtures. A reasonable recommended requirement for the modified Rigdon voids would be 50 based on known performance of the fillers. Two of the fillers were over 50, but both of these fillers (Dankalk and Oyta) tended to stiffen the mortar excessively. The remaining fillers which are less than 50 have been used successfully to produce SMA mixtures.

There is no significant correlation between $G^*/\sin\delta$ and the amount of filler smaller than the 0.02 mm size (Figure 4.8). Also, the correlation between $G^*/\sin\delta$ and mineral filler surface area is weak (Figure 4.9). The best correlation of $G^*/\sin\delta$ at high temperatures is with the modified Rigdon (dry compacted voids). From a specification point of view there is at least two options: to specify the dry-compacted voids for the filler or to specify the stiffness of the mortar. The preference of course would be to specify the mortar stiffness and allow any filler to be used as long as the mortar meets the requirements. For filler screening purposes however, a maximum dry-compacted void level of 50 can be used.

After comparing the data in Tables 4.7 - 4.11, it appears that the mortars are typically at least 5 times stiffer than the asphalt cement. The mineral fiber has the least stiffening effect and it is approximately 5 times higher at 10 percent filler. A good starting point then for writing a specification would be to specify a $G^*/\sin\delta$ of 5.0 kPa minimum prior to RTFO and 11.0 kPa minimum after the RTFO. If these were the specifications, then the SBS and polyolefin stabilized mortars would be in compliance for all fillers evaluated at both high temperatures. The cellulose fiber mortars would meet the requirements at 58°C for all fillers and would meet all of the requirements at 70°C for five mortar combinations. The mineral fiber mortars would meet the requirements at 58°C but not at 70°C.

It can be seen from Tables 4.16 through 4.20 that the $G^*\times\sin\delta$ at intermediate temperatures (19° and 31°C) is affected by amount and type of filler. A higher filler content increases the $G^*\times\sin\delta$. At the intermediate temperature, the type of modifier (mineral fiber, cellulose, SBS, and polyolefin) has very little effect on the stiffness. Also, none of the filler properties (particle shape, particle size, and surface area) correlates well with $G^*\times\sin\delta$ at intermediate temperatures. Hence, the only way to ensure desirable mortar properties at the intermediate temperatures is to actually test the mortar.

The stiffness of the mortars at the intermediate temperatures is up to 5 times the stiffness of the asphalt cement. A starting point for a specification would be to set the maximum limit for

$G^* \times \sin \delta$ to be 5 times that required for asphalt cement. The limit then would become 25,000 kPa maximum. Setting the limits at 25,000 kPa would accept all of the mortars at 31°C and about one third to one half of the mortars at 19°C.

At the low temperatures, the filler type and amount has very little effect on the m-value determined in BBR test. For a specific temperature, there is very little change in the m-value for the various mortars.

The type of filler has very little effect on the mortar stiffness at low temperatures but the amount of filler does seem to have an effect. The properties of the fillers as shown in Figures 4.24-4.26 are not clearly related to the mortar stiffness. This is reasonable since at low temperatures the binder is very stiff and the properties of the binder can minimize the effect of any change in filler properties.

As shown for the high and intermediate temperatures, the maximum mortar stiffness at low temperatures is approximately equal to 5 times the stiffness of the asphalt cement. Again, a good starting point for a specification for the mortar is 5 times the low temperature specification of asphalt cement ($5 \times 300 \text{ MPa} = 1500 \text{ MPa}$ maximum). For this specification, all mortars are in compliance at -6°C and a large number of the mortars would meet the criteria at -18°C.

It appears that the best solution for mortar would be to test for stiffness at high and low temperatures. Mortars probably should not be tested at intermediate temperatures. The high temperature requirements should be a DSR $G^*/\sin \delta$ of 5.0 kPa before aging and a DSR $G^*/\sin \delta$ of 11.0 kPa after aging. The requirement at low temperatures should be a BBR result of 1500 MPa maximum on PAV aged material. There should be no m-value requirement.

5.3 MIXTURE DESIGN

A number of aggregates and mortars were used to validate the tentative mix design procedure developed in the first part of this study. SMA mix designs were developed with these materials. The tentative procedure seemed to do a good job of selecting the desired aggregate gradation and asphalt content. There are some problems that need to be addressed. There is a significant amount of aggregate breakdown that will be discussed further in Section 5.5. As a result of this aggregate breakdown, VMA requirements sometimes cannot be met. When the aggregate does not breakdown excessively the VMA requirements are easily met. There is no problem in meeting the VCA requirements for most mixtures.

Even with sufficiently high VMA values, the optimum asphalt content by weight may be relatively low when using high specific gravity aggregate. The best approach is to specify a minimum VMA (17% is recommended) and not to be concerned about the asphalt content by weight. There is nothing wrong with specifying a minimum asphalt content but this ends up being a different requirement for aggregates with differing specific gravity. It is much easier meeting the minimum asphalt content requirement when the specific gravity of the aggregate is low. Also, there are some cases where the mixture will meet the minimum 6.0 percent asphalt content but not meet the desired VMA. This results when a low specific gravity aggregate is used or when the aggregate absorbs a significant amount of asphalt cement. If a minimum asphalt content requirement is used it should be based on effective asphalt content.

At the present time there is no good performance test to evaluate the quality of an asphalt mixture. This is a problem with SMA mixtures but is also a problem with dense graded mixtures.

Many people are beginning to use a laboratory loaded wheel test to evaluate resistance to permanent deformation. This test is equally applicable to evaluate quality of SMA mixtures.

Another problem that has been observed in designing SMA mixtures is poor test results in moisture susceptibility tests. There is no reason to believe that moisture susceptibility is a problem with SMA mixtures but most mixtures do poorly in this test. Based on the aggregates used and the test results obtained it appears that a TSR requirement of 70% minimum is reasonable.

A comparison of the Superpave Gyrotory Compactor (SGC) and 50-blow Marshall designs is shown in Figures 4.27 and 4.28. These data show that the correlation between the two methods is good. It appears that in the range of lower optimum asphalt cement contents, the Marshall hammer tends to give a higher optimum for a given aggregate type and gradation. Conversely, in the range of higher optimum asphalt cement contents, the SGC gives the higher optimum for a given aggregate type and gradation.

Work was performed to evaluate SMA mixes at 35, 50, and 75 blow compactive efforts (Tables 4.28-4.30). The data is summarized below:

	<u>35-Blows Optimum</u>	<u>50-Blow Optimum</u>	<u>75-Blow Optimum</u>
Limestone (1)	7.1	6.4	5.8
Granite (1)	6.8	6.1	5.6
Traprock	5.5	5.3	4.7
Granite (2)	6.5	6.0	5.2

The differences in the optimum asphalt cement contents between 35 and 50 blows averages approximately 0.5% and between 50 and 75 blows averages approximately 0.6 percent. Much of this difference is thought to be due to breakdown of aggregate. Since 50-blow compaction is generally considered to be satisfactory, the other 2 compactive efforts should not be considered for future work. It was hoped that the 35 blow compaction would give about the same optimum asphalt content with less aggregate breakdown but this did not occur.

Work was performed to evaluate the differences between 75, 100, and 125 revolutions of the SGC. The results for these mixtures are summarized below:

	<u>75 Revolution Optimum</u>	<u>100 Revolution Optimum</u>	<u>125 Revolution Optimum</u>
Limestone (1)	6.2	5.8	5.5
Granite (1)	6.2	5.5	5.3
Traprock	5.7	5.6	5.1
Granite (2)	6.3	4.9	4.8

The differences between the various SGC compactive efforts is less than that for the Marshall hammer. The average difference between 75 revolutions and 100 revolutions is 0.4% and the average difference between 100 and 125 revolutions is 0.3 percent. From this data it

appears that 100 revolutions is acceptable and should continue to be used for SMA mixtures. As stated earlier, it appears that the SGC at 100 revolutions gives higher optimum asphalt contents than 50-blow Marshall when the asphalt content is high but lower optimum asphalt content when the asphalt content is low.

5.4 FLAT OR ELONGATED PROPERTIES

Aggregates from one source were crushed using two different methods to produce flat or elongated particles in one case, and to produce more cubicle particles in the other case. Using these two aggregates in various combinations provided SMA mixtures with varying amounts of flat or elongated particles. Mixtures were prepared with 100 percent of each aggregate, and in the ratios of 25-75 percent, 50-50 percent, and 75-25 percent to provide 5 different SMA mixtures. The data shown in Figure 4.29 indicates that the VMA is higher for the mixture with 100 percent flat or elongated particles. As more cubical shaped aggregate is added, the VMA appears to drop to a point and then increase again for the more cubical aggregate. From a VMA standpoint all of these mixtures are good since the VMA is well above 17.

The amount of aggregate breakdown was determined after compaction for all five mixtures. The results are shown in Table 4.42. Looking at the 4.75-mm sieve size, the more cubical mix (A2) had less breakdown than the flat or elongated mix (A1). The percent passing the 4.75-mm sieve before compaction was 21.0% for all mixtures. After compaction the percent passing was 26.0% for A2 and 30.4% for A1. This is shown graphically in Figure 4.30. The figure shows that adding flat or elongated particles clearly increases the percent passing the 4.75-mm sieve after compaction. Therefore, aggregate breakdown in the laboratory, and likely in the field, can be a bigger problem with flat or elongated particles.

The effect of compaction on percent passing the 0.075-mm sieve was also evaluated. There appears to be no significant difference in the percent passing this sieve for the different mixtures. Actually, the amount of 0.075-mm material in the compacted mixtures are slightly less than before compaction. This appears to be random test error and in no way related to flat or elongated particles.

At the beginning of this study, it was believed that the breakdown of aggregate would allow moisture to penetrate into the exposed aggregate and would make the mixture more susceptible to moisture damage. The five mixtures were evaluated for moisture susceptibility and found to have approximately the same tensile strength ratios. Figure 4.32 shows that there are some mixtures with higher TSR values than other mixtures; this is again believed to be random test error.

It appears that flat or elongated particles result in increased VMA and increased aggregate breakdown. However, this breakdown does not appear to affect the TSR. All samples for this part of the study were compacted with 50-blow Marshall. The SGC may orient the particles more and produce different results altogether.

Based on the aggregates evaluated it appears that the requirement of no more than 20% exceeding 3 to 1 and no more than 5% exceeding 5 to 1 is reasonable. The 3 to 1 requirement seems to separate the various aggregates better than the 2 to 1 requirement. If the 2 to 1 requirement is used, the limit should be set at 60%.

5.5 AGGREGATE BREAKDOWN

Gradation tests were conducted before and after compaction to determine the amount of aggregate breakdown. The results are shown in Tables 4.44 and 4.45 and shown graphically in Figures 4.33 - 4.40.

Figure 4.33 shows that for most aggregate there is very little difference in the breakdown with 50-blow Marshall and 100 revolutions with the SGC. For some aggregates, however, the difference is significant (for example, limestone(1) and dolomite). The Marshall hammer always gives as much or more breakdown than the SGC. From an aggregate breakdown standpoint, the SGC appears to be the better compactor. However, as stated above, the difference for most aggregates is insignificant. The change in percent passing the 4.75-mm sieve for the harder aggregates was 5-10 percent; it was greater than 10 percent for the softer aggregates.

The same trend was observed for the 0.075-mm sieve (Figure 4.34) as for the 4.75-mm sieve. The SGC gave lower breakdown than the Marshall hammer. The better aggregates had less than 0.5% breakdown while the remaining aggregates had up to 1 percent. Again, the SGC appears to be the best compactor to minimize breakdown.

There is a good correlation between the amount of aggregate breakdown and the LA Abrasion values for both the Marshall hammer and SGC (Figures 4.35 and 4.36, respectively). Both figures indicate that breakdown on the 4.75-mm sieve is directly related to the LA Abrasion value. High abrasion values produce high aggregate breakdown. For some reason, the data fits the regression line much better for the SGC than the Marshall hammer. The expected aggregate breakdown at L.A. Abrasion of 30 is approximately 10 percent. It is believed that additional breakdown would be excessive so the existing L.A. Abrasion requirement of 30 is reasonable.

Surprisingly, the amount of breakdown on the 4.75-mm sieve does not vary significantly for 35, 50, and 75 blows of the Marshall hammer (Figure 4.37). The higher compactive efforts do provide higher densities but this is the result of fitting the aggregate closer together and not so much the result of aggregate breakdown. The worst case is granite (2) where there is about 3-4 percent additional breakdown between 35 and 75 blows.

Granite (1) does experience more breakdown on the 0.075-mm sieve than the other aggregates. The difference in breakdown between 35 and 75 blows is typically less than 0.3 percent. It is interesting to note that the dense-graded mixture had more aggregate breakdown on the 0.075-mm sieve than the SMA mixture.

The same trend was observed on the SGC for breakdown on the 4.75-mm sieve. The curves for 75, 100, and 125 revolutions plot almost on top of each other (Figure 4.39). There are some differences in the breakdown on the 0.075-mm sieve for the different aggregates. Again, the differences are small.

It appears that the compactive effort with a particular compactor has little effect on the breakdown but the type of compactor has an effect for some aggregates.

5.6 WORKABILITY

The Brookfield viscometer test appears to be useful in determining the workability of SMA mixtures. For SMA mixtures the mortar stiffness is believed to be the primary source of mixture stiffness, so if the mortar stiffness can be measured then the mixture stiffness can likely be determined.

Test results indicated that the mortar mixture has a wide range of stiffness values at 135° and 175°C. In fact, mortar mixes G and H had a higher stiffness at 175°C than mortar mixes A, B, and C at 135°C. Generally the mortars that were expected to be stiffer were shown to be stiffer with the Brookfield viscometer.

The mortar stiffness is likely to be useful for setting mixing and compaction temperatures and for evaluating workability of mixture. Even though this test appears to be useful the acceptable stiffness values could not be determined in the laboratory. This test will be evaluated on a number of field mixes in the continuation project to establish realistic requirements.

Since this test evaluates mortar mixes only it may be difficult to conduct as part of the normal quality control program. If this is used in the field, the sample will have to be blended based on proportioning at the plant since the mortar can not easily be recovered from an SMA mixture.

The use of the Brookfield viscometer is a step in the right direction but additional work is needed. Further work needs to be done to evaluate the stiffness of the entire mix. This will allow for testing and evaluation of a mixture as it exits the plant.

5.7 MIXTURE PERMEABILITY

The permeability of the various mixture types varies considerably (Table 4.50). In general, the traprock and gravel mixtures tend to have the higher permeability and the limestone (1) and granite (2) mixtures tend to have the lowest permeability. The difference in permeability may be due to a difference in aggregate breakdown. The aggregates that break down more may tend to break up the internal void structure resulting in lower permeability.

Analyzing the data in Table 4.50 for average voids between 2-3, 3-4, 4-5, 5-6, 6-7, and above 7 provide the following results:

<u>Air Voids</u>	<u>Permeability, cm/sec</u>
2.8	0.022
3.6	0.036
4.4	0.101
5.4	0.230
6.5	0.326
7.4	0.650

It can be seen from the results that the permeability approximately doubles for each 1 percent increase in air voids.

Looking close at each mix shows that the permeability generally increases significantly at some void level for a slight increase in voids. For example the following data is extracted from Table 4.50.

There is some judgment used in selecting the range of air voids above but it is reasonable. The gravel aggregate is an outlier from the others and it has been shown to be unacceptable based on other tests. After deleting the gravel aggregates it can be seen from the other data that the point at which the permeability increases rapidly is typically between 6 and 7 percent. So ideally

<u>Mixture</u>	<u>Compaction Method</u>	<u>Air Voids Percent</u>	<u>Permeability, cm/sec</u>
Limestone (1)	Marshall	6.5	0.03
		7.0	0.600
	SGC	6.5	0.4
		7.6	1.4
Gravel	Marshall	3.6	0.03
		4.2	0.3
	SGC	5.3	0.2
		5.8	0.6
Granite (2)	Marshall	5.4	0.01
		7.1	0.50
	SGC	7.3	0.2
		8.1	0.6
Traprock	Marshall	5.7	0.03
		6.2	0.50
	SGC	5.2	0.30
		6.9	0.60

the SMA mixture should be compacted to around 94 percent of theoretical maximum density. This result will be evaluated in the field in the continuation of this project.

5.8 MIXTURE PERFORMANCE EVALUATION

Two tests were used to characterize SMA mixture performance for rutting and low temperature cracking. The wheel tracking machine was used for rutting and the indirect tensile test was used for low temperature cracking.

The wheel tracking device showed that 6 of the SMA mixtures performed very well while 2 of the mixtures did not perform very well (Table 4.51). The properties of the limestone (1) mix indicated that this mix had lower strength than any of the other mixes so it is reasonable that it did poorly on the wheel tracking test. One of the mortar mixes had a mortar with low stiffness at the high test temperature. This likely explains why the mortar A mix failed. The wheel tracking test should probably be a part of mix design of SMA mixture. At this point there is no other test that will allow the prediction of rutting performance.

The indirect tensile test at low temperature ranked the 8 SMA mixtures for tensile strain at failure (Table 4.52). These test results did not appear to correlate well with other test results. If the indirect tensile test is related to performance then it should be a part of the SMA mix design procedure. At this time, it may be good enough to evaluate the potential for cracking on the low temperature properties of mortar.

CHAPTER 6 - CONCLUSIONS AND RECOMMENDATIONS

The test results have been obtained and analyzed to provide the conclusions and recommendations presented in this chapter. The conclusions and recommendations reported in this report should be used in conjunction with “Guidelines for Materials, Production, and Placement of Stone Matrix Asphalt (SMA),” IS118, NAPA.

- x• The coarse and fine aggregate used in SMA mixtures should be 100 percent crushed. The fine aggregate angularity should equal or exceed 45 when measured with the NAA flow test.
- x• The L. A. Abrasion for the coarse aggregate to be used in SMA mixtures should be set at 30. Higher L.A. Abrasion values result in excessive breakdown.
- x• Flat and elongated particles should be measured on a 3 to 1 and 5 to 1 ratio. A 2 to 1 ratio can be used but the 3 to 1 ratio appears to separate the various aggregates more. The requirement for 3 to 1 should be set at 20%. The requirement for 5 to 1 should be set at 5%.
- x• The requirement that no more than some maximum percentage of filler should pass the 0.02 mm size should be deleted from specifications. There is no relationship between the percentage of material passing the 0.02 mm and its effect on mortar properties.
- x• A good screening test for fillers is to ensure that the angularity does not exceed 50 when measured with the modified Rigdon voids. Fillers that exceed 50 cause the mortar to be excessively stiff and difficult to work.
- x• The asphalt cement for SMA mixtures should be the PG grade for the climate in which it will be used. For best performance on high volume roads, the next higher high temperature grade may be specified.
- x• For mix design the mortars (material finer than 0.02 mm, asphalt cement, and stabilizer) should be tested at the same high and low temperatures as the PG graded asphalt cement. The requirement at the high end should be 5.0 kPa minimum before aging and 11.0 kPa minimum after aging. The requirements at the low end should be 1500 MPa maximum. Intermediate temperatures and m-value should not be specified.
- x• The proposed mix design method will produce an acceptable SMA mixture. It is sometimes difficult to meet desired VMA requirements when aggregate breakdown is excessive. The requirements for VCA are generally easily met.
- x• The minimum VMA requirement should be set at 17 to ensure a durable SMA. If a minimum asphalt content requirement is used it should require that the effective asphalt content be at least 6.0 percent. This minimum effective asphalt content should be adjusted downward when the aggregate specific gravity is high and upward when the aggregate specific gravity is low. The best approach is to establish the minimum VMA requirement at 17.
- x• The 50-blow compactive effort with the Marshall hammer appears reasonable. The compactive effort with the Superpave gyratory compactor should be 100 revolutions.
- x• SMA mixtures should be designed to have 3.5 to 4.0 percent air voids. Higher air voids result in excessive permeability and will lead to durability problems. Lower air voids result in excessive fat spots and can lead to rutting.
- x• The laboratory wheel tracking test appears to be a good approach to evaluate rutting potential of SMA mixtures. This should be considered for inclusion as part of an SMA mix design procedure.
- x• The TSR of SMA mixtures is typically lower than dense graded mixtures. This does not indicate that SMAs are more susceptible to moisture but does indicate that the acceptance

limit for TSR should be lower than for dense graded mixtures. Based on the many mixtures that were evaluated in this study, a TSR requirement of 70% appears reasonable. The test results also showed that hydrated lime is usually effective in increasing the TSR. The TSR test should be conducted at an average void level of 6.0 percent.

- x• The use of fibers tend to do a better job than polymers in reducing draindown. The polymers seem to do a good job of decreasing the temperature susceptibility of a mixture. So there are advantages for both additives and in certain cases both may be used.
- x• The use of flat and elongated particles in SMA mixtures does result in more aggregate breakdown and generally in increased VMA.
- x• During compaction, aggregate breakdown for harder aggregates tends to range from 5-10% on the 4.75-mm sieve. For softer aggregates this breakdown usually exceeds 10%. Limited data indicates that the amount of breakdown in the field is approximately equal to that in the laboratory. The Marshall hammer generally produces more breakdown than the SGC. The breakdown for SMA mixtures is greater than that for dense graded mixtures for the 4.75 mm sieve; however, the breakdown is greater for dense graded mixtures on the 0.075 mm sieve.
- x• The Brookfield viscometer can be used to measure the workability of mortars used in SMA mixtures. Additional work is needed to develop a specific technique for selecting mixing and compaction temperatures using this technique.
- x• SMA mixtures tend to have higher permeability than dense graded mixtures for the same void level. The permeability appears to become a problem between 6 and 7 percent air voids. The data shows that the permeability tends to double for each 1% increase in void level.

Appendix A - Properties of Asphalt Cement

Table A1. Properties of Asphalt Cement: AC-20

ASPHALT: AC-20

OPERATOR: Lynn

PROJECT: NCHRP9-8

DATE: 5-24-94

Kinematic Viscosity (@ 135°C)(by AASHTO T 201) = 389 cSt

Absolute Viscosity (@ 60°C)(by AASHTO T 202) = 2171 P

Original	RTFOT	RTFOT + PAV residue
Flash Pt: --- °C	Loss: 0.30 %	Time/Temp after PAV: 20 HRS AT 100°C
Vis@135: 375 cP		Physical Hardening Index: ---

HIGH TEMPERATURE GRADING				LOW TEMPERATURE GRADING						
GRADE	TEMP °C	ORIGINAL	RTFOT	GRADE	TEMP °C	RTFOT + PAV	TEMP °C	RTFOT + PAV		
		Dynamic Shear 10 rad/s (1.5 Hz)	Dynamic Shear 10 rad/s (1.5 Hz)			Flexural Creep (at 60 sec)		DT (1mm/min)		
		G'/sinδ (kPa) ≥ 1.00 kPa	G'/sinδ (kPa) ≥ 2.20 kPa			S, Stiffness(MPa) ≤ 300 MPa		m, Slope ≥ 0.300	Failure Strain ≥ 1.0%	
94	94			0	31		0			
88	88			-6	28		-6			
82	82			-12	25		-12	204	0.355	0.7
76	76			-18	22	1.688	-18	555	0.295	
70	70	0.457	1.156	-24	19	2.560	-24			
64	64	1.031	2.297	-30	16	3.793	-30			
58	58			-36	13	5.454	-36			
52	52			-42	10		-42			
46	46			-48	7		-48			

GRADE: PG 64-22

Table A2. Properties of Asphalt Cement: AC-20 w/ 3% SBR

ASPHALT: AC-20 w/ 3% SBR

OPERATOR: Lynn

PROJECT: NCHRP9-8

DATE: 7-12-94

Original	RTFOT	RTFOT + PAV residue
Flash Pt: --- °C	Loss: 0.56 %	Time/Temp after PAV: 20 HRS AT 100°C
Vis@135: 562 cP		Physical Hardening Index: ---

HIGH TEMPERATURE GRADING				LOW TEMPERATURE GRADING						
GRADE	TEMP °C	ORIGINAL	RTFOT	GRADE	TEMP °C	RTFOT + PAV	TEMP °C	RTFOT + PAV		
		Dynamic Shear 10 rad/s (1.5 Hz)	Dynamic Shear 10 rad/s (1.5 Hz)			Dynamic Shear 10 rad/s (1.5 Hz)		Flexural Creep (at 60 sec)		DT (1mm/min)
		G'/sinδ (kPa) ≥ 1.00 kPa	G'/sinδ (kPa) ≥ 2.20 kPa					G' sinδ (MPa) ≤ 5.000 MPa	S, Stiffness(MPa) ≤ 300 MPa	m, Slope ≥ 0.300
94	94			0	31		0			
88	88			-6	28		-6			
82	82			-12	25		-12	158	0.381	0.5
76	76			-18	22	3.629	-18	358	0.305	0.1
70	70	0.668	1.196	-24	19	5.522	-24			
64	64	1.290	2.498	-30	16		-30			
58	58			-36	13		-36			
52	52			-42	10		-42			
46	46			-48	7		-48			

GRADE: PG 64-22

Table A3. Properties of Asphalt Cement: AC-20 w/ 8% Polyolefin

ASPHALT: AC-20 w/ 8% Polyolefin

OPERATOR: Lynn

PROJECT: NCHRP9-8

DATE: 7-12-94

Original	RTFOT	RTFOT + PAV residue
Flash Pt: --- °C	Loss: 0.67 %	Time/Temp after PAV: 20 HRS AT 100°C
Vis@135: 804 cP		Physical Hardening Index: ---

HIGH TEMPERATURE GRADING				LOW TEMPERATURE GRADING						
GRADE	TEMP °C	ORIGINAL	RTFOT	GRADE	TEMP °C	RTFOT + PAV	TEMP °C	RTFOT + PAV		
		Dynamic Shear 10 rad/s (1.5 Hz)	Dynamic Shear 10 rad/s (1.5 Hz)			Dynamic Shear 10 rad/s (1.5 Hz)		Flexural Creep (at 60 sec)		DT (1mm/min)
		G'/sinδ (kPa) ≥ 1.00 kPa	G'/sinδ (kPa) ≥ 2.20 kPa					G' sinδ (MPa) ≤ 5.000 MPa	S, Stiffness(MPa) ≤ 300 MPa	m, Slope ≥ 0.300
94	94			0	34		0			
88	88			-6	31		-6			
82	82			-12	28		-12	215	0.323	0.7
76	76	0.545		-18	25	3.825	-18	443	0.250	
70	70	1.136	2.219	-24	22	5.631	-24			
64	64	2.378		-30	19		-30			
58	58			-36	16		-36			
52	52			-42	13		-42			
46	46			-48	10		-48			

GRADE: PG 70-22

Table A4. Properties of Asphalt Cement: AC-20 w/ 4% SBS

ASPHALT: AC-20 w/ 4% SBS

OPERATOR: Lynn

PROJECT: NCHRP9-8

DATE: 7-12-94

Original	RTFOT	RTFOT + PAV residue
Flash Pt: --- °C	Loss: 0.45 %	Time/Temp after PAV: 20 HRS AT 100°C
Vis@135: 1337 cP		Physical Hardening Index: ---

HIGH TEMPERATURE GRADING				LOW TEMPERATURE GRADING						
GRADE	TEMP °C	ORIGINAL	RTFOT	GRADE	TEMP °C	RTFOT + PAV	TEMP °C	RTFOT + PAV		
		Dynamic Shear 10 rad/s (1.5 Hz)	Dynamic Shear 10 rad/s (1.5 Hz)			Flexural Creep (at 60 sec)		DT (1mm/min)		
		G'/sinδ (kPa) ≥ 1.00 kPa	G'/sinδ (kPa) ≥ 2.20 kPa			S, Stiffness(MPa) ≤ 300 MPa			m, Slope ≥ 0.300	Failure Strain ≥ 1.0%
94	94			0	34		0			
88	88			-6	31		-6			
82	82			-12	28	1.306	-12	100	0.356	2.6
76	76	0.718	1.686	-18	25	2.032	-18	229	0.300	
70	70	1.290	3.037	-24	22	3.052	-24	472	0.255	
64	64	2.408		-30	19	4.285	-30			
58	58			-36	16	6.261	-36			
52	52			-42	13		-42			
46	46			-48	10		-48			

GRADE: PG 70-28

Appendix B - Properties of Mineral Filler

Table B1: Mineral Filler Properties

Size (μm)	Mineral Filler Type (Cumulative Percent Passing by Volume) ¹										
	Limestone	Marble	Traprock	SE Flyash	GA Flyash	Aglime	Diabase	Wimpey	Dan-kalk	Oyta	Faxekalk
2360	100	100	100	100	100	100	100	100	100	100	100
1180	100	100	98.96	100	99.82	100	100	100	100	98.54	100
600	100	100	95.51	99.16	99.41	100	100	100	100	94.07	100
300	98.22	97.52	88.11	95.21	93.28	97.27	98.30	99.07	97.84	88.62	99.86
150	92.2	84.72	73.00	88.98	81.44	85.51	84.87	91.84	94.19	82.50	98.09
75	79.25	61.43	52.38	77.65	65.92	60.20	53.48	68.56	81.83	74.30	83.45
45	69.82	45.54	38.17	67.03	53.01	40.05	27.33	45.11	70.71	67.04	69.82
20	57.08	28.11	21.93	49.80	34.65	24.08	8.60	17.87	63.90	56.05	56.47
ASG ²	2.883	2.760	2.911	2.303	2.282	2.702	2.864	2.807	2.717	2.692	2.772
RV ³	33.5	40.1	44.1	35.1	46.0	35.8	46.0	43.0	51.7	65.4	38.5
SA ⁴	1.50	0.52	3.36	1.15	1.81	1.31	5.55	1.00	6.23	4.32	1.34

¹ Determinations made using a Coulter LS-200 laser particle size analyzer.

² ASG: Apparent Specific Gravity determined by AASHTO T100

³ RV: Void volume (%) in Dry-Compacted Dust.

⁴ SA: BET Surface area (m^2/g) determined using a Coulter SA 3100 surface area analyzer.

Appendix C - Mortar Properties

Table C1: Mortar Properties

Asphalt	Fiber	% in Mix	Filler	Original			RTFOT				RTFOT - PAV							
				T E M P °C	G*, kPa	δ	G*/sin δ, kPa	T E M P °C	G*, kPa	δ	G* sin δ, kPa	T E M P °C	G*, kPa	δ	G* sin δ, kPa	T E M P °C	S, MPa	m
AC-20	None	N/A	N/A	58	2.839 2.940	86.2 86.1	2.845 2.947	58	4.751 7.665	83.2 81.9	4.785 7.742	19	10770 10600	42.4 42.8	7262 7202	-6	82.6 90.0	0.417 0.392
				70	0.561 0.607	88.7 88.6	0.561 0.607	70	0.897 1.456	87.0 86.0	0.898 1.459	31	1514 1517	55.8 56.4	1252 1264	-18	376 390	0.288 0.306
AC-20	N/A	8	Limest one Dust	58	9.127 9.717	85.8 86.0	9.152 9.741	58	21.75 23.34	82.0 81.8	21.964 23.581	19	27310 27160	41.9 42.0	18239 18174	-6	317 293	0.406 0.413
				70	1.916 2.028	88.0 88.3	1.917 2.029	70	4.469 4.407	86.0 86.0	4.480 4.418	31	3570 3517	57.8 57.8	3021 2976	-18	1276 1182	0.253 0.263
AC-20	None	10	Limest one Dust	58	9.518 14.16	86.5 85.5	9.536 14.203	58	24.17 32.70	82.3 81.6	24.390 33.060	19	48840 30630	39.1 42.4	30805 20654	-6	413 386	0.373 0.392
				70	1.966 3.030	88.5 88.2	1.967 3.032	70	4.466 5.79	86.2 86.0	4.476 5.804	31	6495 3926	57.5 58.3	5477 3340	-18	1477 1243	0.224 0.255
AC-20	N/A	12	Limest one Dust	58	14.44 15.30	85.7 85.7	14.481 15.343	58	34.37 36.05	81.6 81.7	34.743 36.432	19	46040 46350	39.4 39.1	29250 29235	-6	496 427	0.387 0.420
				70	3.004 3.514	88.1 88.2	3.006 3.516	70	6.578 7.218	85.8 85.8	6.596 7.237	31	5992 5900	57.6 57.6	5059 4982	-18	1460 1522	0.252 0.245
AC-20	N/A	8	Marble Dust	58	10.44 11.10	85.8 85.8	10.468 11.130	58	25.52 27.12	81.7 81.5	25.790 27.421	19	26120 25830	42.1 42.2	17495 17351	-6	290 284	0.402 0.404
				70	2.161 2.349	88.3 88.3	2.162 2.350	70	4.949 5.109	85.8 85.8	4.962 5.123	31	3042 2934	58.4 58.4	2592 2499	-18	1170 1162	0.259 0.265
AC-20	None	10	Marble Dust	58	29.3 34.32	80.9 80.7	29.673 33.867	58	26.69 30.07	82.5 82.0	26.920 29.776	19	33510 31220	42.3 42.1	22553 20931	-6	401 457	0.372 0.383
				70	6.428 6.678	85.3 85.4	6.450 6.656	70	4.935 5.562	86.2 86.2	4.946 5.550	31	4630 3769	58.6 59.0	3953 3231	-18	1493 1826	0.217 0.253
AC-20	N/A	12	Marble Dust	58	13.72 15.09	86.0 85.8	13.754 15.131	58	44.28 43.94	81.1 81.3	44.82 44.451	19	34570 34170	40.3 40.4	22339 22144	-6	559 499	0.381 0.394
				70	3.045 3.220	88.2 88.3	3.047 3.221	70	7.677 7.941	85.5 85.9	7.701 7.961	31	4458 4006	57.8 58.4	3774 3411	-18	1965 1808	0.241 0.251

N/A = Not Applicable

Table C1: Mortar Properties (continued)

Asphalt	Fiber	% in Mix	Filler	Original				RTFOT				RTFOT + PAV						
				T E M P °C	G*, kPa	δ	G*/sin δ, kPa	T E M P °C	G*, kPa	δ	G*/sin δ, kPa	T E M P °C	G*, kPa	δ	G* sin δ, kPa	T E M P °C	S, MPa	m
AC-20	N/A	8	Traprock	58	10.12 12.47	85.6 85.6	10.150 12.507	58	26.48 28.51	81.5 81.2	26.774 28.850	19	38950 39130	40.0 39.9	25037 25100	-6	352 331	0.393 0.402
				70	2.098 2.584	87.8 88.1	2.100 2.585	70	5.324 5.553	85.8 85.7	5.338 5.569	31	4966 4904	57.6 57.6	4193 4141	-18	1338 1282	0.254 0.256
AC-20	None	10	Traprock	58	8.788 15.39	86.6 85.6	8.803 15.436	58	22.38 33.20	82.8 81.8	22.558 33.541	19	83430 32380	46.3 40.7	60317 21115	-6	434 500	0.354 0.365
				70	1.898 3.190	88.4 88.3	1.899 3.191	70	4.284 6.210	86.5 86.2	4.292 6.223	31	2138 4159	57.5 58.0	1803 3527	-18	1736 1691	0.244 0.263
AC-20	N/A	12	Traprock	58	15.48 15.59	85.9 85.9	15.52 15.63	58	39.69 43.16	81.5 81.5	40.131 43.639	19	50530 51100	38.1 38.0	31179 31457	-6	461 533	0.386 0.374
				70	3.226 3.452	87.6 88.1	3.229 3.454	70	7.236 8.035	85.4 85.8	7.259 8.057	31	6904 6456	57.2 57.4	5803 5439	-18	1283 1582	0.268 0.230
AC-20	N/A	8	Diabase	58	9.770 10.74	86.2 85.9	9.792 10.768	58	24.24 25.79	82.2 81.9	24.466 26.050	19	29030 29040	40.7 40.7	18952 18937	-6	358 342	0.391 0.399
				70	2.209 2.443	88.5 88.4	2.210 2.444	70	4.761 5.045	86.2 86.1	4.771 5.057	31	3762 3720	57.3 57.4	3166 3134	-18	1181 1213	0.257 0.314
AC-20	None	10	Diabase	58	11.07 14.99	86.0 85.6	11.097 15.035	58	25.62 14.21	82.5 82.2	25.841 14.342	19	14550 33710	45.9 41.2	10451 22204	-6	517 480	0.328 0.366
				70	2.545 3.230	88.2 88.2	2.546 3.236	70	5.143 2.810	86.3 86.1	5.154 2.820	31	2551 4282	58.8 58.2	2181 3639	-18	1835 1711	0.235 0.250
AC-20	N/A	12	Diabase	58	14.27 17.98	85.8 85.5	14.308 18.036	58	42.05 48.24	81.3 80.9	42.539 48.855	19	416700 418500	8.6 10.9	62311 79136	-6	468 424	0.345 0.378
				70	3.281 3.862	87.6 88.2	3.284 3.864	70	7.763 9.216	85.5 85.6	7.787 9.243	31	182100 165200	33.5 36.2	100497 97559	-18	1612 1374	0.231 0.251

N/A = Not Applicable

Table C1: Mortar Properties (continued)

Asphalt	Fiber	% in Mix	Filler	Original				RTFOT				RTFOT + PAV						
				T E M P °C	G*, kPa	δ	G*/sin δ, kPa	T E M P °C	G*, kPa	δ	G*/sin δ, kPa	T E M P °C	G*, kPa	δ	G*/sin δ, kPa	T E M P °C	S, MPa	m
AC-20w/4 % SBS	N/A	N/A	N/A	58	3.722 7.495	67.2 63.7	4.038 8.36	58	8.316 12.98	62.4 61.4	9.384 14.784	19	6315 7150	43 40.3	4307 4625	-6	50 54	0.424 0.391
				70	1.04 2.196	71.4 67.0	1.097 2.386	70	2.492 3.732	65.9 63.9	2.73 4.156	31	971 49.8	52.5 1218	770 930	-18	239 243	0.312 0.317
AC-20w/4 % SBS	None	8	Limestone Dust	58	14.78 18.44	65.6 64.5	16.23 20.43	58	27.26 37.9	61.3 60.8	31.078 43.417	19	26530 25730	42.1 41.4	17786 17028	-6	96 190	0.418 0.405
				70	4.202 5.566	70.5 68.4	4.458 5.986	70	5.855 11.37	68.5 64.1	6.293 12.64	31	3719 3420	53.7 52.9	2997 2728	-18	575 894	0.272 0.295
AC-20w/4 % SBS	None	10	Limestone Dust	58	21.47 23.6	64.3 63.8	23.827 26.302	58	43.6 51.8	59.9 60	50.396 59.813	19	10570 33710	45.7 40.2	7565 21756	-6	275 266	0.391 0.421
				70	5.943 6.615	68.7 67.8	6.379 7.145	70	12 15.02	63.8 63.7	13.374 16.754	31	1735 5218	53.4 52.9	1393 4162	-18	968 1170	0.266 0.284
AC-20w/4 % SBS	None	12	Limestone Dust	58	25.83 37.53	64.2 62.1	28.69 42.466	58	56.86 65.23	58.8 58.4	66.475 76.586	19	14020 44550	45.2 39.5	9948 28337	-6	165 335	0.373 0.396
				70	6.141 9.772	69.6 67	6.552 10.616	70	15.56 17.7	62.7 62.9	17.51 19.883	31	2151 5705	53.4 53.3	1727 4574	-18	1135 1324	0.244 0.266
AC-20w/4 % SBS	None	10	Marble Dust	58	23.97 24.24	65.2 65.1	26.405 26.724	58	50.92 49.74	61.2 61.4	58.108 56.653	19	16320 33790	44.4 41.4	11419 22346	-6	237 285	0.387 0.403
				70	5.987 6.384	69.2 69.1	6.404 6.834	70	12.48 13.11	64.8 65.2	13.793 14.442	31	2485 4390	54.3 53.8	2018 3543	-18	1151 1214	0.258 0.285
AC-20w/4 % SBS	None	10	Traprock	58	23.69 36.24	65.5 63.2	26.034 40.601	58	45.90 57.82	61.1 60.4	52.429 66.498	19	24680 37900	42.2 38.3	16578 23490	-6	304 291	0.388 0.385
				70	5.671 9.754	70.4 67.7	6.02 10.542	70	12.10 15.09	64.9 64.2	13.362 16.761	31	3535 5599	53.9 52.0	2856 4412	-18	1180 1230	0.245 0.262
AC-20w/4 % SBS	None	10	Diabase	58	19.91 24.93	65.9 64.6	21.820 27.598	58	47.09 54.84	61.4 61.2	53.656 62.581	19	21910 34510	41.9 38.8	14632 21624	-6	290 291	0.384 0.386
				70	5.863 6.608	69.5 68.4	6.259 7.107	70	13.11 14.43	64.7 64.6	14.502 15.974	31	3330 5163	52.7 51.9	2649 4063	-18	828 1218	0.243 0.259

N/A = Not Applicable

Table C1: Mortar Properties (continued)

Asphalt	Fiber	% in Mix	Filler	Original				RTFOT				RTFOT + PAV						
				T E M P °C	G*, kPa	δ	G*/sin δ, kPa	T E M P °C	G*, kPa	δ	G*/sin δ, kPa	T E M P °C	G*, kPa	δ	G*/sin δ, kPa	T E M P °C	S, MPa	m
AC-20 W/8 % Polyole fin	None	N/A	N/A	58	5.309 7.160	80.5 78.7	5.383 7.302	58	12.2 18.71	76 74.4	12.573 19.426	19	10960 8631	42.9 42.7	7460 5853	-6	82 83	0.431 0.392
				70	0.941 1.506	82.5 81.5	0.949 1.523	70	2.493 3.399	80.1 79.3	2.531 3.459	31	1570 1249	56.5 55.7	1310 1032	-18	395 399	0.302 0.297
AC-20 W/8% Polyole fin	None	10	Limestone Dust	58	24.04 37.97	79.3 75.9	24.465 39.149	58	70.94 95.31	73.0 70.3	73.972 101.235	19	39690 23990	41.4 43.3	26248 16453	-6	409 442	0.372 0.39
				70	4.873 7.949	83.1 79.4	4.909 8.087	70	12.78 18.86	79.6 76.0	12.993 19.437	31	5187 2825	58.6 57.1	4427 2372	-18	1728 1695	0.257 0.26
AC-20 W/8% Polyole fin	None	10	Marble Dust	58	32.77 37.13	79.2 78.8	33.361 37.851	58	91.18 109.4	72.2 70.7	95.764 115.914	19	28220 51500	43.2 39.1	19332 32480	-6	447 475	0.365 0.382
				70	6.453 7.636	82.9 82.4	6.503 7.704	70	16.62 19.51	78.7 77.9	16.949 19.953	31	4483 5095	57.1 60.8	3766 5095	-18	1647 1768	0.235 0.248
AC-20 W/8% Polyole fin	None	10	Traprock	58	27.63 44.77	76 73.9	28.476 46.598	58	69.09 105.1	72.5 70.5	72.443 111.495	19	11830 15930	48.0 46.6	8791 11571	-6	478 508	0.359 0.373
				70	4.809 9.53	81 77.2	4.869 9.773	70	12.36 20.89	78.9 76.0	12.596 21.53	31	2025 2052	58.1 60.5	1719 1786	-18	1783 1871	0.229 0.234
AC-20 W/8% Polyole fin	None	10	Diabase	58	32.43 37.92	79.1 77.2	33.02 38.886	58	89.16 99.66	72.4 70.9	93.542 105.466	19	21220 18080	43.3 44.6	14561 12695	-6	383 468	0.34 0.332
				70	6.729 7.318	82.1 80.3	6.794 7.424	70	15.91 19.03	78.6 76.7	16.228 19.554	31	3815 2277	55.7 59.5	3153 1962	-18	1586 1815	0.227 0.252

N/A = Not Applicable

Table C1: Mortar Properties (continued)

Asphalt	Fiber	% in Mix	Filler	Original				RTFOT				RTFOT - PAV						
				TEMP °C	G*, kPa	δ	G*/sin δ, kPa	TEMP °C	G*, kPa	δ	G*/sin δ, kPa	TEMP °C	G*, kPa	δ	G*/sin δ, kPa	TEMP °C	S, MPa	m
AC-20 W/5% CL	5% Cellulose	N/A	N/A	58	5.272 8.123	75.7 76.6	5.441 8.35	58	9.383 14.28	75.9 75.9	9.675 14.724	19	17570 12700	40.9 39.5	11504 8078	-6	65 121	0.357 0.362
				70	1.41 1.98	75.5 77.1	1.456 2.031	70	2.239 3.237	77.4 78.1	2.294 3.308	31	2817 2002	54.5 53.2	2293 1603	-18	256 502	0.238 0.260
AC-20 W/5% CL	5% Cellulose	8	Limestone Dust	58	12.51 17.17	81.1 81.5	12.663 17.361	58	29.6 37.36	78.3 78.1	30.228 38.181	19	39720 37890	40.8 39.5	25954 24101	-6	260 309	0.375 0.374
				70	3.018 4.134	82.0 82.7	3.048 4.168	70	6.292 8.062	80.8 81.2	6.374 8.158	31	5965 5194	56.9 56.3	4997 4321	-18	1226 1383	0.248 0.256
AC-20 W/5% CL	5% Cellulose	10	Limestone Dust	58	14.71 20.46	82.2 82.0	14.847 20.661	58	33.56 46.16	78.8 78.3	34.212 47.139	19	46120 31040	39.3 41.8	29212 20689	-6	439 407	0.352 0.364
				70	3.341 4.600	83.1 83.5	3.365 4.63	70	7.513 10.13	81.6 81.7	7.595 10.236	31	6180 4211	57.1 57.6	5189 3555	-18	1310 1527	0.229 0.250
AC-20 W/5% CL	5% Cellulose	12	Limestone Dust	58	17.87 25.74	82.4 82.0	18.028 25.993	58	38.43 53.92	79.1 78.6	39.136 55.005	19	63100 51430	37.6 38.4	38500 31946	-6	512 473	0.371 0.359
				70	3.812 6.075	83.6 83.8	3.836 6.111	70	7.973 10.33	82.1 82.5	8.049 10.419	31	8944 7031	57.1 57.1	7510 5903	-18	1972 1426	0.223 0.232
AC-20 W/5% CL	5% Cellulose	8	Marble Dust	58	40.77 41.72	77.5 77.5	41.76 42.73	58	35.45 37.84	78.4 84.2	36.189 38.03	19	29840 31050	41.4 41.9	19734 20736	-6	271 290	0.38 0.38
				70	8.746 8.664	80.9 81.4	8.858 8.763	70	7.572 8.138	81.4 81.9	7.656 8.22	31	4174 4195	57.8 58.0	3532 3558	-18	1128 1285	0.254 0.261
AC-20 W/5% CL	5% Cellulose	10	Marble Dust	58	18.71 22.68	82.3 82.2	18.88 22.892	58	42.35 49.79	78.7 78.7	43.187 50.744	19	28140 30220	41.4 40.6	18609 19666	-6	269 392	0.361 0.362
				70	4.321 4.755	83.7 84.1	4.347 4.78	70	8.732 9.707	82.3 82.7	8.811 9.786	31	3830 4266	57.8 57.2	3241 3586	-18	1526 1730	0.251 0.247
AC-20 W/5% CL	5% Cellulose	12	Marble Dust	58	21.00 25.35	82.7 82.8	21.17 25.55	58	52.06 55.93	78.8 78.9	53.071 56.996	19	42790 43680	40.4 40.3	27733 28252	-6	264 538	0.368 0.344
				70	4.945 5.759	84.5 84.7	4.998 5.784	70	10.23 11.83	82.6 82.8	10.316 11.924	31	5713 5761	58.6 58.1	4876 4891	-18	1364 2106	0.210 0.248

N/A = Not Applicable

Table C1: Mortar Properties (continued)

Asphalt	Fiber	% in Mix	Filler	Original				RTFOT				RTFOT + PAV						
				T E M P °C	G*, kPa	δ	G*/sin δ, kPa	T E M P °C	G*, kPa	δ	G*/sin δ, kPa	T E M P °C	G*, kPa	δ	G*/sin δ, kPa	T E M P °C	S, MPa	m
AC-20 W/5 % CL	5% Cellulose	8	Traprock	58	12.38 16.77	82.0 82.1	12.502 16.931	58	29.51 42.22	78.8 78.6	30.083 43.07	19	26680 48290	40.2 38.0	17221 29730	-6	353 349	0.363 0.358
				70	2.923 3.975	82.9 83.8	2.946 3.998	70	6.252 8.806	81.6 82.3	6.320 8.886	31	3.965 7035	56.4 56.0	3303 5832	-18	1324 1464	0.238 0.254
AC-20 W/5 % CL	5% Cellulose	10	Traprock	58	14.34 23.79	82.5 81.8	14.464 24.036	58	37.37 54.09	78.7 77.9	38.109 55.319	19	42780 47710	39.7 37.8	27326 29242	-6	403 490	0.366 0.353
				70	3.359 5.442	83.2 83.7	3.383 5.475	70	8.216 10.81	81.0 82.1	8.318 10.914	31	5.703 6182	57.3 56.4	4799 5149	-18	1497 1733	0.234 0.241
AC-20 W/5 % CL	5% Cellulose	12	Traprock	58	19.55 27.28	82.0 82.2	19.742 27.535	58	47.64 70.91	77.7 77.4	48.759 72.66	19	49540 58860	37.0 36.5	29814 35011	-6	415 562	0.35 0.328
				70	3.891 5.708	83.3 84.5	3.891 5.734	70	8.267 13.28	82.1 82.5	8.346 13.395	31	7082 8814	56.6 55.5	5912 7264	-18	1755 1586	0.223 0.230
AC-20 W/5 % CL	5% Cellulose	8	Diabase	58	17.56 16.92	81.6 82.0	17.75 17.086	58	39.2 36.31	78.1 79.2	40.061 36.965	19	32090 48820	39.6 37.8	20455 29922	-6	333 344	0.36 0.343
				70	3.999 3.959	83.3 83.6	4.026 3.984	70	8.251 8.254	82.1 82.0	8.33 8.335	31	4701 6563	55.7 55.6	3883 5415	-18	1217 1154	0.239 0.231
AC-20 W/5 % CL	5% Cellulose	10	Diabase	58	23.55 22.06	81.2 81.8	23.831 22.288	58	52.48 49.75	77.6 78.4	53.733 50.787	19	2966 14800	42.8 42.7	2015 10037	-6	404 455	0.341 0.34
				70	5.044 5.024	83.2 83.4	5.08 5.058	70	10.07 9.97	81.9 83.7	10.17 10.031	31	687 2047	41.6 53.7	456 1650	-18	1442 1595	0.226 0.242
AC-20 W/5 % CL	5% Cellulose	12	Diabase	58	27.53 25.24	81.1 82.1	27.866 25.482	58	62.78 62.78	76.2 76.2	64.646 64.646	19	39600 54540	38.4 36.7	24597 32594	-6	566 625	0.344 0.32
				70	5.758 5.585	83.6 84.0	5.794 5.616	70	11.68 11.68	81.4 81.4	11.813 11.813	31	6940 8602	55.0 55.3	5685 7072	-18	1564 1726	0.227 0.233
AC-20 W/5 % CL	5% Cellulose	8	Dankalk	58	21.19 19.85	82.0 82.1	21.398 20.040	58	49.53 47.89	78.5 78.4	50.545 48.889	19	37940 37370	39.9 40.3	24337 24182	-6	504 434	0.341 0.400
				70	4.848 4.787	82.9 82.9	4.885 4.824	70	11.02 10.64	81.2 81.2	11.151 10.767	31	4637 4245	58.2 58.4	3940 3616	-18	1226 1050	0.228 0.244

Table C1: Mortar Properties (continued)

Asphalt	Fiber	% in Mix	Filler	Original				RTFOT				RTFOT + PAV						
				T E M P °C	G*, kPa	δ	G*/sin δ, kPa	T E M P °C	G*, kPa	δ	G*/sin δ, kPa	T E M P °C	G*, kPa	δ	G* sin δ, kPa	T E M P °C	S, MPa	m
AC-20 W/5% CL	5 % Cello lose	10	Dankalk	58	25.3 24.6	82.5 82.8	25.52 24.79	58	73.55 69.41	77.5 78.1	75.34 70.934	19	10490 9396	43.9 44.0	7279 6525	-6	627 541	0.358 0.375
				70	5.92 5.88	84.0 84.0	5.95 5.91	70	14.37 14.05	81.7 81.7	14.52 14.19	31	1541 1477	48.2 47.5	1149 1090	-18	1509 1653	0.251 0.219
AC-20 W/5% CL	5 % Cello lose	12	Dankalk	58	39.72 34.83	80.8 82.1	40.24 35.16	58	128.6 105.1	71.9 75.3	135.295 108.66	19	76970 76460	33.8 34.1	42820 42855	-6	644 687	0.365 0.366
				70	8.11 7.86	83.0 83.0	8.17 7.92	70	19.75 18.39	80.5 80.9	20.02 18.62	31	9280 9010	57.6 57.9	7835 7630	-18	2029 1963	0.236 0.207
AC-20 W/5% CL	5 % Cello lose	8	Faxekalk	58	16.2 15.72	81.9 81.9	16.36 15.88	58	38.34 37.59	78.5 78.6	39.12 38.35	19	47130 46910	38.7 38.7	29460 29329	-6	423 304	0.365 0.341
				70	4.02 3.944	83.2 83.2	4.05 3.972	70	8.16 7.893	81.9 82.0	8.25 7.97	31	5892 5875	57.1 57.1	4945 4934	-18	1333 1124	0.252 0.281
AC-20 W/5% CL	5 % Cello lose	10	Faxekalk	58	17.87 16.8	83.0 83.0	18.00 16.93	58	46.29 43.09	78.9 79.0	47.17 43.89	19	65160 65330	36.9 36.8	39135 39139	-6	454 375	0.369 0.356
				70	4.309 4.15	84.6 84.6	4.328 4.16	70	9.26 9.12	82.7 82.7	9.34 9.19	31	8864 8781	56.2 56.5	7369 7319	-18	1672 1653	0.258 0.241
AC-20 W/5% CL	5 % Cello lose	12	Faxekalk	58	21.37 21.57	83.0 83.0	21.53 21.73	58	59.04 59.34	78.9 78.8	60.17 60.49	19	82840 82550	36.6 36.6	49372 49232	-6	571 515	0.358 0.363
				70	5.17 5.26	84.7 84.6	5.192 5.283	70	11.45 11.80	82.9 82.7	11.54 11.89	31	9649 9613	58.3 58.2	8205 8166	-18	2228 2088	0.236 0.251
AC-20 W/5% CL	5 % Cello lose	8	SE Flyash	58	15.02 15.24	82.6 82.6	15.15 15.37	58	45.38 45.03	77.8 77.8	46.43 46.07	19	44820 44840	39.8 39.8	28699 28678	-6	392 337	0.369 0.394
				70	3.72 3.72	84.0 83.9	3.74 3.74	70	8.875 8.759	81.5 81.3	8.97 8.86	31	5988 5775	57.5 57.7	5050 4882	-18	1359 1146	0.235 0.250
AC-20 W/5% CL	5 % Cello lose	10	SE Flyash	58	18.61 18.27	82.7 82.7	18.76 18.42	58	53.87 52.04	77.8 77.9	55.11 53.22	19	45700 45300	38.6 38.8	28493 28368	-6	362 308	0.374 0.397
				70	4.699 4.678	83.8 83.7	4.73 4.71	70	10.81 10.79	81.6 81.4	10.93 10.91	31	5701 5527	57.7 57.8	4819 4676	-18	1395 1288	0.235 0.248

Table C1: Mortar Properties (continued)

Asphalt	Fiber	% in Mix	Filler	Original				RTFOT				RTFOT + PAV						
				T E M P °C	G*, kPa	δ	G*/sin δ, kPa	T E M P °C	G*, kPa	δ	G* sin δ, kPa	T E M P °C	G*, kPa	δ	G* sin δ, kPa	T E M P °C	S, MPa	m
AC-20 W/5 % CL	5 % Cellulose	12	SE Flyash	58	22.84 22.39	83.2 83.2	23.00 22.55	58	65.46 64.42	78.3 78.3	66.84 65.787	19	63750 63880	37.7 37.7	38985 39064	-6	543 495	0.358 0.360
				70	5.102 5.145	84.2 83.9	5.13 5.17	70	12.72 12.86	81.9 81.6	12.85 12.99	31	8085 7966	57.4 57.5	6811 6718	-18	1721 1446	0.246 0.218
AC-20 W/5 % CL	5 % Cellulose	8	GA Flyash	58	21.19 21.29	81.8 81.8	21.41 21.51	58	43.58 43.70	78.6 78.7	44.45 44.57	19	45350 45030	38.2 38.3	28045 27909	-6	409 389	0.336 0.357
				70	4.889 4.91	83.0 82.9	4.94 4.95	70	9.385 9.32	81.8 81.7	9.48 9.42	31	5804 5668	56.8 56.9	4857 4748	-18	1343 1188	0.249 0.261
AC-20 W/5 % CL	5 % Cellulose	10	GA Flyash	58	26.14 25.56	83.3 82.4	26.32 25.79	58	58.47 57.35	77.8 78.4	59.82 58.55	19	63820 63790	35.0 35.2	36606 36771	-6	379 535	0.26 0.343
				70	6.09 6.03	83.8 83.7	6.13 6.06	70	11.69 11.53	81.7 81.7	11.81 11.65	31	8312 8009	56.3 56.5	6915 6679	-18	1969 1798	0.224 0.22
AC-20 W/5 % CL	5 % Cellulose	12	GA Flyash	58	28.85 28.42	83.0 83.1	29.07 28.63	58	75.99 72.43	76.9 77.9	78.01 74.08	19	46410 45920	37.7 37.9	28381 28208	-6	625 669	0.344 0.324
				70	6.43 6.50	83.9 83.7	6.47 6.54	70	13.64 13.50	81.8 81.9	13.78 13.64	31	5529 5584	57.9 57.7	4684 4720	-18	2117 1898	0.213 0.215
AC-20 W/5 % CL	5 % Cellulose	8	Wimpey	58	15.23 15.40	81.4 81.5	15.40 15.57	58	34.81 35.33	78.3 78.3	35.55 36.08	19	31710 31780	41.0 41.0	20803 20850	-6	357 325	0.376 0.381
				70	3.74 3.74	83.1 83.2	3.77 3.77	70	7.21 7.32	81.4 81.5	7.29 7.40	31	3707 3871	57.8 57.8	3137 3276	-18	1095 998	0.238 0.26
AC-20 W/5 % CL	5 % Cellulose	10	Wimpey	58	18.66 29.02	82.4 82.4	18.82 19.19	58	46.5 46.65	78.3 78.4	47.49 47.62	19	18400 18050	43.6 43.4	12689 12402	-6	375 337	0.374 0.391
				70	4.06 4.05	84.4 84.4	4.08 4.07	70	9.1 9.19	82.0 82.4	9.19 9.28	31	2452 2426	56.8 56.6	2052 2025	-18	1631 1418	0.258 0.242
AC-20 W/5 % CL	5 % Cellulose	12	Wimpey	58	23.62 23.05	82.2 82.4	23.84 23.25	58	53.4 51.85	78.6 78.2	54.47 52.97	19	10470 9996	47.3 47.7	7695 7393	-6	586 524	0.357 0.366
				70	5.22 5.38	84.3 84.4	5.25 5.41	70	10.24 10.29	82.8 82.8	10.32 10.37	31	1213 1046	58.6 58.8	1035 895	-18	2250 2891	0.231 0.278

Table C1: Mortar Properties (continued)

Asphalt	Fiber	% in Mix	Filler	Original				RTFOT				RTFOT + PAV						
				T E M P °C	G*, kPa	δ	G*/sin δ, kPa	T E M P °C	G*, kPa	δ	G* sin δ, kPa	T E M P °C	G*, kPa	δ	G* sin δ, kPa	T E M P °C	S, MPa	m
AC-20 W/5% CL	5 % Cellulose	8	Aglime	58	17.63 17.8	81.5 81.5	17.83 17.99	58	38.37 38.98	78.1 78.1	39.21 39.84	19	30330 30110	41.2 41.3	19978 19873	-6	297 338	0.38 0.37
				70	4.28 4.36	83.5 83.4	4.31 4.39	70	8.17 8.08	81.6 81.7	8.26 8.17	31	3659 3635	58.2 58.3	3110 3093	-18	1195 1195	0.24 0.27
AC-20 W/5% CL	5 % Cellulose	10	Aglime	58	19.55 19.92	81.5 81.6	19.77 20.14	58	44.52 43.6	78.5 78.7	45.43 44.46	19	53960 54170	37.4 37.5	32774 32977	-6	416 406	0.377 0.372
				70	4.724 4.74	83.5 83.5	4.75 4.77	70	9.08 9.08	82.5 82.5	9.14 9.16	31	6629 6530	57.5 57.5	5591 5507	-18	1799 1468	0.276 0.248
AC-20 W/5% CL	5 % Cellulose	12	Aglime	58	26.69 27.39	81.6 81.8	26.98 27.67	58	54.0 53.59	77.8 78.3	55.25 54.73	19	65450 65630	36.8 36.6	39206 39130	-6	546 539	0.361 0.357
				70	5.875 5.97	83.8 83.8	5.91 6.00	70	10.87 10.88	82.1 82.1	10.97 10.98	31	8006 8038	57.1 57.0	6722 6741	-18	2023 2134	0.262 0.260
AC-20 W/5% CL	5 % Cellulose	8	Oyta	58	43.66 39.82	75.7 77.5	45.06 40.79	58	486.8 200.7	43.9 57.7	702 237.4	19	59120 60170	34.0 33.6	33059 33298	-6	837 848	0.342 0.341
				70	7.48 7.60	80.8 80.7	7.58 7.70	70	14.49 13.54	78.7 79.6	14.78 13.77	31	7703 7691	55.1 55.2	6318 6315	-18	1953 2374	0.235 0.184
AC-20/6.7 %RW	6.7% Rockwool	N/A	N/A	58	2.809 4.88	85.4 84.6	2.818 4.89	58	6.516 8.86	82.0 81.7	6.58 8.96	19	7817 11460	42.2 42.0	5251 7668	-6	153 136	0.291 0.341
				70	0.631 1.07	87.1 86.7	0.632 1.07	70	1.382 1.79	85.5 85.4	1.39 1.80	31	1239 1527	56.5 57.3	1033 1285	-18	511 494	0.236 0.245
AC-20/6.7 %RW	6.7% Rockwool	10	Limestone Dust	58	10.45 17.54	86.0 85.0	10.48 17.61	58	25.92 35.41	81.8 80.9	26.19 35.86	19	18840 44180	43.4 39.7	12945 28221	-6	590 584	0.326 0.328
				70	2.36 3.53	88.1 87.7	2.361 3.53	70	5.28 7.06	85.9 85.6	5.29 7.09	31	3008 5622	56.0 58.2	2494 5622	-18	1941 1966	0.233 0.222
AC-20/6.7 %RW	6.7% Rockwool	10	Marble Dust	58	13.82 14.14	85.5 85.6	13.86 14.18	58	33.72 33.09	81.7 81.8	34.08 33.43	19	45710 39350	40.7 40.8	29807 25712	-6	593 623	0.34 0.335
				70	3.08 3.11	87.9 88.0	3.09 3.11	70	6.20 6.41	85.9 85.9	6.22 6.43	31	6029 5089	58.8 58.6	5157 4344	-18	1965 2204	0.217 0.225

N/A = Not Applicable

Table C1: Mortar Properties (continued)

Asphalt	Fiber	% in Mix	Filler	Original				RTFOT				RTFOT + PAV						
				T E M P °C	G*, kPa	δ	G*/sin δ, kPa	T E M P °C	G*, kPa	δ	G*/sin δ, kPa	T E M P °C	G*, kPa	δ	G*/sinδ, kPa	T E M P °C	S, MPa	m
AC-20/W6.7% RW	6.7% Rockwool	10	Traprock	58	11.51 18.83	86.1 85.0	11.54 18.90	58	30.55 41.86	82.2 80.9	30.83 42.39	19	32450 45940	40.4 37.5	21031 27967	-6	530 564	0.343 0.323
				70	2.46 4.01	87.9 87.7	2.46 4.02	70	5.61 7.73	85.9 85.6	5.62 7.75	31	5561 6547	54.1 56.8	4505 5478	-18	1680 1733	0.219 0.233
AC-20 W/6.7% RW	6.7% Rockwool	10	Diabase	58	13.7 18.32	85.1 84.8	13.75 18.39	58	27.81 34.86	81.8 81.4	28.09 35.26	19	32160 41420	41.5 39.0	21310 26066	-6	337 481	0.344 0.357
				70	3.20 3.66	87.2 87.6	3.21 3.66	70	5.81 6.81	85.7 85.8	5.83 6.83	31	4801 6091	57.6 56.6	4054 5085	-18	1202 1498	0.225 0.225

Appendix D - Coarse Aggregate Properties

Table D.1: Coarse Aggregate Properties

Specific Gravity and Absorption (AASHTO T85)									
Aggregate	Apparent Specific Gravities			Bulk Specific Gravities			Absorptions		
	Sample 1	Sample 2	Average	Sample 1	Sample 2	Average	Sample 1	Sample 2	Average
Limestone (1)	2.786	2.775	2.781	2.763	2.740	2.752	0.3	0.5	0.4
Granite (1)	2.737	2.732	2.735	2.694	2.681	2.688	0.6	0.7	0.7
Traprock	3.020	3.028	3.024	2.956	2.977	2.967	0.7	0.6	0.7
Granite (2)	2.666	2.670	2.668	2.575	2.557	2.566	0.6	1.1	0.9
Dolomite	2.683	2.721	2.702	2.453	2.451	2.452	4.1	3.5	3.8
Limestone (2)	2.657	2.663	2.660	2.463	2.451	2.457	2.8	3.5	3.2
Slag	2.502	2.499	2.501	2.263	2.263	2.263	4.0	4.4	4.2
Gravel	2.667	2.689	2.678	2.555	2.557	2.556	1.7	1.9	1.8

Flat or Elongated (ASTM D4791)									
Ratio 2:1	% Flat			% Elongated			% Flat or Elongated		
	Sample 1	Sample 2	Average	Sample 1	Sample 2	Average	Sample 1	Sample 2	Average
Limestone (1)	30	27	29	9	7	8	39	34	37
Granite (1)	15	18	17	10	12	11	26	30	28
Traprock	14	12	13	12	4	8	25	16	21
Granite (2)	15	19	17	4	2	3	19	21	20
Dolomite	16	12	14	3	2	3	18	14	16
Limestone (2)	13	7	10	0	1	1	13	7	10
Slag	8	8	8	5	3	4	13	10	12
Gravel	23	21	22	4	3	4	27	24	26

Flat or Elongated (ASTM D4791)									
Ratio 3:1	% Flat			% Elongated			% Flat or Elongated		
	Sample 1	Sample 2	Average	Sample 1	Sample 2	Average	Sample 1	Sample 2	Average
Limestone (1)	10	15	13	1	1	1	11	16	14
Granite (1)	1	1	1	1	1	1	2	2	2
Traprock	2	4	3	1	0	1	3	4	4
Granite (2)	2	3	3	0	0	0	2	3	3
Dolomite	4	5	5	0	0	0	4	5	5
Limestone (2)	2	1	2	0	0	0	2	1	2
Slag	0	0	0	0	0	0	0	0	0
Gravel	5	5	5	0	0	0	5	5	5

Flat or Elongated (ASTM D4791)									
Ratio 5:1	% Flat			% Elongated			% Flat or Elongated		
	Sample 1	Sample 2	Average	Sample 1	Sample 2	Average	Sample 1	Sample 2	Average
Limestone (1)	2	2	2	0	0	0	2	2	2
Granite (1)	0	0	0	0	0	0	0	0	0
Traprock	1	1	1	0	0	0	1	1	1
Granite (2)	0	0	0	0	0	0	0	0	0
Dolomite	1	1	1	0	0	0	1	1	1
Limestone (2)	0	0	0	0	0	0	0	0	0
Slag	0	0	0	0	0	0	0	0	0
Gravel	0	0	0	0	0	0	0	0	0

Crushed Content (ASTM Draft), Los Angeles Abrasion (AASHTO T96), and Soundness (AASHTO T104)										
Aggregate	One Face				Two Face				LA Wear % Loss	Soundness 5 Cycles
	Sample 1	Sample 2	Sample 3	Average	Sample 1	Sample 2	Sample 3	Average		
Limestone (1)	100	100	100	100	100	100	100	100	24	0.2
Granite (1)	100	100	100	100	100	100	100	100	37	0.3
Traprock	100	100	100	100	100	100	100	100	17	1.1
Granite (2)	100	100	100	100	100	100	100	100	55	1
Dolomite	100	100	100	100	100	100	100	100		
Limestone (2)	100	100	100	100	100	100	100	100		
Slag	100	100	100	100	100	100	100	100		
Gravel	77	73	71	74	52	51	54	52		

Appendix E - Mix Designs

Table E1.1: Results from Aggregate Gradation Optimization for Limestone (1) using 50-Blow Marshall
National Center for Asphalt Technology
SMA Trial Gradation Summary

GRADATION A--20% Passing 4.75-mm

MARSHALL 50 BLOW

PROJECT: NCHRP 9-8			MATERIALS: Labstock Limestone/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate:			DATE:		
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa})= 2.790		Effective Sp. Gr. of Agg. (G _{se})= 2.786		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.759								80			JUNE 26, 1995	
															2.752				
															95.90				
															1536.2				
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS							
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc		
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S		
						(F-E)	D		(100-B) x I	B x I	(1 x 62.4)	100(1-I/J)	(100-K)	100(O-N)					
						(F-E)	(F-E)		(Gsb)	(Gb)				O					
LMS-A1	6.3	2.566	1216.8	714.4	1218.7	504.3	2.413	2.514	81.9	14.8	150.6	4.0	18.1	77.7	34.3	44.1	0.777		
LMS-A2	6.3	2.553	1211.8	712.0	1213.2	501.2	2.418	2.514	82.1	14.9	150.9	3.8	17.9	78.6	34.1	44.1	0.774		
LMS-A3	6.3	2.538	1215.7	714.1	1217.8	503.7	2.414	2.514	82.0	14.8	150.6	4.0	18.0	77.8	34.3	44.1	0.776		
												3.9	18.0	78.1	34.2	44.1	0.776		

Computed By: Kristen Stinson Checked By: Todd Lynn

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gb = Specific Gravity of Asphalt Cement

GRADATION B--24% Passing 4.75-mm

MARSHALL 50 BLOW

PROJECT: NCHRP 9-8			MATERIALS: Labstock Limestone/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate:			DATE:		
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa})= 2.789		Effective Sp. Gr. of Agg. (G _{se})= 2.776		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.755								76			JUNE 26, 1995	
															2.752				
															95.90				
															1536.2				
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS							
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc		
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S		
						(F-E)	D		(100-B) x I	B x I	(1 x 62.4)	100(1-I/J)	(100-K)	100(O-N)					
						(F-E)	(F-E)		(Gsb)	(Gb)				O					
LMS-B1	6.3	2.516	1216.7	721.7	1217.2	495.5	2.455	2.506	83.4	15.1	153.2	2.0	16.6	87.9	33.1	44.1	0.751		
LMS-B2	6.3	2.507	1213.1	719.5	1213.7	494.2	2.455	2.506	83.4	15.1	153.2	2.0	16.6	87.7	33.1	44.1	0.751		
LMS-B3	6.3	2.533	1210.1	717.0	1211.0	494.0	2.450	2.506	83.2	15.1	152.9	2.3	16.8	86.6	33.3	44.1	0.754		
												2.1	16.7	87.4	33.2	44.1	0.752		

Computed By: Kristen Stinson Checked By: Todd Lynn

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gb = Specific Gravity of Asphalt Cement

GRADATION C--28% Passing 4.75-mm

MARSHALL 50 BLOW

PROJECT: NCHRP 9-8			MATERIALS: Labstock Limestone/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate:			DATE:		
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa})= 2.787		Effective Sp. Gr. of Agg. (G _{se})= 2.763		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.751								72			JUNE 26, 1995	
															2.752				
															95.90				
															1536.2				
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS							
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc		
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S		
						(F-E)	D		(100-B) x I	B x I	(1 x 62.4)	100(1-I/J)	(100-K)	100(O-N)					
						(F-E)	(F-E)		(Gsb)	(Gb)				O					
LMS-C1	6.3	2.468	1216.0	723.0	1217.0	494.0	2.462	2.496	83.6	15.1	153.6	1.4	16.4	91.6	33.0	44.1	0.747		
LMS-C2	6.3	2.453	1216.9	723.4	1217.6	494.2	2.462	2.496	83.6	15.1	153.7	1.3	16.4	91.8	32.9	44.1	0.746		
LMS-C3	6.3	2.48	1217.8	719.7	1218.6	498.9	2.441	2.496	82.9	15.0	152.3	2.2	17.1	87.1	33.5	44.1	0.759		
												1.6	16.6	90.2	33.1	44.1	0.751		

Computed By: Kristen Stinson Checked By: Todd Lynn

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gb = Specific Gravity of Asphalt Cement

Table E1.2: Results from Asphalt Cement Optimization for Limestone (1) using 50-Blow Marshall
National Center for Asphalt Technology
SMA Mix Design Summary

OPTIMUM GRADATION--21% Passing 4.75mm Sieve

MARSHALL 50 BLOW

PROJECT: NCHRP 9-8			MATERIAL: Labstock Limestone/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:				Percent Coarse Aggregate: 79		DATE: JUNE 29, 1995		
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa}) = 2.790		Effective Sp. Gr. of Agg. (G _{se}) = 2.797		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.758						Bulk Specific Gravity of CA (G _{ca}): 2.752		Unit wt. of CA in DRC (pcf): 95.90		
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)			
5.8-1	5.8	2.549	1209.6	708.9	1211.6	502.7	2.406	2.542	82.2	13.6	150.1	5.3	17.8	70.0	34.9	44.1	0.792
5.8-2	5.8	2.518	1213.6	713.2	1215.1	501.9	2.418	2.542	82.6	13.7	150.9	4.9	17.4	72.0	34.6	44.1	0.784
5.8-3	5.8	2.552	1217.3	714.0	1219.9	505.9	2.406	2.542	82.2	13.6	150.1	5.3	17.8	70.0	34.9	44.1	0.792
AVG												5.2	17.7	70.7	34.8	44.1	0.789
6.3-1	6.3	2.526	1219.8	717.8	1220.4	502.6	2.427	2.522	82.5	14.9	151.4	3.8	17.5	78.5	34.7	44.1	0.787
6.3-2	6.3	2.504	1218.4	716.1	1219.6	503.5	2.420	2.522	82.2	14.9	151.0	4.0	17.8	77.2	34.9	44.1	0.791
6.3-3	6.3	2.515	1217.4	716.0	1218.8	502.8	2.421	2.522	82.3	14.9	151.1	4.0	17.7	77.5	34.9	44.1	0.790
AVG												3.9	17.7	77.7	34.8	44.1	0.789
6.8-1	6.8	2.52	1222.8	719.8	1224.0	504.2	2.425	2.502	82.0	16.1	151.3	3.1	18.0	83.0	35.1	44.1	0.796
6.8-2	6.8	2.527	1221.0	717.3	1222.0	504.7	2.419	2.502	81.8	16.0	151.0	3.3	18.2	81.9	35.3	44.1	0.799
6.8-3	6.8	2.534	1220.1	717.2	1221.6	504.4	2.419	2.502	81.7	16.0	150.9	3.3	18.3	81.8	35.3	44.1	0.800
AVG												3.2	18.2	82.2	35.2	44.1	0.798

Computed By: Kristen Stinson Checked By: Todd Lynn

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gb = Specific Gravity of Asphalt Cement

Table E1.3: Results from Asphalt Cement Optimization for Limestone (1) using 35-Blow Marshall
National Center for Asphalt Technology
SMA Gradation Summary

OPTIMUM GRADATION--21% Passing 4.75mm Sieve

MARSHALL 35 BLOW

PROJECT: NCHRP 9-8			MATERIAL: Labstock Limestone/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:								DATE: JULY 7, 1995				
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa)= 2.790		Effective Sp. Gr. of Agg. (Gse)= 2.793		Bulk Sp. Gr. of Agg. (Gsb) = 2.758			Percent Coarse Aggregate: 79				Bulk Specific Gravity of CA (Gca): 2.752				Unit wt. of CA in DRC (pcf): 95.90		Unit wt. of CA in DRC (kg/m3): 1536.2	
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS									
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc				
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S				
						(F-E)	D (F-E)		(100-B) x I (Gsb)	B x I (Gb)	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N) O							
6.3-1	6.3	2.628	1213.3	706.3	1214.9	508.6	2.386	2.515	81.0	14.7	148.9	5.1	19.0	72.8	35.8	44.1	0.812				
6.3-2	6.3	2.654	1216.3	706.4	1218.4	512.0	2.376	2.515	80.7	14.6	148.2	5.5	19.3	71.3	36.1	44.1	0.818				
6.3-3	6.3	2.655	1208.5	702.9	1210.8	507.9	2.379	2.515	80.8	14.6	148.5	5.4	19.2	71.9	36.0	44.1	0.816				
AVG												5.4	19.1	72.0	36.0	44.1	0.815				
6.8-1	6.8	2.625	1220.8	711.2	1222.4	511.2	2.388	2.499	80.7	15.8	149.0	4.4	19.3	77.0	36.1	44.1	0.818				
6.8-2	6.8	2.647	1215.8	704.5	1218.4	513.9	2.366	2.499	79.9	15.7	147.6	5.3	20.1	73.4	36.7	44.1	0.832				
6.8-3	6.8	2.595	1219.7	711.8	1221.0	509.2	2.395	2.499	80.9	15.9	149.5	4.1	19.1	78.2	35.9	44.1	0.814				
AVG												4.6	19.5	76.2	36.2	44.1	0.821				
7.3-1	7.3	2.581	1228.1	717.6	1229.0	511.4	2.401	2.483	80.7	17.1	149.9	3.3	19.3	83.0	36.1	44.1	0.818				
7.3-2	7.3	2.610	1230.0	718.4	1231.6	513.2	2.397	2.483	80.6	17.1	149.6	3.5	19.4	82.1	36.2	44.1	0.821				
7.3-3	7.3	2.600	1230.3	718.6	1231.1	512.5	2.401	2.483	80.7	17.1	149.8	3.3	19.3	82.8	36.1	44.1	0.819				
AVG												3.4	19.3	82.6	36.1	44.1	0.819				

Computed By: Kristen Stinson

Checked By: Todd Lynn

SSD = Saturated Surface Dry

gm = gram

pcf = pounds per cubic foot

Gmb = Bulk Specific Gravity of Compacted Mix

Gsb = Bulk Specific Gravity of Aggregate

Sp. Gr. = Specific Gravity

cc = cubic centimeter

in = inches

Gmm = Theoretical Maximum Specific Gravity of Mix

Gse = Effective Specific Gravity of Aggregate

TMD = Theoretical Maximum Density

AC = Asphalt Cement

Gb = Specific Gravity of Asphalt Cement

Table E1.4: Results from Asphalt Cement Optimization for Limestone (1) using 75-Blow Marshall
National Center for Asphalt Technology
SMA Mix Design Summary

OPTIMUM GRADATION--21% Passing 4.75mm Sieve

MARSHALL 75 BLOW

PROJECT: NCHRP 9-8			MATERIAL: Labstock Limestone/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:							Percent Coarse Aggregate: 79		DATE: JULY 7, 1995		
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa)= 2.790		Effective Sp. Gr. of Agg. (Gse)= 2.793		Bulk Sp. Gr. of Agg. (Gsb) = 2.758			Bulk Specific Gravity of CA (Gca): 2.752							Unit wt. of CA in DRC (pcf): 95.90		Unit wt. of CA in DRC (kg/m3): 1536.2	
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS								
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc			
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S			
						(F-E)	D		(100-B) x I	B x I	(1 x 62.4)	100(1-I/J)	(100-K)	100(O-N)						
5.3-1	5.3	2.527	1211.0	715.6	1212.7	497.1	2.436	2.560	83.6	12.6	152.0	4.8	16.4	70.4	33.8	44.1	0.765			
5.3-2	5.3	2.534	1211.0	712.7	1213.0	500.3	2.421	2.560	83.1	12.5	151.0	5.4	16.9	67.7	34.2	44.1	0.775			
5.3-3	5.3	2.513	1208.9	715.5	1211.7	496.2	2.436	2.560	83.7	12.6	152.0	4.8	16.3	70.4	33.8	44.1	0.765			
AVG												5.0	16.5	69.5	33.9	44.1	0.769			
5.8-1	5.8	2.527	1205.2	714.6	1206.9	492.3	2.448	2.540	83.6	13.9	152.8	3.6	16.4	77.9	33.8	44.1	0.766			
5.8-2	5.8	2.501	1212.1	717.4	1213.5	496.1	2.443	2.540	83.4	13.8	152.5	3.8	16.6	77.0	33.9	44.1	0.769			
5.8-3	5.8	2.543	1217.8	720.0	1219.3	499.3	2.439	2.540	83.3	13.8	152.2	4.0	16.7	76.2	34.0	44.1	0.772			
AVG												3.8	16.5	77.0	33.9	44.1	0.769			
6.3-1	6.3	2.541	1216.8	717.2	1218.5	501.3	2.427	2.515	82.5	14.9	151.5	3.5	17.5	80.1	34.7	44.1	0.787			
6.3-2	6.3	2.532	1218.2	719.9	1219.5	499.6	2.438	2.515	82.8	15.0	152.2	3.0	17.2	82.2	34.4	44.1	0.780			
6.3-3	6.3	2.515	1211.3	714.9	1212.9	498.0	2.432	2.515	82.6	14.9	151.8	3.3	17.4	81.1	34.6	44.1	0.784			
AVG												3.3	17.4	81.1	34.6	44.1	0.783			

Computed By: Kristen Stinson
 SSD = Saturated Surface Dry
 Sp. Gr. = Specific Gravity
 TMD = Theoretical Maximum Density

Checked By: Todd Lynn

gm = gram
 cc = cubic centimeter
 AC = Asphalt Cement

pcf = pounds per cubic foot
 in = inches

Gmb = Bulk Specific Gravity of Compacted Mix
 Gmm = Theoretical Maximum Specific Gravity of Mix

Gsb = Bulk Specific Gravity of Aggregate
 Gse = Effective Specific Gravity of Aggregate
 Gb = Specific Gravity of Asphalt Cement

**Table E1.5: Various Test Results for Limestone (1) SMA Mixtures Compacted With Marshall Hammer
NCHRP 9-8
Aggregate: Limestone(1)**

Marshall Stability				Marshall Flow	
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
26	4048	1.00	4048	26	11.5
27	5115	1.04	5320	27	16.0
32	5449	1.04	5667	32	12.5
Average			5012	Average 13.3	

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
5	5449	523
29	5338	512
30	5671	542
Average		526

Permeability						
Blows	Specimen A		Specimen B		average	
	VTM	k(in/min)	VTM	k(in/min)	VTM	k(in/min)
10	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A
50	N/A	N/A	N/A	N/A	N/A	N/A

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number		
				Average
ERR	25			ERR
	4			ERR
	40			ERR

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number			
		23	24	25	Average
40.1	3600	48.6	39.4	32.4	40.1
	4500	51.1	39.6	32.4	41.0

Moisture Susceptibility									
without Lime Conditioned					with 1% Lime Conditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
5	6	66.1	6172	576	1	6.1	63.1	7173	676
6	5.7	63	6561	614	2	5.4	57.3	6895	655
9	6.3	61.1	6283	583	6	6.1	60.8	6617	625
Average Tensile Strength (kPa)				523	Average Tensile Strength (kPa)				604
Unconditioned					Unconditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
1	6.2	N/A	6339	594	3	5.9	N/A	7784	733
3	6.1	N/A	7951	745	8	6.1	N/A	7673	725
8	5.9	N/A	5949	552	10	5.7	N/A	7117	678
Average Tensile Strength (kPa)				837	Average Tensile Strength (kPa)				844
Tensile Strength Ratio (%)				62.4	Tensile Strength Ratio (%)				71.5

Draindown (%)	Test Temp (deg C)	Sample Number		
		A	B	Average
0.018	140	0.008	0.033	0.018
	155	0.024	0.016	0.026
	170	0.008	0.024	0.025

Aggregate Breakdown Sieve Analysis													
Sieve (mm)	Optimum Gradation	Marshall 35 Blows				Marshall 50 Blows				Marshall 75 Blows			
		11	17	18	average	6	34	35	average	1	2	3	average
19	100	100	100	100	100	100	100	100	100	100	100	100	
12.5	90.1	93.7	95.6	92.9	94.1	94.3	94.5	94.0	94.3	94.7	93.4	93.7	
9.5	52.6	66.2	66.4	66.0	66.2	63.5	68.6	64.7	65.6	66.9	67.2	64.0	
4.75	21.0	29.9	31.5	29.2	30.2	29.7	30.1	30.3	30.0	31.0	30.0	31.9	
2.36	17.9	21.2	22.9	21.9	22.0	21.9	22.3	22.2	22.1	22.4	21.9	22.7	
1.18	15.8	17.3	18.9	18.3	18.2	18.1	18.4	18.2	18.2	18.2	18.1	18.7	
0.6	13.4	14.0	15.7	15.0	14.9	15.1	15.0	15.0	15.0	14.9	14.9	15.5	
0.3	12.4	12.6	14.0	13.7	13.4	13.7	13.5	13.4	13.5	13.2	13.5	13.9	
0.15	11.1	11.2	12.7	12.4	12.1	12.4	12.1	12.0	12.2	11.7	12.1	12.6	
0.75	10.0	9.4	10.8	10.6	10.3	10.6	10.2	10.2	10.3	9.6	10.2	10.2	

Table E1.7: Results from Asphalt Cement Optimization for Limestone (1) using 100 Revolutions of the SGC
National Center for Asphalt Technology
SMA Mix Design Summary

OPTIMUM GRADATION - - 23% Passing 4.75 mm Sieve

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIAL: Labstock Limestone/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:				Percent Coarse Aggregate: 77		DATE: November 15, 1995		
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gs Effective Sp. Gr. of Agg. (Gse) Bulk Sp. Gr. of Agg. (Gsb) = 2.790 2.782 2.759						Bulk Specific Gravity of CA (Gca): 2.752				Unit wt. of CA in DRC (pcf): 95.90		Unit wt. of CA in DRC (kg/m3): 1536.2		
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUM	SPECIFIC GRAVITY		VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	$\frac{D}{(F-E)}$		$\frac{(100-B) \times I}{(Gsb)}$	$\frac{B \times I}{(Gb)}$	(1 x 62.4)	100(1-I/J)	(100-K)	$\frac{100(O-N)}{O}$			
5.5-1	5.5	102.4	4184.7	2465.7	4197.7	1732.0	2.416	2.542	82.8	13.0	150.8	5.0	17.2	71.3	36.1	44.1	0.819
5.5-2	5.5	102.0	4215.0	2493.0	4222.8	1729.8	2.437	2.542	83.5	13.1	152.0	4.1	16.5	75.0	35.6	44.1	0.806
5.5-3	5.5	102.7	4208.5	2486.3	4219.9	1733.6	2.428	2.542	83.1	13.0	151.5	4.5	16.9	73.3	35.8	44.1	0.812
AVG												4.5	16.9	73.2	35.8	44.1	0.812
6.0-1	6.0	101.3	4221.8	2503.2	4227.0	1723.8	2.449	2.523	83.4	14.3	152.8	2.9	16.6	82.3	35.6	44.1	0.806
6.0-2	6.0	101.7	4234.4	2508.2	4240.7	1732.5	2.444	2.523	83.3	14.3	152.5	3.1	16.7	81.3	35.7	44.1	0.809
6.0-3	6.0	101.6	4202.3	2489.9	4209.4	1719.5	2.444	2.523	83.3	14.3	152.5	3.1	16.7	81.3	35.7	44.1	0.810
AVG												3.1	16.7	81.6	35.7	44.1	0.809
6.5-1	6.5	101.3	4228.8	2504.5	4233.4	1728.9	2.446	2.503	82.9	15.5	152.6	2.3	17.1	86.7	36.0	44.1	0.816
6.5-2	6.5	101.5	4227.0	2502.5	4231.5	1729.0	2.445	2.503	82.9	15.5	152.6	2.3	17.1	86.4	36.0	44.1	0.817
6.5-3	6.5	101.7	4254.1	2523.9	4258.6	1734.7	2.452	2.503	83.1	15.6	153.0	2.0	16.9	88.0	35.8	44.1	0.812
AVG												2.2	17.1	87.0	36.0	44.1	0.815

Computed By: G. FLOWERS

Checked By: T. LYNN

SSD = Saturated Surface Dry

Sp. Gr. = Specific Gravity

TMD = Theoretical Maximum Density

gm = gram

cc = cubic centimeter

AC = Asphalt Cement

pcf = pounds per cubic foot

in = inches

Gmb = Bulk Specific Gravity of Compacted Mix

Gmm = Theoretical Maximum Specific Gravity of Mix

Gsa = Apparent Specific Gravity of Aggregate

Gsb = Bulk Specific Gravity of Aggregate

Gse = Effective Specific Gravity of Aggregate

Gb = Specific Gravity of Asphalt Cement

Table E1.8: Results from Asphalt Cement Optimization for Limestone (1) using 75 Revolutions of the SGC

**National Center for Asphalt Technology
SMA Mix Design Summary**

OPTIMUM GRADATION - - 23% Passing 4.75 mm Sieve

SHRP 75 REV

PROJECT: NCHRP 9-8			MATERIAL: Labstock Limestone/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate: 77		DATE: 77	
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gs Effective Sp. Gr. of Agg. (Gse) Bulk Sp. Gr. of Agg. (Gsb) = 2.790 2.782 2.758											Bulk Specific Gravity of CA (Gca): 2.752		December 18, 1995	
			WEIGHTS			MIX VOLUM	SPECIFIC GRAVI	VOLUMES					VOIDS				
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	$\frac{D}{(F-E)}$			$\frac{B \times I}{(100-B) \times I}$	(1 x 62.4)	100(1-I/J)	(100-K)	$\frac{100(O-N)}{O}$			
5.5-1	5.5	104.2	4168.5	2451.7	4187.1	1735.4	2.402	2.542	82.3	12.9	149.9	5.5	17.7	68.9	36.5	44.1	0.827
5.5-2	5.5	104.1	4208.2	2475.2	4222.0	1746.8	2.409	2.542	82.5	12.9	150.3	5.2	17.5	70.0	36.3	44.1	0.823
5.5-3	5.5	104.2	4211.6	2481.5	4226.8	1745.3	2.413	2.542	82.7	12.9	150.6	5.1	17.3	70.7	36.2	44.1	0.820
AVG												5.3	17.5	69.9	36.3	44.1	0.823
6.0-1	6.0	103.1	4219.0	2485.2	4226.3	1741.1	2.423	2.523	82.6	14.2	151.2	4.0	17.4	77.3	36.3	44.1	0.822
6.0-2	6.0	103.5	4216.9	2483.4	4227.2	1743.8	2.418	2.523	82.4	14.2	150.9	4.2	17.6	76.4	36.4	44.1	0.825
6.0-3	6.0	103.5	4219.6	2479.9	4228.3	1748.4	2.413	2.523	82.3	14.1	150.6	4.3	17.7	75.5	36.5	44.1	0.828
AVG												4.2	17.6	76.4	36.4	44.1	0.825
6.5-1	6.5	103.3	4242.5	2499.4	4247.7	1748.3	2.427	2.503	82.3	15.4	151.4	3.1	17.7	82.8	36.5	44.1	0.828
6.5-2	6.5	103.5	4227.1	2491.2	4233.2	1742.0	2.427	2.503	82.3	15.4	151.4	3.1	17.7	82.8	36.5	44.1	0.828
6.5-3	6.5	103.0	4234.0	2498.0	4239.0	1741.0	2.432	2.503	82.4	15.4	151.8	2.8	17.6	83.8	36.4	44.1	0.824
AVG												3.0	17.7	83.1	36.5	44.1	0.827

Computed By: G.FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

Table E1.11: Void in the Coarse Aggregate Test Results for Limestone (1)
NCHRP 9-8
Aggregate: Limestone(1)

Voids in th Course Aggregate (VCA) and Sieve Analysis																		
Sieve (mm)	Batched Gradation	Actual Tested Gradation	D.R.U.W. Method				Troxler SGC Method											
			D.R.U.W. (pcf)			Average	75 Revolutions				100 Revolutions				125 Revolutions			
			95.5	97.3	94.9	95.9				Average				Average				Average
19	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
12.5	87.5	87.9	87.9	86.9	85.1	86.6	91.8	91.5	91.9	91.7	91.8	92.0	92.7	92.2	91.2	90.9	90.9	91.0
9.5	40	39.9	39.9	40.4	39.3	39.9	50.1	48.9	48.8	49.3	49.2	50.4	48.6	49.4	49.2	49.1	48.5	48.9
4.75	0	0.8	0.7	0.8	0.7	0.7	9.6	7.2	6.7	7.8	7.0	7.1	7.1	7.1	6.8	6.7	6.6	6.7
2.36		0.2	0.2	0.4	0.2	0.3	3.9	3.3	3.2	3.5	3.4	3.7	3.5	3.5	3.3	3.2	3.1	3.2
1.18		0.2	0.2	0.4	0.2	0.3	2.4	2.1	2.1	2.2	2.1	2.3	2.1	2.2	2.2	2.1	2.0	2.1
0.6		0.2	0.2	0.4	0.2	0.3	1.5	1.3	1.3	1.4	1.4	1.5	1.3	1.4	1.3	1.3	1.2	1.3
0.3		0.2	0.2	0.3	0.2	0.2	1.0	0.9	0.9	0.9	1.0	1.1	0.9	1.0	0.9	0.9	0.8	0.9
0.15		0.2	0.2	0.3	0.2	0.2	0.7	0.6	0.7	0.7	0.8	0.8	0.7	0.8	0.6	0.6	0.6	0.6
0.75		0.2	0.2	0.3	0.1	0.2	0.6	0.4	0.5	0.5	0.6	0.6	0.5	0.6	0.5	0.5	0.4	0.5
VCA (%)	N/A	N/A	44.4	43.3	44.7	44.1	34.5	35.3	35.8	35.2	34.6	35.0	34.7	34.8	34.6	34.6	34.6	34.6

**Table E1.13: Various Test Results for Limestone (1) Dense-Graded Mixtures Compacted with Marshall Hammer
NCHRP 9-8
Aggregate: Limestone(1)**

Marshall Stability				Marshall Flow	
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
Average			ERR	Average ERR	

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
Average		ERR

Permeability						
	Specimen A		Specimen B		Average	
Blows	VTM	k(in/min)	VTM	k(in/min)	VTM	k(in/min)
10	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A
50	N/A	N/A	N/A	N/A	N/A	N/A

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number		
				Average
	25			ERR
	4			ERR
	40			ERR

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number		
				Average
	3600			ERR
	4500			ERR

Moisture Susceptability											
without Lime Conditioned					with 1% Lime Conditioned						
Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					394.72	Average Tensile Strength (kPa)					684
Unconditioned					Unconditioned						
Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					762.766666667	Average Tensile Strength (kPa)					827
Tensile Strength Ratio (%)					ERR	Tensile Strength Ratio (%)					ERR
					ERR						ERR

Draindown (%)	Test Temp (deg C)	Sample Number		
		A	B	Average
	140	0.025	0.016	0.015
	155	0.025	0.000	0.220
	170	0.000	0.025	0.160

Aggregate Breakdown Sieve Analysis						
Sieve (mm)	Optimum Gradation	SHRP 75 Revolutions				Average
		6	7	8		
19	100.0	100.0	100.0	100.0	100.0	
12.5	97.0	97.4	97.3	97.2	97.3	
9.5	83.0	87.0	86.4	84.6	86.0	
4.75	56.0	58.0	58.9	58.7	58.5	
2.36	39.0	42.7	41.8	42.0	42.2	
1.18	28.0	30.7	30.2	30.4	30.4	
0.6	19.0	21.1	20.7	20.8	20.9	
0.3	13.0	14.6	14.4	14.5	14.5	
0.15	7.0	9.0	9.0	8.9	9.0	
0.75	4.0	6.0	5.6	5.6	5.7	

82.70858524788

Table E1.14: Results from Limestone (1) Dense-Graded Design Compacted with Nmax=208 Revolutions of SGC
National Center for Asphalt Technology
Dense Mix Design Summary

Dense Mix Gradation

SHRP N-MAX=208 REV

PROJECT: NCHRP 9-8			MATERIALS: Limestone/Dolocito/Ergon AC-20						COARSE AGGREGATE INFORMATION:								DATE: 44 January 30, 1996			
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa) = 2.766		Effective Sp. Gr. of Agg. (Gse) = 2.762		Bulk Sp. Gr. of Agg. (Gsb) = 2.704		Percent Coarse Aggregate: 2.752								Unit wt. of CA in DRC (pcf): N/A		Unit wt. of CA in DRC (kg/m3): N/A	
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS							
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc			
A	B	C	D	E	F	G	D	J	K	L	M	N	O	P	Q	R	S			
						(F-E)			(100-B) x I (Gsb)	B x I (Gb)	(1 x 62.4)	100(1-I/J)	(100-K)	100(O-N) O						
4.5-1	4.5	96.3	4171.4	2502.2	4175.5	1673.3	2.493	2.566	88.0	10.9	155.6	2.8	12.0	76.2	61.9	N/A	N/A			
4.5-2	4.5	96.1	4178.8	2509.6	4180.7	1671.1	2.501	2.566	88.3	11.0	156.1	2.5	11.7	78.3	61.8	N/A	N/A			
Avg												2.7	11.8	77.2	61.9	N/A	N/A			
5.0-1	5.0	95.6	4183.7	2519.2	4185.5	1666.3	2.511	2.546	88.2	12.2	156.7	1.4	11.8	88.3	61.9	N/A	N/A			
5.0-2	5.0	95.9	4191.4	2525.4	4182.4	1657.0	2.530	2.546	88.9	12.3	157.9	0.6	11.1	94.3	61.6	N/A	N/A			
Avg												1.0	11.4	91.3	61.7	N/A	N/A			
5.5-1	5.5	95.3	7179.4	2519.5	4179.9	1660.4	2.517	2.526	88.0	13.5	157.1	0.4	12.0	97.0	62.0	N/A	N/A			
5.5-2	5.5	95.3	4178.5	2519.7	4179.2	1659.5	2.518	2.526	88.0	13.5	157.1	0.3	12.0	97.4	62.0	N/A	N/A			
Avg												0.3	12.0	97.2	62.0	N/A	N/A			

Computed By: S.BUCHANNAN Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

**Table E1.15: Various Test Results for Limestone (1) Dense-Graded Mixtures Compacted with SGC NCHRP 9-8
Aggregate: Limestone(1)**

Marshall Stability				Marshall Flow	
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
Average			ERR	Average	ERR

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
Average		ERR

Permeability						
Blows	Specimen A		Specimen B		Average	
	VTM	k(in/min)	VTM	k(in/min)	VTM	k(in/min)
10	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A
50	N/A	N/A	N/A	N/A	N/A	N/A

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number			Average
	25				ERR
4				ERR	
40				ERR	

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number			Average
	3600				ERR
4500				ERR	

Moisture Susceptibility											
without Lime Conditioned					with 1% Lime Conditioned						
Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					988.8	Average Tensile Strength (kPa)					383.5422142375
Unconditioned					Unconditioned						
Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					1447.7	Average Tensile Strength (kPa)					454.8439295773
Tensile Strength Ratio (%)					ERR	Tensile Strength Ratio (%)					ERR
					ERR						ERR

Draindown (%)	Test Temp (deg C)	Sample Number			Average
		A	B		
	140	0.025	0.016		0.015
	155	0.025	0.000		0.220
	170	0.000	0.025		0.160

Aggregate Breakdown Sieve Analysis					68.3014436692685
Sieve (mm)	Optimum Gradation	SHRP 75 Revolutions			Average
		6	7	8	
19					ERR
12.5					ERR
9.5					ERR
4.75					ERR
2.36					ERR
1.18					ERR
0.6					ERR
0.3					ERR
0.15					ERR
0.75					ERR

84.32391624836

Table E2.1: Results from Aggregate Gradation Optimization for Granite (1) using 50-Blow Marshall
National Center for Asphalt Technology
SMA Trial Gradation Summary

GRADATION A--20% PASSING 4.75-mm

MARSHALL 50 BLOW

PROJECT: NCHRP 9-8			MATERIALS: Labstock Granite/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate:			DATE:	
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa) = 2.753		Effective Sp. Gr. of Agg. (Gse) = 2.739		Bulk Sp. Gr. of Agg. (Gsb) = 2.713								Bulk Specific Gravity of CA (Gca): 80			JUNE 22, 1995
										Unit wt. of CA in DRC (pcf): 100.93					Unit wt. of CA in DRC (kg/m ³): 1616.7			
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D	J	(100-B) x I	B x I	(1 x 62.4)	100(1-IJ)	(100-K)	100(O-N)				
						(F-E)	(F-E)	(F-E)	(Gsb)	(Gsb)				O				
GRAN-A1	6.3	2.609	1220.5	708.4	1222.4	514.0	2.375	2.478	82.0	14.6	148.2	4.2	18.0	76.8	29.3	39.8	0.737	
GRAN-A2	6.3	2.575	1215.1	707.2	1217.4	510.2	2.382	2.478	82.3	14.6	148.6	3.9	17.7	78.1	29.1	39.8	0.732	
GRAN-A3	6.3	2.586	1219.1	707.7	1221.3	513.6	2.374	2.478	82.0	14.6	148.1	4.2	18.0	76.6	29.4	39.8	0.738	
												4.1	17.9	77.2	29.3	39.8	0.736	

Computed By: Kristen Stinson Checked By: Todd Lynn

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

GRADATION B--24% PASSING 4.75-mm

MARSHALL 50 BLOW

PROJECT: NCHRP 9-8			MATERIALS: Labstock Granite/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate:			DATE:	
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa) = 2.753		Effective Sp. Gr. of Agg. (Gse) = 2.726		Bulk Sp. Gr. of Agg. (Gsb) = 2.714								Bulk Specific Gravity of CA (Gca): 76			JUNE 22, 1995
										Unit wt. of CA in DRC (pcf): 100.93					Unit wt. of CA in DRC (kg/m ³): 1616.7			
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D	J	(100-B) x I	B x I	(1 x 62.4)	100(1-IJ)	(100-K)	100(O-N)				
						(F-E)	(F-E)	(F-E)	(Gsb)	(Gsb)				O				
GRAN-B1	6.3	2.511	1215.9	712.5	1216.7	504.2	2.412	2.468	83.3	14.8	150.5	2.3	16.7	86.3	31.8	39.8	0.800	
GRAN-B2	6.3	2.522	1213.5	712.1	1214.7	502.6	2.414	2.468	83.4	14.8	150.7	2.2	16.6	86.9	31.7	39.8	0.797	
GRAN-B3	6.3	2.512	1216.1	712.8	1217.2	504.4	2.411	2.468	83.3	14.8	150.4	2.3	16.7	86.2	31.8	39.8	0.800	
												2.3	16.7	86.5	31.8	39.8	0.799	

Computed By: Kristen Stinson Checked By: Todd Lynn

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

GRADATION C--28% PASSING 4.75-mm

MARSHALL 50 BLOW

PROJECT: NCHRP 9-8			MATERIALS: Labstock Granite/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate:			DATE:	
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa) = 2.753		Effective Sp. Gr. of Agg. (Gse) = 2.727		Bulk Sp. Gr. of Agg. (Gsb) = 2.715								Bulk Specific Gravity of CA (Gca): 72			JUNE 22, 1995
										Unit wt. of CA in DRC (pcf): 100.93					Unit wt. of CA in DRC (kg/m ³): 1616.7			
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D	J	(100-B) x I	B x I	(1 x 62.4)	100(1-IJ)	(100-K)	100(O-N)				
						(F-E)	(F-E)	(F-E)	(Gsb)	(Gsb)				O				
GRAN-C1	6.3	2.502	1221.5	719.0	1222.1	503.1	2.428	2.469	83.9	14.9	151.5	1.7	16.1	89.7	35.0	39.8	0.879	
GRAN-C2	6.3	2.500	1223.7	720.5	1224.5	504.0	2.428	2.469	83.9	14.9	151.5	1.7	16.1	89.7	35.0	39.8	0.879	
GRAN-C3	6.3	2.496	1221.2	718.5	1221.8	503.3	2.426	2.469	83.8	14.9	151.4	1.7	16.2	89.3	35.0	39.8	0.880	
												1.7	16.2	89.6	35.0	39.8	0.879	

Computed By: Kristen Stinson Checked By: Todd Lynn

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

**Table E2.2: Results from Asphalt Cement Optimization for Granite (1) using 50-Blow Marshall
National Center for Asphalt Technology
SMA Gradation Summary**

OPTIMUM GRADATION -- 21 % Passing 4.75 mm Sieve

MARSHALL 50 BLOW

PROJECT: NCHRP 9-8			MATERIAL: Labstock Granite/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:				Percent Coarse Aggregate: 79		DATE: JULY 7, 1995		
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa)= 2.753		Effective Sp. Gr. of Agg. (Gse)= 2.744		Bulk Sp. Gr. of Agg. (Gsb) = 2.713		Bulk Specific Gravity of CA (Gca): 2.688				Unit wt. of CA in DRC (pcf): 100.93		Unit wt. of CA in DRC (kg/m3): 1616.7		
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUM	SPECIFIC GRAVITIES		VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(I-I/J)	(100-K)	100(O-N)			
							(F-E)		(Gsb)	(Gb)				O			
5.8-1	5.8	2.548	1207.5	706.1	1209.2	503.1	2.400	2.501	83.3	13.6	149.8	4.0	16.7	75.8	29.5	39.8	0.740
5.8-2	5.8	2.530	1215.3	709.0	1217.1	508.1	2.392	2.501	83.0	13.5	149.3	4.4	17.0	74.3	29.7	39.8	0.746
5.8-3	5.8	2.567	1211.4	706.7	1212.9	506.2	2.393	2.501	83.1	13.5	149.3	4.3	16.9	74.5	29.7	39.8	0.746
AVG												4.2	16.8	74.8	29.6	39.8	0.744
6.3-1	6.3	2.557	1217.3	710.3	1218.7	508.4	2.394	2.482	82.7	14.7	149.4	3.5	17.3	79.6	29.6	39.8	0.745
6.3-2	6.3	2.540	1214.0	710.4	1215.0	504.6	2.406	2.482	83.1	14.8	150.1	3.1	16.9	81.9	29.3	39.8	0.736
6.3-3	6.3	2.551	1216.6	709.7	1218.0	508.3	2.393	2.482	82.7	14.7	149.4	3.6	17.3	79.4	29.7	39.8	0.745
AVG												3.4	17.2	80.3	29.5	39.8	0.742
6.8-1	6.8	2.595	1219.8	708.4	1221.3	512.9	2.378	2.463	81.7	15.8	148.4	3.4	18.3	81.2	30.1	39.8	0.757
6.8-2	6.8	2.552	1208.2	703.8	1209.3	505.5	2.390	2.463	82.1	15.9	149.1	3.0	17.9	83.5	29.8	39.8	0.748
6.8-3	6.8	2.562	1219.7	712.7	1221.7	509.0	2.396	2.463	82.3	15.9	149.5	2.7	17.7	84.7	29.6	39.8	0.743
AVG												3.0	18.0	83.1	29.8	39.8	0.749

Computed By: Kristen Stinson

Checked By: Todd Lynn

SSD = Saturated Surface Dry
Sp. Gr. = Specific Gravity
TMD = Theoretical Maximum Density

gm = gram
cc = cubic centimeter
AC = Asphalt Cement
pcf = pounds per cubic foot
in = inches

Gmb = Bulk Specific Gravity of Compacted Mix
Gmm = Theoretical Maximum Specific Gravity of Mix
Gsa = Apparent Specific Gravity of Aggregate

Gsb = Bulk Specific Gravity of Aggregate
Gse = Effective Specific Gravity of Aggregate
Gb = Specific Gravity of Asphalt Cement

Table E2.3: Results from Asphalt Cement Optimization for Granite (1) using 35-Blow Marshall
National Center for Asphalt Technology
SMA Gradation Summary

OPTIMUM GRADATION

MARSHALL 35 BLOW

PROJECT: NCHRP9-8			MATERIAL: Labstock Granite/Dolcito/Ergon AC-20/Cellulose					COARSE AGGREGATE INFORMATION:										79		DATE:	
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa)= 2.753		Effective Sp. Gr. of Agg. (Gse)= 2.744		Bulk Sp. Gr. of Agg. (Gsb) = 2.713			Percent Coarse Aggregate: 2.688			Bulk Specific Gravity of CA (Gca): 100.93		Unit wt. of CA in DRC (pcf): 1616.7		Unit wt. of CA in DRC (kg/m3): 1616.7		JULY 13, 1995		
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUM	SPECIFIC GRAVITIES		VOLUMES		Unit Weight (pcf)	VOIDS									
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)		Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc				
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S				
						(F-E)	D		$\frac{(100-B) \times I}{(Gsb)}$	$\frac{B \times I}{(Gb)}$	(I x 62.4)	100(1-I/J)	(100-K)	$\frac{100(O-N)}{O}$							
6.3-1	6.3	2.647	1206.8	695.8	1209.6	513.8	2.349	2.476	81.1	14.4	146.6	5.1	18.9	72.8	31.0	39.8	0.778				
6.3-2	6.3	2.607	1217.7	702.4	1218.8	516.4	2.358	2.476	81.4	14.5	147.1	4.8	18.6	74.3	30.7	39.8	0.771				
6.3-3	6.3	2.593	1220.5	706.2	1221.8	515.6	2.367	2.476	81.8	14.5	147.7	4.4	18.2	75.9	30.4	39.8	0.765				
AVG												4.8	18.6	74.3	30.7	39.8	0.771				
6.8-1	6.8	2.597	1219.2	708.1	1220.5	512.4	2.379	2.458	81.7	15.8	148.5	3.2	18.3	82.5	30.1	39.8	0.756				
6.8-2	6.8	2.619	1222.2	704.5	1223.1	518.6	2.357	2.458	81.0	15.6	147.1	4.1	19.0	78.4	30.7	39.8	0.772				
6.8-3	6.8	2.610	1217.5	703.2	1218.5	515.3	2.363	2.458	81.2	15.7	147.4	3.9	18.8	79.4	30.6	39.8	0.768				
AVG												3.7	18.7	80.1	30.5	39.8	0.765				
7.3-1	7.3	2.612	1220.3	705.2	1221.6	516.4	2.363	2.440	80.7	16.8	147.5	3.2	19.3	83.6	30.5	39.8	0.768				
7.3-2	7.3	2.565	1218.1	706.5	1219.4	512.9	2.375	2.440	81.1	16.9	148.2	2.7	18.9	85.9	30.2	39.8	0.759				
7.3-3	7.3	2.604	1217.6	702.7	1218.6	515.9	2.360	2.440	80.6	16.8	147.3	3.3	19.4	83.1	30.6	39.8	0.770				
AVG												3.0	19.2	84.2	30.5	39.8	0.766				

Computed By: **Kristen Stinson** Checked By: **Todd Lynn**

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gb = Specific Gravity of Asphalt Cement

Table E2.4: Results from Asphalt Cement Optimization for Granite (1) using 75-Blow Marshall
National Center for Asphalt Technology
SMA Gradation Summary

OPTIMUM GRADATION

MARSHALL 75 BLOW

PROJECT: NCHRP 9-8			MATERIAL: Labstock Granite/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate: 79		DATE: 79		
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa) = 2.753		Effective Sp. Gr. of Agg. (Gse) = 2.744		Bulk Sp. Gr. of Agg. (Gsb) = 2.713			Bulk Specific Gravity of CA (Gca): 2.688					Unit wt. of CA in DRC (pcf): 100.93		Unit wt. of CA in DRC (kg/m3): 1616.7	
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUM	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D		(100-B) x I	B x I	(1 x 62.4)	100(1-I/J)	(100-K)	100(O-N)				
						(F-E)			(Gsb)	(Gb)				O				
5.3-1	5.3	2.570	1204.1	704.4	1206.5	502.1	2.398	2.514	83.7	12.4	149.6	4.6	16.3	71.7	29.5	39.8	0.742	
5.3-2	5.3	2.544	1209.7	707.3	1210.8	503.5	2.403	2.514	83.9	12.4	149.9	4.4	16.1	72.5	29.4	39.8	0.739	
5.3-3	5.3	2.531	1209.5	709.6	1211.4	501.8	2.410	2.514	84.1	12.5	150.4	4.1	15.9	74.0	29.2	39.8	0.733	
AVG												4.4	16.1	72.7	29.4	39.8	0.738	
5.8-1	5.8	2.502	1210.3	709.7	1211.1	501.4	2.414	2.495	83.8	13.7	150.6	3.3	16.2	79.9	29.1	39.8	0.730	
5.8-2	5.8	2.507	1207.4	708.1	1208.4	500.3	2.413	2.495	83.8	13.7	150.6	3.3	16.2	79.8	29.1	39.8	0.731	
5.8-3	5.8	2.517	1213.9	710.5	1215.2	504.7	2.405	2.495	83.5	13.6	150.1	3.6	16.5	78.2	29.3	39.8	0.737	
AVG												3.4	16.3	79.3	29.1	39.8	0.732	
6.3-1	6.3	2.518	1213.1	709.9	1213.7	503.8	2.408	2.476	83.2	14.8	150.3	2.8	16.8	83.7	29.2	39.8	0.735	
6.3-2	6.3	2.511	1208.7	707.8	1209.6	501.8	2.409	2.476	83.2	14.8	150.3	2.7	16.8	83.8	29.2	39.8	0.734	
6.3-3	6.3	2.508	1210.6	709.1	1211.3	502.2	2.411	2.476	83.3	14.8	150.4	2.6	16.7	84.2	29.2	39.8	0.733	
AVG												2.7	16.8	83.9	29.2	39.8	0.734	

Computed By: Kristen Stinson Checked By: Todd Lynn

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate

Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate

TMD = Theoretical Maximum Density AC = Asphalt Cement Gb = Specific Gravity of Asphalt Cement

**Table E2.5: Various Test Results for Granite (1) SMA Mixtures Compacted with the Marshall Hammer
NCHRP 9-8
Aggregate: Granite (1)**

Marshall Stability				Marshall Flow	
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
13	1750	1.00	1750	13	11.0
19	1500	1.04	1560	19	11.0
20	1700	1.04	1768	20	10.0
Average			1693	Average 10.7	

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
24	7406	709
26	6672	643
28	7006	652
Average		668

Permeability						
Blows	Specimen A		Specimen B		average	
	VTM	k(in/min)	VTM	k(in/min)	VTM	k(in/min)
10	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A
50	N/A	N/A	N/A	N/A	N/A	N/A

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number		
				Average
ERR	25			ERR
	4			ERR
	40			ERR

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number			
		11	23	25	Average
68.0	3600	42.6	106.1	55.2	68.0
	4500	42.7	111.2	56.3	70.1

Moisture Susceptability									
without Lime Conditioned					with 1% Lime Conditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
2	5.8	56.3	6005	561	5	6.4	56.6	7340	684
3	5.6	61.5	5894	559	6	6.2	57.9	7673	716
5	6.1	55.8	6228	587	10	6.7	59.6	7117	661
Average Tensile Strength (kPa)				523	Average Tensile Strength (kPa)				604
Unconditioned					Unconditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
4	5.8	N/A	9286	874	2	6.9	N/A	8841	827
6	5.6	N/A	10064	945	7	6.2	N/A	10620	987
7	6.1	N/A	9119	846	8	6	N/A	10008	932
Average Tensile Strength (kPa)				837	Average Tensile Strength (kPa)				844
Tensile Strength Ratio (%)				105.6	Tensile Strength Ratio (%)				92.2

62.43935209375

71.5332790405

Draindown (%)	Test Temp (deg C)	Sample Number		Average
		A	B	
0.017	140	0.000	0.033	0.017
	155	0.000	0.082	0.041
	170	0.000	0.000	0.000

Aggregate Breakdown Sieve Analysis												
Sieve (mm)	Optimum Gradation	Marshall 35 Blows				Marshall 50 Blows				Marshall 75 Blows		
		1	5	6	Average	1	2	27	Average	1	2	3
19	100	100	100	100	100	100	100	100	100	100	100	100
12.5	90.1	92.5	91.8	92.7	92.9	93.3	91.3	92.5	91.9	93.4	93.9	93.1
9.5	52.6	62.7	63.3	63.0	63.6	63.5	64.1	63.7	63.9	66.5	66.5	65.6
4.75	21.0	31.3	31.3	32.4	31.9	32.0	31.9	31.9	33.0	32.7	35.3	33.7
2.36	19.9	23.1	24.2	24.5	24.3	24.4	24.2	24.3	24.7	25.4	26.7	25.6
1.18	15.8	19.5	20.6	20.8	20.3	20.8	20.9	21.0	20.9	21.0	22.5	21.8
0.6	13.4	16.8	17.3	17.5	17.2	17.5	17.7	17.6	17.6	18.0	18.8	18.4
0.3	12.4	12.4	15.0	15.1	14.2	15.3	15.3	15.5	15.4	15.9	15.9	16.1
0.15	11.1	12.8	12.9	12.9	12.9	13.1	13.1	13.3	13.2	13.8	13.7	13.7
0.75	10.0	10.4	10.5	10.4	10.4	10.8	10.7	10.9	10.8	11.3	11.2	11.2

Table E2.6: Results from Aggregate Gradation Optimization for Granite (1) using 100 Revolutions of the SGC
National Center for Asphalt Technology
SMA Trial Gradation Summary

GRADATION A--20% Passing 4.75 mm Sieve

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIALS: Labstock Granite/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate: 80		DATE: October 19,1995		
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa})= 2.753		Effective Sp. Gr. of Agg. (G _{se})= 2.753		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.713			Bulk Specific Gravity of CA (G _{ca}): 2.688					Unit wt. of CA in DRC (pcf): 100.93		Unit wt. of CA in DRC (kg/m ³): 1616.7	
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb) (Gmb)	TMD (Gmm) (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)				
						(F-E)	(Gsb)		(Gsb)	(Gsb)				O				
GRAN-A1	6.3	101.7	4200.8	2473.3	4204.4	1731.1	2.427	2.489	83.8	14.9	151.4	2.5	16.2	84.5	32.3	39.8	0.812	
GRAN-A2	6.3	102.2	4217.1	2487.0	4221.2	1734.2	2.432	2.489	84.0	14.9	151.7	2.3	16.0	85.6	32.2	39.8	0.809	
GRAN-A3	6.3	101.6	4215.8	2484.9	4219.2	1734.3	2.431	2.489	84.0	14.9	151.7	2.3	16.0	85.4	32.2	39.8	0.809	
												2.4	16.1	85.2	32.2	39.8	0.810	

Computed By: G. FLOWERS Checked By: T. LYNN
 SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gsb = Bulk Specific Gravity of Aggregate
 Gse = Effective Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

GRADATION B--24% Passing 4.75 mm

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIALS: Labstock Granite/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate: 76		DATE: October 19,1995		
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa})= 2.753		Effective Sp. Gr. of Agg. (G _{se})= 2.740		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.714			Bulk Specific Gravity of CA (G _{ca}): 2.688					Unit wt. of CA in DRC (pcf): 100.93		Unit wt. of CA in DRC (kg/m ³): 1616.7	
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb) (Gmb)	TMD (Gmm) (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)				
						(F-E)	(Gsb)		(Gsb)	(Gsb)				O				
GRAN-B1	6.3	99.6	4217.8	2503.3	4219.9	1716.6	2.457	2.479	84.9	15.1	153.3	0.9	15.1	94.2	31.5	39.8	0.791	
GRAN-B2	6.3	99.1	4214.3	2503.2	4217.0	1713.8	2.459	2.479	84.9	15.1	153.4	0.8	15.1	94.7	31.4	39.8	0.790	
GRAN-B3	6.3	99.3	4230.3	2514.1	4231.5	1717.4	2.463	2.479	85.1	15.1	153.7	0.6	14.9	95.7	31.3	39.8	0.787	
												0.8	15.0	94.8	31.4	39.8	0.789	

Computed By: G. FLOWERS Checked By: T. LYNN
 SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gsb = Bulk Specific Gravity of Aggregate
 Gse = Effective Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

GRADATION C--28% Passing 4.75 mm Sieve

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIALS: Labstock Granite/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate: 72		DATE: October 19,1995		
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa})= 2.753		Effective Sp. Gr. of Agg. (G _{se})= 2.739		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.715			Bulk Specific Gravity of CA (G _{ca}): 2.688					Unit wt. of CA in DRC (pcf): 100.93		Unit wt. of CA in DRC (kg/m ³): 1616.7	
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb) (Gmb)	TMD (Gmm) (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)				
						(F-E)	(Gsb)		(Gsb)	(Gsb)				O				
GRAN-C1	6.3	98.4	4232.3	2520.0	4234.0	1714.0	2.469	2.478	85.3	15.2	154.1	0.4	14.7	97.6	31.1	39.8	0.783	
GRAN-C2	6.3	98.6	4227.2	2516.7	4228.9	1712.2	2.469	2.478	85.3	15.2	154.1	0.4	14.7	97.5	31.2	39.8	0.783	
GRAN-C3	6.3	98.5	4221.9	2510.9	4223.9	1713.0	2.465	2.478	85.1	15.1	153.8	0.5	14.9	96.4	31.3	39.8	0.786	
												0.4	14.8	97.2	31.2	39.8	0.784	

Computed By: G. FLOWERS Checked By: T. LYNN
 SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gsb = Bulk Specific Gravity of Aggregate
 Gse = Effective Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

Table E2.6: Results from Asphalt Cement Optimization for Granite (1) using 75 Revolutions of the SGC
National Center for Asphalt Technology
SMA Mix Design Summary

OPTIMUM GRADATION - - 20% Passing 4.75 mm Sieve

SHRP 75 REV

PROJECT: NCHRP9-8			MATERIAL: Labstock Granite/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:								Percent Coarse Aggregate: 80		DATE: February 13, 1995
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gs Effective Sp. Gr. of Agg. (Gs Bulk Sp. Gr. of Agg. (Gsb) = 2.753 2.738 2.713														Bulk Specific Gravity of CA (Gca): 2.688		
			WEIGHTS			MIX VOLUM	SPECIFIC GRAVITIES			VOLUMES			VOIDS						
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc		
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S		
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)					
						(F-E)	(Gsb)	(Gb)											
5.5-1	5.5	105.1	4218.2	2471.6	4231.3	1759.7	2.397	2.508	83.5	12.9	149.6	4.4	16.5	73.2	32.6	39.8	0.819		
5.5-2	5.5	105.8	4193.8	2437.8	4210.2	1772.4	2.366	2.508	82.4	12.7	147.6	5.7	17.6	67.8	33.5	39.8	0.841		
5.5-3	5.5	105.9	4230.3	2466.1	4242.5	1776.4	2.381	2.508	82.9	12.8	148.6	5.0	17.1	70.4	33.0	39.8	0.830		
AVG												5.0	17.0	70.5	33.0	39.8	0.830		
6.0-1	6.0	105.0	4208.4	2455.4	4217.1	1761.7	2.389	2.488	82.8	14.0	149.1	4.0	17.2	76.9	33.2	39.8	0.834		
6.0-2	6.0	105.0	4227.6	2471.5	4234.5	1763.0	2.398	2.488	83.1	14.0	149.6	3.6	16.9	78.6	32.9	39.8	0.827		
6.0-3	6.0	104.9	4191.0	2438.4	4198.7	1760.3	2.381	2.488	82.5	13.9	148.6	4.3	17.5	75.4	33.4	39.8	0.839		
AVG												4.0	17.2	77.0	33.2	39.8	0.833		
6.5-1	6.5	104.5	4227.3	2467.0	4231.6	1764.6	2.396	2.470	82.6	15.2	149.5	3.0	17.4	82.7	33.3	39.8	0.838		
6.5-2	6.5	104.8	4232.8	2472.9	4237.1	1764.2	2.399	2.470	82.7	15.2	149.7	2.9	17.3	83.5	33.2	39.8	0.835		
6.5-3	6.5	104.3	4207.8	2462.3	4213.7	1751.4	2.403	2.470	82.8	15.2	149.9	2.7	17.2	84.1	33.1	39.8	0.833		
AVG												2.9	17.3	83.4	33.2	39.8	0.835		

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

Table E2.6: Results from Asphalt Cement Optimization for Granite (1) using 125 Revolutions of the SGC
National Center for Asphalt Technology
SMA Mix Design Summary

OPTIMUM GRADATION - - 20% Passing 4.75 mm Sieve

SHRP 125 REV

PROJECT: NCHRP9-8			MATERIAL: Labstock Granite/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:										80		DATE: DECEMBER 15, 1995	
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gs Effective Sp. Gr. of Agg. (Gse)- Bulk Sp. Gr. of Agg. (Gsb) = 2.753 2.738 2.713						Percent Coarse Aggregate: 2.688 Bulk Specific Gravity of CA (Gca): 100.93 Unit wt. of CA in DRC (pcf): 1616.7 Unit wt. of CA in DRC (kg/m3):													
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUM	SPECIFIC GRAVITIES		VOLUMES			VOIDS										
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc					
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S					
						(F-E)	D (F-E)		$\frac{(100-B) \times I}{Gsb}$	$\frac{B \times I}{Gb}$	(I x 62.4)	100(I-I/J)	(100-K)	$\frac{100(O-N)}{O}$								
4.5-1	4.5	102.9	4198.6	2471.2	4217.4	1746.2	2.404	2.546	84.6	10.6	150.0	5.6	15.4	63.8	31.7	39.8	0.796					
4.5-2	4.5	103.2	4187.4	2468.4	4206.9	1738.5	2.409	2.546	84.8	10.6	150.3	5.4	15.2	64.5	31.5	39.8	0.793					
4.5-3	4.5	103.2	4183.9	2463.1	4203.7	1740.6	2.404	2.546	84.6	10.6	150.0	5.6	15.4	63.7	31.7	39.8	0.796					
AVG												5.5	15.3	64.0	31.6	39.8	0.795					
5.0-1	5.0	102.3	4194.9	2469.3	4206.0	1736.7	2.415	2.527	84.6	11.8	150.7	4.4	15.4	71.4	31.7	39.8	0.797					
5.0-2	5.0	102.6	4204.1	2475.8	4214.1	1738.3	2.419	2.527	84.7	11.8	150.9	4.3	15.3	72.0	31.6	39.8	0.795					
5.0-3	5.0	103.0	4195.4	2467.8	4207.1	1739.3	2.412	2.527	84.5	11.8	150.5	4.5	15.5	70.7	31.8	39.8	0.799					
AVG												4.4	15.4	71.4	31.7	39.8	0.797					
5.5-1	5.5	102.3	4204.1	2468.2	4210.3	1742.1	2.413	2.508	84.1	12.9	150.6	3.8	15.9	76.3	28.2	39.8	0.708					
5.5-2	5.5	102.0	4214.4	2491.0	4223.0	1732.0	2.433	2.508	84.8	13.1	151.8	3.0	15.2	80.5	27.6	39.8	0.693					
5.5-3	5.5	102.6	4215.5	2483.2	4223.0	1739.8	2.423	2.508	84.4	13.0	151.2	3.4	15.6	78.3	27.9	39.8	0.701					
AVG												3.4	15.6	78.3	27.9	39.8	0.701					

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

Table E2.10: Various Test Results for Granite (1) SMA Mixtures Compacted with the SGC NCHRP 9-8 Aggregate: Granite (1)

Marshall Stability				Marshall Flow	
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
Average			ERR	Average ERR	

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
Average		ERR

Permeability						
	Specimen A		Specimen B		Average	
Blows	VTM	k(in/min)	VTM	k(in/min)	VTM	k(in/min)
10	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A
50	N/A	N/A	N/A	N/A	N/A	N/A

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number		
				Average
	25			ERR
	4			ERR
	40			ERR

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number		
				Average
	3600			ERR
	4500			ERR

Moisture Susceptability											
without Lime Conditioned					with 1% Lime Conditioned						
Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					ERR	Average Tensile Strength (kPa)					ERR
Unconditioned					Unconditioned						
Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					ERR	Average Tensile Strength (kPa)					ERR
Tensile Strength Ratio (%)						Tensile Strength Ratio (%)					

Draindown (%)	Test Temp (deg C)	Sample Number		
		A	B	Average
	140	0.008	0.016	0.010
	155	0.008	0.000	0.024
	170	0.008	0.016	0.015

Aggregate Breakdown Sieve Analysis													
Sieve (mm)	Optimum Gradation	SHRP 75 Revolutions				SHRP 100 Revolutions				SHRP 125 Revolutions			
		1	2	3	Average	3	4	5	Average	1	2	6	Average
19	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
12.5	90.0	91.4	90.2	90.3	90.6	91.8	91.8	90.8	91.5	92.2	91.4	91.6	91.7
9.5	52.0	61.5	60.0	61.2	60.9	61.1	62.2	61.5	61.6	63.1	62.1	62.4	62.5
4.75	20.0	28.9	26.3	28.9	28.0	30.0	29.6	29.5	29.7	30.7	29.4	29.7	29.9
2.36	17.0	22.4	22.0	22.0	22.1	23.1	22.7	22.9	22.9	22.7	22.6	22.8	22.7
1.18	15.0	19.0	18.9	18.8	18.9	19.7	19.5	19.7	19.6	19.3	19.3	19.5	19.4
0.6	13.0	16.3	16.1	16.1	16.2	16.7	16.6	16.9	16.7	16.5	16.6	16.8	16.6
0.3	12.0	14.2	14.0	14.1	14.1	14.6	14.4	14.7	14.6	14.6	14.5	14.7	14.6
0.15	11.0	13.1	12.1	12.3	12.5	12.7	12.5	12.7	12.6	12.8	12.6	12.8	12.7
0.75	10.0	9.9	10.0	10.0	10.0	10.4	10.2	10.5	10.4	10.6	10.4	10.6	10.5

Table E2.11: Voids in the Coarse Aggregate Test Results for Granite (1)
NCHRP 9-8
Aggregate: Granite (1)

Voids in th Course Aggregate (VCA) and Sieve Analysis																		
Sieve (mm)	Batched Gradation	Actual Tested Gradation	D.R.U.W. Method				Troxler SGC Method											
			D.R.U.W. (pcf)			average	75 Revolutions			average	100 Revolutions			average	125 Revolutions			average
			100.7	101.0	101.1		100.9											
19	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
12.5	87.5	87.3	88.2	87.6	87.3	87.7	89.8	88.8	89.2	89.6	89.6	88.7	90.2	89.5	89.7	89.4	89.3	89.5
9.5	40	41.6	38.8	41.1	40.1	40.0	52.0	52.2	52.1	52.1	52.8	55.6	55.0	54.5	52.7	53.1	53.0	52.9
4.75	0	1.4	1.1	1.2	1.6	1.3	12.2	11.9	11.7	11.9	12.9	13.5	13.1	13.2	13.6	13.6	13.3	13.5
2.36		0.3	0.4	0.4	0.7	0.5	6.9	6.4	6.4	6.6	7.0	7.6	7.5	7.4	7.6	7.6	7.2	7.5
1.18		0.3	0.4	0.4	0.6	0.5	5.1	4.8	4.8	4.9	5.0	5.5	5.4	5.3	5.6	5.6	5.4	5.5
0.6		0.3	0.4	0.4	0.6	0.5	3.7	3.5	3.5	3.6	3.7	4.1	4.0	3.9	4.1	4.1	3.9	4.0
0.3		0.3	0.3	0.3	0.6	0.4	2.6	2.5	2.5	2.5	2.7	2.9	2.9	2.8	2.9	2.9	2.8	2.9
0.15		0.3	0.3	0.3	0.6	0.4	1.7	1.6	1.6	1.6	1.9	2.0	2.0	2.0	2.0	1.9	1.9	1.9
0.75		0.2	0.3	0.3	0.5	0.4	1.1	1.1	1.1	1.1	1.2	1.3	1.3	1.3	1.3	1.2	1.2	1.2
VCA (%)	N/A	N/A				ERR	32.0	32.5	32.5	32.3	31.1	31.1	31.4	31.2	30.6	30.9	30.8	30.8

Table E2.12: Results for Granite (1) Dense-Graded Mixture Design Compacted with 75-Blow Marshall Hammer
National Center for Asphalt Technology
Dense Mix Design Summary

Dense Mix Gradation

MARSHALL 75 BLOWS

PROJECT: NCHRP 9-8			MATERIALS: Granite/Dolcito/Ergon AC-20						COARSE AGGREGATE INFORMATION:										DATE: 44 October 23, 1995	
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa}) = 2.742		Effective Sp. Gr. of Agg. (G _{se}) = 2.713		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.709		Percent Coarse Aggregate: 2.688										Bulk Specific Gravity of CA (G _{ca}): N/A	
									Unit wt. of CA in DRC (pcf): N/A										Unit wt. of CA in DRC (kg/m ³): N/A	
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES		VOIDS								
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (G _{mb})	TMD (G _{mm})	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc			
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S			
						(F-E)	D		(100-B) x 1	B x 1	(1 x 62.4)	100(1-I/J)	(100-K)	100(O-N)						
						(F-E)	(F-E)		(G _b)	(G _b)				O						
4.5-1	4.5	2.542	1246.5	729.1	1248.1	519.0	2.402	2.526	84.7	10.5	149.9	4.9	15.3	67.9	62.5	N/A	N/A			
4.5-2	4.5	2.552	1248.5	728.6	1249.0	520.4	2.399	2.526	84.6	10.5	149.7	5.0	15.4	67.4	62.5	N/A	N/A			
4.5-3	4.5	2.563	1254.3	733.5	1255.0	521.5	2.405	2.526	84.8	10.6	150.1	4.8	15.2	68.5	62.4	N/A	N/A			
Avg												4.9	15.3	67.9	62.5	N/A	N/A			
5.0-1	5.0	2.557	1252.1	733.2	1253.0	519.8	2.409	2.507	84.5	11.8	150.3	3.9	15.5	74.8	62.5	N/A	N/A			
5.0-2	5.0	2.552	1257.7	738.4	1258.4	520.0	2.419	2.507	84.8	11.8	150.9	3.5	15.2	76.8	62.4	N/A	N/A			
5.0-3	5.0	2.552	1259.2	738.6	1260.0	521.4	2.415	2.507	84.7	11.8	150.7	3.7	15.3	76.0	62.4	N/A	N/A			
Avg												3.7	15.3	75.9	62.5	N/A	N/A			
5.5-1	5.5	2.548	1264.8	743.3	1265.1	521.8	2.424	2.488	84.6	13.0	151.3	2.6	15.4	83.3	62.5	N/A	N/A			
5.5-2	5.5	2.552	1262.7	743.7	1263.2	519.5	2.431	2.488	84.8	13.0	151.7	2.3	15.2	84.8	62.4	N/A	N/A			
5.5-3	5.5	2.542	1262.9	742.9	1263.3	520.4	2.427	2.488	84.7	13.0	151.4	2.5	15.3	83.9	62.5	N/A	N/A			
Avg												2.5	15.3	84.0	62.5	N/A	N/A			

Computed By: S.BUCHANNAN	Checked By: T. LYNN
SSD = Saturated Surface Dry Sp. Gr. = Specific Gravity TMD = Theoretical Maximum Density	gm = gram cc = cubic centimeter AC = Asphalt Cement pcf = pounds per cubic foot in = inches G _{mb} = Bulk Specific Gravity of Compacted Mix G _{mm} = Theoretical Maximum Specific Gravity of Mix G _{sa} = Apparent Specific Gravity of Aggregate
	G _{sb} = Bulk Specific Gravity of Aggregate G _{se} = Effective Specific Gravity of Aggregate G _b = Specific Gravity of Asphalt Cement

**Table E2.13: Various Test Results for Granite (1) Dense-Graded Mixtures Compacted with Marshall Hammer
NCHRP 9-8
Aggregate: Granite (1)**

Marshall Stability				Marshall Flow	
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
Average			ERR	Average ERR	

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
Average		ERR

Permeability						
	Specimen A		Specimen B		Average	
Blows	VTM	k(in/min)	VTM	k(in/min)	VTM	k(in/min)
10	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A
50	N/A	N/A	N/A	N/A	N/A	N/A

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number			Average
	25				ERR
4				ERR	
40				ERR	

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number			Average
	3600				ERR
4500				ERR	

Moisture Susceptibility											
without Lime Conditioned					with 1% Lime Conditioned						
Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					405.98	Average Tensile Strength (kPa)					523
Unconditioned					Unconditioned						
Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					759.9	Average Tensile Strength (kPa)					775
Tensile Strength Ratio (%)					ERR	Tensile Strength Ratio (%)					ERR
					ERR						ERR

Draindown (%)	Test Temp (deg C)	Sample Number			Average
		A	B		
	140	0.025	0.016		0.015
	155	0.025	0.000		0.220
	170	0.000	0.025		0.160

Aggregate Breakdown Sieve Analysis					53.4254507171996
Sieve (mm)	Optimum Gradation	SHRP 75 Revolutions			Average
		6	7	8	
19					ERR
12.5					ERR
9.5					ERR
4.75					ERR
2.36					ERR
1.18					ERR
0.6					ERR
0.3					ERR
0.15					ERR
0.75					ERR

67.48387096774

Table E2.12: Results for Granite (1) Dense-Graded Mixture Design Compacted with Nmax=208 Revolutions with SGC
National Center for Asphalt Technology
Dense Mix Design Summary

Dense Mix Gradation

SHRP N-MAX=208 REV

PROJECT: NCHRP 9-8			MATERIALS: Granite/Dolcito/Ergon AC-20						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate: 44		DATE: 2.688 January 30, 1996		
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa})= 2.742		Effective Sp. Gr. of Agg. (G _{se})= 2.739		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.709			Bulk Specific Gravity of CA (G _{ca}): N/A					Unit wt. of CA in DRC (pcf): N/A		Unit wt. of CA in DRC (kg/m ³): N/A	
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (G _{mb})	TMD (G _{mm})	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	J	K	L	M	N	O	P	Q	R	S		
						(F-E)	D	(100-B) x 1 (G _{sb})	B x 1 (G _b)	(1 x 62.4)	100(1-I/J)	(100-K)	100(O-N)					
4.5-1	4.5	97.8	4151.5	2452.6	4160.1	1707.5	2.431	85.7	10.7	151.7	4.6	14.3	68.0	62.0	N/A	N/A		
4.5-2	4.5	99.6	4190.0	2461.8	4201.0	1739.2	2.409	84.9	10.6	150.3	5.4	15.1	63.8	62.3	N/A	N/A		
Avg											5.0	14.7	65.9	62.2	N/A	N/A		
5.0-1	5.0	98	4190.6	2481.1	4192.3	1711.2	2.449	85.9	11.9	152.8	3.1	14.1	77.8	61.9	N/A	N/A		
5.0-2	5.0	98.5	4202.3	2490.2	4206.5	1716.3	2.448	85.9	11.9	152.8	3.1	14.1	77.7	61.9	N/A	N/A		
Avg											3.1	14.1	77.8	61.9	N/A	N/A		
5.5-1	5.5	98.1	4209.6	2502.5	4211.6	1709.1	2.463	85.9	13.2	153.7	1.8	14.1	87.0	61.9	N/A	N/A		
5.5-2	5.5	97.8	4221.2	2514.6	4221.9	1707.3	2.472	86.2	13.3	154.3	1.5	13.8	89.4	61.8	N/A	N/A		
Avg											1.6	13.9	88.2	61.8	N/A	N/A		

Computed By: S.BUCHANNAN Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot G_{mb} = Bulk Specific Gravity of Compacted Mix G_{sb} = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches G_{mm} = Theoretical Maximum Specific Gravity of Mix G_{se} = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement G_{sa} = Apparent Specific Gravity of Aggregate G_b = Specific Gravity of Asphalt Cement

**Table E2.15: Various Test Results for Granite (1) Dense-Graded Mixtures Compacted with the SGC NCHRP 9-8
Aggregate: Granite (1)**

Marshall Stability				Marshall Flow	
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
Average			ERR	Average ERR	

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
Average		ERR

Permeability						
	Specimen A		Specimen B		Average	
Blows	VTM	k(in/min)	VTM	k(in/min)	VTM	k(in/min)
10	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A
50	N/A	N/A	N/A	N/A	N/A	N/A

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number		
				Average
	25			ERR
	4			ERR
	40			ERR

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number		
				Average
	3600			ERR
	4500			ERR

Moisture Susceptibility											
without Lime Conditioned					with 1% Lime Conditioned						
Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					1028.357142857	Average Tensile Strength (kPa)					229.19075594
Unconditioned					Unconditioned						
Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					1504.88	Average Tensile Strength (kPa)					313.2787149752
Tensile Strength Ratio (%)					ERR	Tensile Strength Ratio (%)					ERR
					ERR						ERR

Draindown (%)	Test Temp (deg C)	Sample Number		
		A	B	Average
	140	0.025	0.016	0.015
	155	0.025	0.000	0.220
	170	0.000	0.025	0.160

Aggregate Breakdown Sieve Analysis					68.3348268870038
Sieve (mm)	Optimum Gradation	SHRP 75 Revolutions			Average
		6	7	8	
19					ERR
12.5					ERR
9.5					ERR
4.75					ERR
2.36					ERR
1.18					ERR
0.6					ERR
0.3					ERR
0.15					ERR
0.75					ERR

73.15873852398

Table E3.1: Results from Aggregate Gradation Optimization for Traprock using 50-Blow Marshall
National Center for Asphalt Technology
SMA Trial Gradation Summary

GRADATION A--20% PASSING 4.75-mm

MARSHALL 50 BLOW

PROJECT: NCHRP9-8			MATERIALS: Traprock/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate:		DATE:		
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa}) = 3.004		Effective Sp. Gr. of Agg. (G _{se}) = 2.962		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.953								Bulk Specific Gravity of CA (G _{ca}): 2.967		JUNE 26, 1995	
										Unit wt. of CA in DRC (pcf): 108.30					1734.8			
										Unit wt. of CA in DRC (kg/m ³): 1734.8								
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D		(100-B) x I	B x I	(1 x 62.4)	100(1-I/J)	(100-K)	100(O-N)				
						(F-E)	D		(Gsb)	(G _b)				O				
TRAP-A1	6.0	2.440	1174.2	710.1	1177.3	467.2	2.513	2.660	80.0	14.7	156.8	5.5	20.0	72.4	36.3	41.5	0.875	
TRAP-A2	6.0	2.488	1205.8	729.6	1208.8	479.2	2.516	2.660	80.1	14.7	157.0	5.4	19.9	72.9	36.2	41.5	0.873	
TRAP-A3	6.0	2.409	1181.9	718.8	1185.8	467.0	2.531	2.660	80.6	14.8	157.9	4.9	19.4	75.0	35.9	41.5	0.865	
												5.3	19.8	73.4	36.1	41.5	0.871	

Computed By: Kristen Stinson
 SSD = Saturated Surface Dry
 Sp. Gr. = Specific Gravity
 TMD = Theoretical Maximum Density

gm = gram
 cc = cubic centimeter
 AC = Asphalt Cement

pcf = pounds per cubic foot
 in = inches

Checked By: Todd Lynn
 Gmb = Bulk Specific Gravity of Compacted Mix
 Gmm = Theoretical Maximum Specific Gravity of Mix

Gsb = Bulk Specific Gravity of Aggregate
 Gse = Effective Specific Gravity of Aggregate
 Gb = Specific Gravity of Asphalt Cement

GRADATION B--24% PASSING 4.75-mm

MARSHALL 50 BLOW

PROJECT: NCHRP9-8			MATERIALS: Traprock/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate:		DATE:		
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa}) = 3.003		Effective Sp. Gr. of Agg. (G _{se}) = 2.977		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.951								Bulk Specific Gravity of CA (G _{ca}): 2.967		JUNE 26, 1995	
										Unit wt. of CA in DRC (pcf): 108.30					1734.8			
										Unit wt. of CA in DRC (kg/m ³): 1734.8								
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D		(100-B) x I	B x I	(1 x 62.4)	100(1-I/J)	(100-K)	100(O-N)				
						(F-E)	D		(Gsb)	(G _b)				O				
TRAP-B1	6.0	2.374	1215.1	741.5	1216.4	474.9	2.559	2.672	81.4	15.0	159.7	4.2	18.6	77.1	35.1	41.5	0.848	
TRAP-B2	6.0	2.395	1220.5	750.2	1221.9	471.7	2.587	2.672	82.4	15.1	161.5	3.2	17.6	82.1	34.4	41.5	0.830	
TRAP-B3	6.0	2.367	1206.6	740.6	1207.9	467.3	2.582	2.672	82.2	15.1	161.1	3.4	17.8	81.1	34.6	41.5	0.833	
												3.6	18.0	80.1	34.7	41.5	0.837	

Computed By: Kristen Stinson
 SSD = Saturated Surface Dry
 Sp. Gr. = Specific Gravity
 TMD = Theoretical Maximum Density

gm = gram
 cc = cubic centimeter
 AC = Asphalt Cement

pcf = pounds per cubic foot
 in = inches

Checked By: Todd Lynn
 Gmb = Bulk Specific Gravity of Compacted Mix
 Gmm = Theoretical Maximum Specific Gravity of Mix

Gsb = Bulk Specific Gravity of Aggregate
 Gse = Effective Specific Gravity of Aggregate
 Gb = Specific Gravity of Asphalt Cement

GRADATION C--28% PASSING 4.75-mm

MARSHALL 50 BLOW

PROJECT: NCHRP9-8			MATERIALS: Traprock/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate:		DATE:		
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa}) = 3.003		Effective Sp. Gr. of Agg. (G _{se}) = 3.002		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.949								Bulk Specific Gravity of CA (G _{ca}): 2.967		JUNE 26, 1995	
										Unit wt. of CA in DRC (pcf): 108.30					1734.8			
										Unit wt. of CA in DRC (kg/m ³): 1734.8								
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D		(100-B) x I	B x I	(1 x 62.4)	100(1-I/J)	(100-K)	100(O-N)				
						(F-E)	D		(Gsb)	(G _b)				O				
TRAP-C1	6.0	2.335	1211.2	749.0	1212.6	463.6	2.613	2.691	83.2	15.3	163.0	2.9	16.8	82.7	33.8	41.5	0.815	
TRAP-C2	6.0	2.318	1208.5	748.9	1209.6	460.7	2.623	2.691	83.5	15.4	163.7	2.5	16.5	84.7	33.5	41.5	0.808	
TRAP-C3	6.0	2.326	1195.3	741.6	1196.2	454.6	2.629	2.691	83.7	15.4	164.1	2.3	16.3	85.9	33.4	41.5	0.804	
												2.6	16.5	84.5	33.6	41.5	0.809	

Computed By: Kristen Stinson
 SSD = Saturated Surface Dry
 Sp. Gr. = Specific Gravity
 TMD = Theoretical Maximum Density

gm = gram
 cc = cubic centimeter
 AC = Asphalt Cement

pcf = pounds per cubic foot
 in = inches

Checked By: Todd Lynn
 Gmb = Bulk Specific Gravity of Compacted Mix
 Gmm = Theoretical Maximum Specific Gravity of Mix

Gsb = Bulk Specific Gravity of Aggregate
 Gse = Effective Specific Gravity of Aggregate
 Gb = Specific Gravity of Asphalt Cement

Table E3.2: Results from Asphalt Cement Optimization for Traprock using 50-Blow Marshall
National Center for Asphalt Technology
SMA Gradation Summary

OPTIMUM GRADATION - - 25% Passing 4.75 mm Sieve

MARSHALL 50 BLOW

PROJECT: NCHRP 9-8			MATERIAL: Traprock/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:								Percent Coarse Aggregate: 75	DATE: JULY 7, 1995
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _s) Effective Sp. Gr. of Agg. (G _{se}) Bulk Sp. Gr. of Agg. (G _{sb}) = 3.003 2.990 2.951														Bulk Specific Gravity of CA (G _{ca}): 2.967	
																	Unit wt. of CA in DRC (pcf): 108.30	
																	Unit wt. of CA in DRC (kg/m ³): 1734.8	
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUM	SPECIFIC GRAVITIES		VOLUMES			VOIDS						
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	$\frac{D}{(F-E)}$		$\frac{(100-B) \times I}{(Gsb)}$	$\frac{B \times I}{(Gb)}$	(I x 62.4)	100(1-I/J)	(100-K)	$\frac{100(O-N)}{O}$				
5.5-1	5.5	2.387	1207.6	742.5	1209.2	466.7	2.588	2.678	82.9	13.9	161.5	3.4	17.1	80.3	38.2	41.5	0.921	
5.5-2	5.5	2.378	1210.7	747.2	1211.9	464.7	2.605	2.678	83.4	14.0	162.6	2.7	16.6	83.6	37.8	41.5	0.911	
5.5-3	5.5	2.387	1210.3	745.3	1211.3	466.0	2.597	2.678	83.2	13.9	162.1	3.0	16.8	82.1	38.0	41.5	0.915	
AVG							2.597					3.0	16.8	82.0	38.0	41.5	0.916	
6.0-1	6.0	2.371	1214.4	745.6	1215.6	470.0	2.584	2.655	82.3	15.1	161.2	2.7	17.7	84.9	38.6	41.5	0.931	
6.0-2	6.0	2.374	1215.6	748.3	1216.6	468.3	2.596	2.655	82.7	15.2	162.0	2.2	17.3	87.1	38.3	41.5	0.924	
6.0-3	6.0	2.394	1214.6	746.6	1215.7	469.1	2.589	2.655	82.5	15.2	161.6	2.5	17.5	85.9	38.5	41.5	0.928	
AVG							2.590					2.5	17.5	85.9	38.5	41.5	0.928	
6.5-1	6.5	2.436	1215.1	744.0	1216.3	472.3	2.573	2.633	81.5	16.3	160.5	2.3	18.5	87.6	39.2	41.5	0.945	
6.5-2	6.5	2.403	1215.1	743.3	1215.9	472.6	2.571	2.633	81.5	16.3	160.4	2.4	18.5	87.3	39.2	41.5	0.946	
6.5-3	6.5	2.354	1219	745.2	1219.8	474.6	2.568	2.633	81.4	16.3	160.3	2.5	18.6	86.8	39.3	41.5	0.947	
AVG							2.571					2.4	18.5	87.3	39.2	41.5	0.946	

Computed By: Kristen Stinson Checked By: Todd Lynn

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gb = Specific Gravity of Asphalt Cement

Table E3.3: Results from Asphalt Cement Optimization for Traprock using 35-Blow Marshall
National Center for Asphalt Technology
SMA Gradation Summary

OPTIMUM GRADATION - - 25% Passing 4.75 mm Sieve

MARSHALL 35 BLOW

PROJECT: NCHRP 9-8			MATERIAL: Traprock/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate: 75		DATE: 2.967 August 26, 1995	
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _s Effective Sp. Gr. of Agg. (G _{se}) Bulk Sp. Gr. of Agg. (G _{sb}) = 3.003 2.990 2.951											Bulk Specific Gravity of CA (G _{ca}): 2.967		Unit wt. of CA in DRC (pcf): 108.30	
			WEIGHTS			MIX VOLUM	SPECIFIC GRAVITIES		VOLUMES			VOIDS					
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)			
							(F-E)		(Gsb)	(G)				O			
5.0-1	5.0	2.423	1210.9	742.2	1216.7	474.5	2.552	2.691	82.2	12.4	159.2	5.2	17.8	71.0	35.5	41.5	0.856
5.0-2	5.0	2.416	1208.8	741.4	1215.0	473.6	2.552	2.691	82.2	12.5	159.3	5.2	17.8	71.1	35.5	41.5	0.856
5.0-3	5.0	2.441	1209.1	739.6	1217.2	477.6	2.532	2.691	81.5	12.3	158.0	5.9	18.5	68.0	36.0	41.5	0.868
AVG												5.4	18.1	70.0	35.7	41.5	0.860
5.5-1	5.5	2.492	1212.3	733.3	1215.5	482.2	2.514	2.669	80.5	13.5	156.9	5.8	19.5	70.2	36.4	41.5	0.879
5.5-2	5.5	2.489	1207.5	725.6	1210.3	484.7	2.491	2.669	79.8	13.4	155.5	6.7	20.2	67.1	37.0	41.5	0.893
5.5-3	5.5	2.480	1212.4	730.8	1215.6	484.8	2.501	2.669	80.1	13.4	156.1	6.3	19.9	68.4	36.8	41.5	0.887
AVG												6.3	19.9	68.6	36.8	41.5	0.886
5.5-4	5.5	2.395	1211.8	742.4	1214.5	472.1	2.567	2.669	82.2	13.8	160.2	3.8	17.8	78.5	35.1	41.5	0.847
5.5-5	5.5	2.375	1211.9	745.4	1214.2	468.8	2.585	2.669	82.8	13.9	161.3	3.1	17.2	81.7	34.7	41.5	0.836
5.5-6	5.5	2.387	1212.3	741.3	1214.0	472.7	2.565	2.669	82.1	13.8	160.0	3.9	17.9	78.1	35.2	41.5	0.848
AVG												3.6	17.6	79.5	35.0	41.5	0.843
6.0-1	6.0		1215.8	746.1	1217.3	471.2	2.580	2.646	82.2	15.1	161.0	2.5	17.8	86.0	34.8	41.5	0.839
6.0-2	6.0		1215.1	740.8	1216.3	475.5	2.555	2.646	81.4	15.0	159.5	3.4	18.6	81.6	35.4	41.5	0.854
6.0-3	6.0		1213.0	742.6	1214.1	471.5	2.573	2.646	81.9	15.1	160.5	2.8	18.1	84.6	35.0	41.5	0.843
AVG												2.9	18.2	84.1	35.0	41.5	0.845
6.5-1	6.5		1218.1	745.0	1218.8	473.8	2.571	2.624	81.5	16.3	160.4	2.0	18.5	89.1	35.0	41.5	0.844
6.5-2	6.5		1216.3	744.8	1216.9	472.1	2.576	2.624	81.6	16.3	160.8	1.8	18.4	90.1	34.9	41.5	0.841
6.5-3	6.5		1214.5	739.7	1215.4	475.7	2.553	2.624	80.9	16.2	159.3	2.7	19.1	85.9	35.5	41.5	0.855
AVG												2.2	18.7	88.4	35.1	41.5	0.847
7.0-1	7.0		1231.5	749.2	1232.3	483.1	2.549	2.611	80.3	17.4	159.1	2.4	19.7	88.0	35.6	41.5	0.858
7.0-2	7.0		1223.9	742.6	1224.7	482.1	2.539	2.611	80.0	17.3	158.4	2.8	20.0	86.1	35.8	41.5	0.864
7.0-3	7.0		1218	741.8	1218.9	477.1	2.553	2.611	80.5	17.4	159.3	2.2	19.5	88.6	35.5	41.5	0.855
AVG												2.5	19.7	87.6	35.6	41.5	0.859

Computed By: Kristen Stinson Checked By: Todd Lynn

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gb = Specific Gravity of Asphalt Cement

**Table E3.5: Various Test Results for Traprock SMA Mixtures Compacted with Marshall Hammer
NCHRP 9-8
Marshall SMA Mix Properties**

Marshall Stability				Marshall Flow	
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
1	6228	1.14	7100	1	13.0
5	7673	1.19	9131	5	13.5
36	6450	1.19	7676	36	9.0
Average			7969	Average 11.8	

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
33	10565	1100
37	9675	1011
38	10064	1039
Average		1050

Permeability						
Blows	Specimen A		Specimen B		average	
	VTM	k(in/min)	VTM	k(in/min)	VTM	k(in/min)
10						
20						
30						
40						
50						

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number		
				Average
	25			ERR
	4			ERR
	40			ERR

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number			
		2	30	45	25.7
	3600	70.7	71.1	60.5	67.4
	4500	72.6	74.9	62.7	70.1

Moisture Susceptibility									
without Lime Conditioned					with 1% Lime Conditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
1	6.4	67.7	5783	556	1	6.4	73.6	5393	523
7	6.1	71.9	4615	454	7	5.9	70.2	5894	571
8	5.8	70.7	5671	543	8	6	73.8	5894	569
Average Tensile Strength (kPa)				523	Average Tensile Strength (kPa)				604
Unconditioned					Unconditioned				
3	6.3	N/A	8285	791	3	6.3	N/A	8007	775
15BLOW	5.8	N/A	8507	819	4	5.9	N/A	8285	803
20BLOW	6.2	N/A	8952	874	10	6.1	N/A	8007	778
Average Tensile Strength (kPa)				837	Average Tensile Strength (kPa)				844
Tensile Strength Ratio (%)					Tensile Strength Ratio (%)				

Draindown (%)	Test Temp (deg C)	Sample Number		
		A	B	Average
	140	0.041	0.000	0.014
	155	0.025	0.017	0.030
	170	0.025	0.025	0.042

Aggregate Breakdown Sieve Analysis												
Sieve (mm)	Optimum Gradation	Marshall 35 Blows				Marshall 50 Blows				Marshall 75 Blows		
		7	4	6	Average	3	24	35	Average	1	2	3
19	100	100	100	100	100	100	100	100	100	100	100	100
12.5	90.6	92.6	91.0	93.3	92.3	91.1	90.9	91.7	91.2	90.3	91.3	91.5
9.5	55.0	62.5	61.8	59.3	61.2	60.8	62.8	62.0	61.9	60.9	62.3	61.5
4.75	25.0	30.3	30.3	31.3	30.6	30.9	31.2	31.4	31.2	31.5	32.7	32.2
2.36	21.4	23.9	23.7	24.0	23.9	24.3	24.0	24.2	24.2	24.5	25.1	24.9
1.18	18.8	20.4	20.5	20.6	20.5	20.9	20.7	20.9	20.8	21.1	21.6	21.3
0.6	14.9	16.5	16.6	16.7	16.6	17.1	16.7	16.9	16.9	17.1	17.5	17.3
0.3	13.9	15.1	15.1	15.1	15.1	15.5	15.1	15.4	15.3	15.5	15.8	15.6
0.15	11.6	12.6	12.9	12.8	12.8	13.2	12.8	13.1	13.0	13.0	13.4	13.2
0.75	10.0	10.1	10.3	10.4	10.3	10.6	10.4	10.5	10.5	10.3	10.8	10.6

Table E3.6: Results from Aggregate Gradation Optimization for Traprock using 100 Revolutions of the SGC National Center for Asphalt Technology SMA Trial Gradation Summary

GRADATION A--20% Passing 4.75-mm Sieve

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIALS: Traprock/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:			Percent Coarse Aggregate: 80			DATE: OCTOBER 26, 1995			
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa)= 3.004		Effective Sp. Gr. of Agg. (Gse)= 2.959		Bulk Sp. Gr. of Agg. (Gsb) = 2.953			Bulk Specific Gravity of CA (Gca): 2.967			Unit wt. of CA in DRC (pcf): 108.30		Unit wt. of CA in DRC (kg/m3): 1734.8			
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS						
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D	J	(100-B) x I	B x I	(1 x 62.4)	100(1-I/J)	(100-K)	100(O-N)				
						(F-E)	(F-E)	(Gsb)	(Gsb)	(Gsb)	(Gsb)	(Gsb)	O					
TRAP-A1	6.0	99.4	4213.9	2555.8	4222.8	1667.0	2.528	2.658	80.5	14.8	157.7	4.9	19.5	74.9	35.9	41.5	0.866	
TRAP-A2	6.0	100.2	4189.8	2530.1	4200.8	1670.7	2.508	2.658	79.8	14.7	156.5	5.7	20.2	72.0	36.4	41.5	0.879	
TRAP-A3	6.0	100.4	4200.5	2538.8	4209.4	1670.6	2.514	2.658	80.0	14.7	156.9	5.4	20.0	72.9	36.3	41.5	0.875	
												5.3	19.9	73.3	36.2	41.5	0.873	

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

GRADATION B--24% Passing 4.75-mm Sieve

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIALS: Traprock/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:			Percent Coarse Aggregate: 76			DATE: OCTOBER 26, 1995			
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa)= 3.003		Effective Sp. Gr. of Agg. (Gse)= 2.960		Bulk Sp. Gr. of Agg. (Gsb) = 2.951			Bulk Specific Gravity of CA (Gca): 2.967			Unit wt. of CA in DRC (pcf): 108.30		Unit wt. of CA in DRC (kg/m3): 1734.8			
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS						
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D	J	(100-B) x I	B x I	(1 x 62.4)	100(1-I/J)	(100-K)	100(O-N)				
						(F-E)	(F-E)	(Gsb)	(Gsb)	(Gsb)	(Gsb)	(Gsb)	O					
TRAP-B1	6.0	95.3	4201.5	2589.7	4205.5	1615.8	2.600	2.659	82.8	15.2	162.3	2.2	17.2	87.2	34.1	41.5	0.822	
TRAP-B2	6.0	96.3	4219.4	2595.3	4223.4	1628.1	2.592	2.659	82.5	15.2	161.7	2.5	17.5	85.5	34.3	41.5	0.827	
TRAP-B3	6.0	95.8	4190.7	2570.3	4193.9	1623.6	2.581	2.659	82.2	15.1	161.1	2.9	17.8	83.6	34.6	41.5	0.834	
												2.6	17.5	85.4	34.3	41.5	0.828	

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

GRADATION C--28% Passing 4.75-mm Sieve

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIALS: Traprock/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:			Percent Coarse Aggregate: 72			DATE: OCTOBER 26, 1995			
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa)= 3.003		Effective Sp. Gr. of Agg. (Gse)= 2.954		Bulk Sp. Gr. of Agg. (Gsb) = 2.949			Bulk Specific Gravity of CA (Gca): 2.967			Unit wt. of CA in DRC (pcf): 108.30		Unit wt. of CA in DRC (kg/m3): 1734.8			
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS						
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D	J	(100-B) x I	B x I	(1 x 62.4)	100(1-I/J)	(100-K)	100(O-N)				
						(F-E)	(F-E)	(Gsb)	(Gsb)	(Gsb)	(Gsb)	(Gsb)	O					
TRAP-C1	6.0	93.2	4207.3	2607.1	4208.6	1601.5	2.627	2.654	83.6	15.4	163.9	1.0	16.4	93.8	33.4	41.5	0.806	
TRAP-C2	6.0	92.8	4207.4	2607.0	4208.3	1601.3	2.627	2.654	83.6	15.4	164.0	1.0	16.4	93.9	33.4	41.5	0.805	
TRAP-C3	6.0	92.3	4206.5	2611.1	4207.2	1596.1	2.635	2.654	83.9	15.4	164.5	0.7	16.1	95.7	33.2	41.5	0.801	
												0.9	16.3	94.5	33.3	41.5	0.804	

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

Table E3.7: Results from Asphalt Cement Optimization for Traprock using 100 Revolutions of the SGC
National Center for Asphalt Technology
SMA Mix Design Summary

OPTIMUM GRADATION -- 24% Passing 4.75 mm Sieve

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIALS: Traprock/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:								76	DATE:
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gs Effective Sp. Gr. of Agg. (Gs Bulk Sp. Gr. of Agg. (Gsb) = 3.003 2.973 2.951)						Percent Coarse Aggregate: 2.967								December 8, 1995	
			WEIGHTS			MIX VOLUM	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)				
							(F-E)		(Gsb)	(Gb)				O				
5.0-1	5.0	97.0	4218.9	2598.4	4229.5	1631.1	2.587	2.707	83.3	12.6	161.4	4.5	16.7	73.4	37.1	41.5	0.894	
5.0-2	5.0	97.1	4188.4	2572.6	4199.7	1627.1	2.574	2.707	82.9	12.6	160.6	4.9	17.1	71.4	37.4	41.5	0.901	
5.0-3	5.0	97.3	4195.3	2581.7	4210.9	1629.2	2.575	2.707	82.9	12.6	160.7	4.9	17.1	71.5	37.3	41.5	0.900	
AVG												4.7	17.0	72.1	37.3	41.5	0.898	
5.5-1	5.5	96.9	4191.8	2585.8	4202.7	1616.9	2.592	2.684	83.0	13.9	161.8	3.4	17.0	79.9	37.2	41.5	0.898	
5.5-2	5.5	97.0	4210.6	2586.1	4218.8	1632.7	2.579	2.684	82.6	13.8	160.9	3.9	17.4	77.5	37.6	41.5	0.906	
5.5-3	5.5	97.0	4212.8	2591.3	4221.4	1630.1	2.584	2.684	82.8	13.9	161.3	3.7	17.2	78.5	37.4	41.5	0.903	
AVG												3.7	17.2	78.6	37.4	41.5	0.902	
6.0-1*	6.0	95.3	4201.5	2589.7	4205.5	1615.8	2.600	2.661	82.8	15.2	162.3	2.3	17.2	86.7	37.4	41.5	0.902	
6.0-2*	6.0	96.3	4219.4	2595.3	4223.4	1628.1	2.592	2.661	82.6	15.2	161.7	2.6	17.4	85.1	37.6	41.5	0.907	
6.0-3*	6.0	95.8	4190.7	2570.3	4193.9	1623.6	2.581	2.661	82.2	15.1	161.1	3.0	17.8	83.1	37.9	41.5	0.913	
AVG												2.6	17.5	85.0	37.6	41.5	0.907	

Computed By: G. Flowers Checked By: T.LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

* -- These values from gradation optimization.

Table E3.8: Results from Asphalt Cement Optimization for Traprock using 75 Revolutions of the SGC
National Center for Asphalt Technology
SMA Mix Design Summary

OPTIMUM GRADATION - - 24% Passing 4.75 mm Sieve

SHRP 75 REV

PROJECT: NCHRP 9-8			MATERIAL: Traprock/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:								DATE: December 13, 1995	
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gs) Effective Sp. Gr. of Agg. (Gs Bulk Sp. Gr. of Agg. (Gsb) = 3.003 2.962 2.951						Percent Coarse Aggregate: 76 Bulk Specific Gravity of CA (Gca): 2.967 Unit wt. of CA in DRC (pcf): 108.30 Unit wt. of CA in DRC (kg/m3): 1734.8									
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUM	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)				
						(F-E)	(F-E)		(Gsb)	(Gb)				O				
5.5-1	5.5	98.3	4188.0	2568.2	4203.7	1635.5	2.561	2.684	82.0	13.7	159.8	4.6	18.0	74.5	38.0	41.5	0.917	
5.5-2	5.5	98.2	4198.6	2579.9	4210.2	1630.3	2.575	2.684	82.5	13.8	160.7	4.0	17.5	76.9	37.7	41.5	0.908	
5.5-3	5.5	97.8	4204.3	2572.4	4212.3	1639.9	2.564	2.684	82.1	13.8	160.0	4.5	17.9	75.0	37.9	41.5	0.915	
AVG												4.4	17.8	75.5	37.9	41.5	0.913	
6.0-1	6.0	97.7	4210.1	2582.5	4218.2	1635.7	2.574	2.661	82.0	15.1	160.6	3.3	18.0	81.8	38.0	41.5	0.917	
6.0-2	6.0	98.6	4269.2	2622.7	4274.7	1652.0	2.584	2.661	82.3	15.1	161.3	2.9	17.7	83.7	37.8	41.5	0.911	
6.0-3	6.0	97.7	4232.0	2595.3	4236.8	1641.5	2.578	2.661	82.1	15.1	160.9	3.1	17.9	82.6	37.9	41.5	0.914	
AVG												3.1	17.9	82.7	37.9	41.5	0.914	
6.5-1	6.5	97.7	4303.5	2649.4	4306.5	1657.1	2.597	2.638	82.3	16.5	162.1	1.6	17.7	91.2	37.8	41.5	0.911	
6.5-2	6.5	97.6	4216.5	2585.3	4221.6	1636.3	2.577	2.638	81.6	16.3	160.8	2.3	18.4	87.4	38.3	41.5	0.923	
6.5-3	6.5	97.2	4225.1	2581.6	4228.0	1646.4	2.566	2.638	81.3	16.3	160.1	2.7	18.7	85.5	38.5	41.5	0.929	
AVG												2.2	18.3	88.0	38.2	41.5	0.921	

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

Table E3.9: Results from Asphalt Cement Optimization for Traprock using 125 Revolutions of the SGC
National Center for Asphalt Technology
SMA Mix Design Summary

OPTIMUM GRADATION - - 24% Passing 4.75 mm Sieve

SHRP 125 REV

PROJECT: NCHRP 9-8			MATERIAL: Traprock/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:				Percent Coarse Aggregate: 76		DATE: December 15, 1995		
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gs Effective Sp. Gr. of Agg. (Gs Bulk Sp. Gr. of Agg. (Gsb) = 3.003 2.962 2.951						Bulk Specific Gravity of CA (Gca): 2.967				Unit wt. of CA in DRC (pcf): 108.30		Unit wt. of CA in DRC (kg/m3): 1734.8		
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUM SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)			
						(F-E)	(F-E)		(Gsb)	(Gb)				O			
5.0-1	5.0	95.4	4190.6	2586.7	4199.9	1613.2	2.598	2.707	83.6	12.7	162.1	4.0	16.4	75.3	36.8	41.5	0.887
5.0-2	5.0	95.3	4188.3	2586.7	4196.1	1609.4	2.602	2.707	83.8	12.7	162.4	3.9	16.2	76.2	36.7	41.5	0.884
5.0-3	5.0	95.9	4197.5	2591.5	4208.3	1616.8	2.596	2.707	83.6	12.7	162.0	4.1	16.4	75.1	36.8	41.5	0.888
AVG												4.0	16.3	75.5	36.8	41.5	0.886
5.5-1	5.5	96.1	4198.9	2588.8	4207.0	1618.2	2.595	2.684	83.1	13.9	161.9	3.3	16.9	80.3	37.2	41.5	0.897
5.5-2	5.5	95.6	4213.1	2605.0	4219.1	1614.1	2.610	2.684	83.6	14.0	162.9	2.8	16.4	83.2	36.8	41.5	0.888
5.5-3	5.5	95.4	4197.5	2593.9	4203.0	1609.1	2.609	2.684	83.5	14.0	162.8	2.8	16.5	82.9	36.9	41.5	0.889
AVG												3.0	16.6	82.2	37.0	41.5	0.891
6.0-1	6.0	95.3	4220.0	2602.8	4224.5	1621.7	2.602	2.661	82.9	15.2	162.4	2.2	17.1	87.1	37.3	41.5	0.900
6.0-2	6.0	95.4	4219.7	2608.2	4223.7	1615.5	2.612	2.661	83.2	15.3	163.0	1.8	16.8	89.0	37.1	41.5	0.895
6.0-3	6.0	94.9	4205.6	2593.7	4209.3	1615.6	2.603	2.661	82.9	15.2	162.4	2.2	17.1	87.3	37.3	41.5	0.900
AVG												2.1	17.0	87.8	37.3	41.5	0.898

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

**Table E3.11: Voids in the Coarse Aggregate Test Results for Traprock
NCHRP 9-8
Marshall & SHRP SMA Mix Properties**

Voids in th Course Aggregate (VCA) and Sieve Analysis																		
Sieve (mm)	Batched Gradation	Actual Tested Gradation	D.R.U.W. Method				Troxler SGC Method											
			D.R.U.W. (pcf)				75 Revolutions				100 Revolutions				125 Revolutions			
			108.1	108.7	108.0	average 108.3				average				average				average
19	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
12.5	87.5	87.5	87.3	86.8	86.9	87.0	91.0	89.0	90.4	89.1	88.9	88.4	88.4	88.6	89.8	89.8	89.8	
9.5	40	43.3	40.7	39.4	41.1	40.4	50.3	46.8	47.6	48.2	47.9	46.8	47.8	47.5	48.9	49.4	49.2	
4.75	0	2.6	2.6	2.2	2.4	2.4	5.2	4.5	4.6	4.8	6.9	7.0	6.7	6.9	4.7	5.6	5.3	
2.36		0.5	0.7	0.5	0.5	0.6	1.8	1.8	1.7	1.8	3.0	3.0	2.9	3.0	1.9	2.1	1.9	
1.18		0.5	0.4	0.4	0.5	0.4	1.1	1.1	1.1	1.1	1.9	1.9	1.8	1.9	1.3	1.3	0.9	
0.6		0.4	0.4	0.4	0.4	0.4	0.8	0.8	0.7	0.8	1.3	1.4	1.2	1.3	0.9	1.0	0.9	
0.3		0.4	0.4	0.4	0.4	0.4	0.6	0.6	0.6	0.6	1.0	1.0	0.9	1.0	0.8	0.8	0.7	
0.15		0.4	0.3	0.4	0.4	0.4	0.5	0.5	0.4	0.5	0.8	0.8	0.7	0.8	0.6	0.6	0.6	
0.75		0.4	0.3	0.4	0.4	0.4	0.3	0.4	0.3	0.3	0.6	0.6	0.5	0.6	0.5	0.5	0.4	
VCA (%)	N/A	N/A		41.6	41.3	41.6	41.5	38.0	37.8	38.2	38.0	39.5	39.5	39.9	39.6	37.6	37.2	37.4

Table E3.13: Various Test Results for Traprock Dense-Graded Mixtures Compacted with the Marshall Hammer
NCHRP 9-8
SHRP SMA Mix Properties

Marshall Stability				Marshall Flow	
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
3	13144	1.14	14984	3	14.9
13	13567	1.14	15466	13	15.5
16	12477	1.09	13600	16	14.2
Average			14683	Average 14.9	

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
5	9341	978
12	9564	1009
18	9452	992
Average		993

Permeability						
	Specimen A		Specimen B		Average	
Blows	VTM	k(in/min)	VTM	k(in/min)	VTM	k(in/min)
10	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A
50	N/A	N/A	N/A	N/A	N/A	N/A

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number			Average
	25				ERR
4				ERR	
40				ERR	

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number			Average
	3600				ERR
4500				ERR	

Moisture Susceptibility											
without Lime					with 1% Lime						
Conditioned					Conditioned						
Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)						
Unconditioned					Unconditioned						
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)						
Tensile Strength Ratio (%)					Tensile Strength Ratio (%)						

Aggregate Breakdown Sieve Analysis						
Sieve (mm)	Optimum Gradation	SHRP 75 Revolutions				Average
		3	4	5		
19	100.0	100.0	100.0	100.0	100.0	
12.5	97.0	96.5	97.1	97.1	96.9	
9.5	83.0	84.2	83.4	84.3	84.0	
4.75	56.0	58.0	57.7	57.7	57.8	
2.36	39.0	41.8	41.5	41.4	41.6	
1.18	28.0	30.2	30.3	30.2	30.2	
0.6	19.0	21.9	22.0	22.2	22.0	
0.3	13.0	15.2	15.4	15.4	15.3	
0.15	7.0	9.2	9.5	9.4	9.4	
0.75	4.0	5.5	5.7	5.7	5.6	

Table E3.14: Results for Traprock Dense-Graded Mixture Design Compacted with Nmax=208 Revolutions of the SGC
National Center for Asphalt Technology
Dense Mix Design Summary

Dense Mix Gradation

SHRP N-MAX=208 REV

PROJECT: NCHRP 9-8			MATERIALS: Traprock/Dolcito/Ergon AC-20						COARSE AGGREGATE INFORMATION:										44 DATE: January 30, 1996				
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa})= 3.007		Effective Sp. Gr. of Agg. (G _{se})= 2.978		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.940			Percent Coarse Aggregate: 2.967										Unit wt. of CA in DRC (pcf): N/A		Unit wt. of CA in DRC (kg/m ³): N/A	
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS										
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (G _{mb})	TMD (G _{mm})	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc						
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S						
						(F-E)	D		(100-B) x I	B x I	(1 x 62.4)	100(1-I/J)	(100-K)	100(O-N)									
							(F-E)		(Gsb)	(G _b)				O									
4.5-1	4.5	91.0	4144.9	2571.3	4149.9	1578.6	2.626	2.743	85.3	11.5	163.8	4.3	14.7	70.9	62.8	N/A	N/A						
4.5-2	4.5	91.5	4168.8	2586.9	4174.0	1587.1	2.627	2.743	85.3	11.5	163.9	4.2	14.7	71.1	62.8	N/A	N/A						
Avg												4.3	14.7	71.0	62.8	N/A	N/A						
5.0-1	5.0	90.9	4187.9	2612.4	4191.0	1578.6	2.653	2.719	85.7	12.9	165.5	2.4	14.3	83.0	62.6	N/A	N/A						
5.0-2	5.0	91.0	4184.2	2608.7	4186.4	1577.7	2.652	2.719	85.7	12.9	165.5	2.5	14.3	82.8	62.6	N/A	N/A						
Avg												2.4	14.3	82.9	62.6	N/A	N/A						
5.5-1	5.5	90.4	4190.0	2617.7	4190.9	1573.2	2.663	2.696	85.6	14.3	166.2	1.2	14.4	91.6	62.7	N/A	N/A						
5.5-2	5.5	90.2	4187.7	2618.7	4188.4	1569.7	2.668	2.696	85.8	14.3	166.5	1.0	14.2	92.7	62.6	N/A	N/A						
Avg												1.1	14.3	92.1	62.6	N/A	N/A						

Computed By: S.BUCHANNAN Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot G_{mb} = Bulk Specific Gravity of Compacted Mix G_{sb} = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches G_{mm} = Theoretical Maximum Specific Gravity of Mix G_{se} = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement G_{sa} = Apparent Specific Gravity of Aggregate G_b = Specific Gravity of Asphalt Cement

**Table E4.1: Results from Aggregate Gradation Optimization for Granite (2) using 50-Blow Marshall
National Center for Asphalt Technology
SMA Trial Gradation Summary**

GRADATION A2--20% Passing 4.75-mm Sieve / 60% Passing 9.5 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP 9-8			MATERIALS: South Carolina Granite/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:				Percent Coarse Aggregate: 80			DATE: August 8, 1995		
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa})= 2.695		Effective Sp. Gr. of Agg. (G _{se})= 2.688		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.604			Bulk Specific Gravity of CA (G _{ca}): 2.566			Unit wt. of CA in DRC (pcf): 96.20			Unit wt. of CA in DRC (kg/m ³): 1541.0		
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (G _{mb})	TMD (G _{mm})	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D	J	(100-B) x I	B x I	(I x 62.4)	100(I-L)	(100-K)	100(O-N)				
						(F-E)	(F-E)		(Gsb)	(G _b)		O						
SCGRNA2-1	6.3	2.551	1221.7	705.3	1223.3	518.0	2.358	2.439	84.9	14.5	147.2	3.3	15.1	78.2	31.1	39.9	0.780	
SCGRNA2-2	6.3	2.551	1219.6	704.9	1221.5	516.6	2.361	2.439	84.9	14.5	147.3	3.2	15.1	78.7	31.0	39.9	0.778	
SCGRNA2-3	6.3	2.577	1221.4	704.5	1223.6	519.1	2.353	2.439	84.7	14.5	146.8	3.5	15.3	77.0	31.3	39.9	0.784	
												3.3	15.2	78.0	31.1	39.9	0.781	

Computed By: G. FLOWERS Checked By: T. LYNN
 SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

GRADATION A3--20% Passing 4.75-mm Sieve / 65% Passing 9.5 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP 9-8			MATERIALS: South Carolina Granite/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:				Percent Coarse Aggregate: 80			DATE: August 8, 1995		
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa})= 2.695		Effective Sp. Gr. of Agg. (G _{se})= 2.678		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.608			Bulk Specific Gravity of CA (G _{ca}): 2.566			Unit wt. of CA in DRC (pcf): 96.20			Unit wt. of CA in DRC (kg/m ³): 1541.0		
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (G _{mb})	TMD (G _{mm})	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D	J	(100-B) x I	B x I	(I x 62.4)	100(I-L)	(100-K)	100(O-N)				
						(F-E)	(F-E)		(Gsb)	(G _b)		O						
SCGRNA3-1	6.3	2.578	1220.3	703.9	1222.1	518.2	2.355	2.431	84.7	14.5	146.9	3.1	15.3	79.5	31.2	39.9	0.782	
SCGRNA3-2	6.3	2.568	1222.5	705.0	1224.2	519.2	2.355	2.431	84.7	14.5	146.9	3.1	15.3	79.4	31.2	39.9	0.783	
SCGRNA3-3	6.3	2.577	1222.1	704.4	1223.8	519.4	2.353	2.431	84.7	14.5	146.8	3.2	15.3	79.1	31.3	39.9	0.784	
												3.2	15.3	79.3	31.2	39.9	0.783	

Computed By: G. FLOWERS Checked By: T. LYNN
 SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

GRADATION A4--20% Passing 4.75-mm Sieve / 70% Passing 9.5 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP 9-8			MATERIALS: South Carolina Granite/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:				Percent Coarse Aggregate: 80			DATE: August 8, 1995		
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa})= 2.695		Effective Sp. Gr. of Agg. (G _{se})= 2.675		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.612			Bulk Specific Gravity of CA (G _{ca}): 2.566			Unit wt. of CA in DRC (pcf): 96.20			Unit wt. of CA in DRC (kg/m ³): 1541.0		
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (G _{mb})	TMD (G _{mm})	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D	J	(100-B) x I	B x I	(I x 62.4)	100(I-L)	(100-K)	100(O-N)				
						(F-E)	(F-E)		(Gsb)	(G _b)		O						
SCGRNA4-1	6.3	2.559	1220.0	702.2	1221.4	519.2	2.350	2.429	84.6	14.4	146.6	3.3	15.4	78.9	31.4	39.9	0.786	
SCGRNA4-2	6.3	2.563	1219.9	702.7	1221.3	518.6	2.352	2.429	84.6	14.5	146.8	3.2	15.4	79.4	31.3	39.9	0.784	
SCGRNA4-3	6.3	2.570	1222.4	704.8	1223.8	519.0	2.355	2.429	84.8	14.5	147.0	3.0	15.2	80.1	31.2	39.9	0.782	
												3.2	15.4	79.5	31.3	39.9	0.784	

Computed By: G. FLOWERS Checked By: T. LYNN
 SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

Table E4.2: Results from Asphalt Cement Optimization for Granite (2) using 50-Blow Marshall Hammer
National Center for Asphalt Technology
SMA Mix Design Summary

OPTIMUM GRADATION--20% Passing 4.75mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP 9-8			MATERIAL: South Carolina Granite/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:				Percent Coarse Aggregate: 80		DATE: August 18, 1995		
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gs Effective Sp. Gr. of Agg. (Gse) Bulk Sp. Gr. of Agg. (Gsb) = 2.695 2.675 2.604						Bulk Specific Gravity of CA (Gca): 2.566				Unit wt. of CA in DRC (pcf): 96.20		Unit wt. of CA in DRC (kg/m3): 1541.0		
Specimen Number	Asphalt Content (%)	Average Thickness (inches)	WEIGHTS			MIX VOLUM	SPECIFIC GRAVITY		VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)			
						(F-E)	(F-E)		(Gsb)	(Gb)				O			
5.5-1	5.5	2.582	1211.6	694.9	1213.9	519.0	2.334	2.457	84.7	12.5	145.7	5.0	15.3	67.4	31.2	39.9	0.783
5.5-2	5.5	2.576	1210.2	695.3	1212.7	517.4	2.339	2.457	84.9	12.6	146.0	4.8	15.1	68.2	31.1	39.9	0.779
5.5-3	5.5	2.576	1210.4	699.0	1213.7	514.7	2.352	2.457	85.3	12.6	146.7	4.3	14.7	70.8	30.7	39.9	0.770
AVG												4.7	15.0	68.8	31.0	39.9	0.777
6.0-1	6.0	2.578	1215.5	699.1	1217.4	518.3	2.345	2.439	84.7	13.7	146.3	3.8	15.3	74.9	31.3	39.9	0.784
6.0-2	6.0	2.574	1216.9	701.6	1218.6	517.0	2.354	2.439	85.0	13.8	146.9	3.5	15.0	76.8	31.0	39.9	0.778
6.0-3	6.0	2.576	1216.3	701.0	1218.3	517.3	2.351	2.439	84.9	13.8	146.7	3.6	15.1	76.2	31.1	39.9	0.780
AVG												3.6	15.2	76.0	31.1	39.9	0.780
6.5-1	6.5	2.584	1228.0	707.4	1229.6	522.2	2.352	2.421	84.4	14.9	146.7	2.9	15.6	81.6	31.5	39.9	0.788
6.5-2	6.5	2.579	1222.6	703.6	1224.1	520.5	2.349	2.421	84.3	14.9	146.6	3.0	15.7	81.0	31.5	39.9	0.790
6.5-3	6.5	2.858	1208.9	692.4	1211.1	518.7	2.331	2.421	83.7	14.8	145.4	3.7	16.3	77.1	32.1	39.9	0.804
AVG												3.2	15.8	79.9	31.7	39.9	0.794

Computed By: G. FLOWERS

Checked By: T. LYNN

SSD = Saturated Surface Dry
 Sp. Gr. = Specific Gravity
 TMD = Theoretical Maximum Density

gm = gram
 cc = cubic centimeter
 AC = Asphalt Cement
 pcf = pounds per cubic foot
 in = inches

Gmb = Bulk Specific Gravity of Compacted Mix
 Gmm = Theoretical Maximum Specific Gravity of Mix
 Gsa = Apparent Specific Gravity of Aggregate

Gsb = Bulk Specific Gravity of Aggregate
 Gse = Effective Specific Gravity of Aggregate
 Gb = Specific Gravity of Asphalt Cement

Table E4.3: Results from Asphalt Cement Optimization for Granite (2) using 35-Blow Marshall Hammer
National Center for Asphalt Technology
SMA Mix Design Summary

OPTIMUM GRADATION - - 20% Passing 4.75mm Sieve

MARSHALL 35 BLOWS

PROJECT: NCHRP 9-8			MATERIAL: South Carolina Granite/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate: 80		DATE: August 21, 1995	
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gs Effective Sp. Gr. of Agg. (Gse) Bulk Sp. Gr. of Agg. (Gsb) = 2.695 2.670 2.604											Bulk Specific Gravity of CA (Gca): 2.564		Unit wt. of CA in DRC (pcf): 96.20	
														Unit wt. of CA in DRC (kg/m3): 1541.0			
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUM	SPECIFIC GRAVIT		VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D (F-E)		(100-B) x I (Gsb)	B x I (Gb)	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N) O			
6.5-1	6.5	2.652	1219.5	696.9	1223.1	526.2	2.318	2.422	83.2	14.7	144.6	4.3	16.8	74.3	27.7	39.8	0.695
6.5-2	6.5	2.629	1219.8	699.7	1222.6	522.9	2.333	2.422	83.8	14.8	145.6	3.7	16.2	77.3	27.2	39.8	0.683
6.5-3	6.5	2.581	1209.7	696.1	1211.7	515.6	2.346	2.422	84.2	14.9	146.4	3.1	15.8	80.1	26.8	39.8	0.673
6.5-4	6.5	2.626	1223.4	703.0	1226.3	523.3	2.338	2.422	83.9	14.8	145.9	3.5	16.1	78.4	27.1	39.8	0.679
AVG												3.7	16.2	77.5	27.2	39.8	0.682
7.0-1	7.0	2.625	1227.2	703.9	1229.4	525.5	2.335	2.405	83.4	15.9	145.7	2.9	16.6	82.5	27.1	39.8	0.681
7.0-2	7.0	2.610	1220.6	699.6	1222.7	523.1	2.333	2.405	83.3	15.9	145.6	3.0	16.7	82.1	27.2	39.8	0.683
7.0-3	7.0	2.609	1218.3	699.9	1220.5	520.6	2.340	2.405	83.6	16.0	146.0	2.7	16.4	83.6	27.0	39.8	0.677
AVG												2.9	16.6	82.8	27.1	39.8	0.680
7.5-1	7.5	2.596	1217.4	698.8	1219.6	520.8	2.338	2.387	83.0	17.1	145.9	2.1	17.0	87.8	27.1	39.8	0.679
7.5-2	7.5	2.629	1226.1	702.5	1228.3	525.8	2.332	2.387	82.8	17.1	145.5	2.3	17.2	86.5	27.2	39.8	0.684
7.5-3	7.5	2.623	1221.7	699.8	1224.5	524.7	2.328	2.387	82.7	17.0	145.3	2.5	17.3	85.8	27.4	39.8	0.687
AVG												2.3	17.1	86.7	27.2	39.8	0.683

Computed By: Kristen Stinson Checked By: Todd Lynn

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

Table E4.4: Results from Asphalt Cement Optimization for Granite (2) using 75-Blow Marshall Hammer
National Center for Asphalt Technology
SMA Mix Design Summary

OPTIMUM GRADATION--20% Passing 4.75mm Sieve

MARSHALL 75 BLOWS

PROJECT: NCHRP 9-8			MATERIAL: South Carolina Granite/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate: 80		DATE: August 21, 1995		
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gs Effective Sp. Gr. of Agg. (Gse)- Bulk Sp. Gr. of Agg. (Gsb) = 2.695 2.676 2.604											Bulk Specific Gravity of CA (Gca): 2.564		Unit wt. of CA in DRC (pcf): 96.20		
												Unit wt. of CA in DRC (kg/m3): 1541.0						
Specimen Number	Asphalt Content (%)	Average Thickness (inches)	WEIGHTS			MIX VOLUM	SPECIFIC GRAVIT		VOLUMES			VOIDS						
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	$\frac{D}{(F-E)}$		$\frac{(100-B) \times I}{(F-E)}$	$\frac{B \times I}{(Gb)}$	(I x 62.4)	100(1-I/J)	(100-K)	$\frac{100(O-N)}{O}$				
5.0-1	5.0	2.452	1196.1	694.6	1198.9	504.3	2.372	2.476	86.5	11.6	148.0	4.2	13.5	68.8	29.7	39.8	0.745	
5.0-2	5.0	2.516	1205.5	700.9	1208.1	507.2	2.377	2.476	86.7	11.6	148.3	4.0	13.3	69.8	29.5	39.8	0.742	
5.0-3	5.0	2.526	1206.4	700.2	1209.6	509.4	2.368	2.476	86.4	11.6	147.8	4.4	13.6	68.0	29.8	39.8	0.748	
AVG												4.2	13.5	68.9	29.7	39.8	0.745	
5.5-1	5.5	2.519	1208.0	702.7	1210.5	507.8	2.379	2.458	86.3	12.8	148.4	3.2	13.7	76.5	29.9	39.8	0.749	
5.5-2	5.5	2.496	1210.4	706.1	1212.3	506.2	2.391	2.458	86.8	12.8	149.2	2.7	13.2	79.4	29.5	39.8	0.740	
5.5-3	5.5	2.495	1204.0	701.1	1205.7	504.6	2.386	2.458	86.6	12.8	148.9	2.9	13.4	78.2	29.6	39.8	0.744	
AVG												3.0	13.4	78.0	29.7	39.8	0.745	
6.0-1	6.0	2.516	1212.0	703.3	1213.2	509.9	2.377	2.440	85.8	13.9	148.3	2.6	14.2	81.8	30.3	39.8	0.760	
6.0-2	6.0	2.512	1209.8	704.1	1211.6	507.5	2.384	2.440	86.1	14.0	148.8	2.3	13.9	83.5	30.1	39.8	0.755	
6.0-3	6.0	2.506	1210.0	704.4	1211.5	507.1	2.386	2.440	86.1	14.0	148.9	2.2	13.9	84.1	30.0	39.8	0.753	
AVG												2.4	14.0	83.1	30.1	39.8	0.756	

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

**Table E4.5: Various Test Results for Granite (2) SMA Mixtures Compacted with the Marshall Hammer
NCHRP 9-8
Marshall SMA Mix Properties**

Marshall Stability				Marshall Flow	
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
3	8852	1.00	8852	3	13.0
9	8563	1.00	8563	9	10.0
17	8118	1.00	8118	17	11.5
Average			8511	Average 11.5	

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
10	9675	923
15	9452	902
16	9831	943
Average		923

Permeability						
Blows	Specimen A		Specimen B		average	
	VTM	k(in/min)	VTM	k(in/min)	VTM	k(in/min)
10						
20						
30						
40						
50						

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number		
				Average
	25			ERR
	4			ERR
	40			ERR

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number			
		4	7	20	Average
	3600	46	46	42.8	44.9
	4500	47.2	47.2	44.5	46.3

Moisture Susceptibility									
without Lime Conditioned					with 1% Lime Conditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
1	5.9	68.2	3837	354	1	5.9	59.8	6450	593
4	6.4	62.5	3559	329	2	6.2	61.6	6950	640
6	5.8	62.8	4226	392	3	6.5	68.7	6950	640
Average Tensile Strength (kPa)				358	Average Tensile Strength (kPa)				624
Unconditioned					Unconditioned				
2	5.9	N/A	9786	905	4	6	N/A	9564	880
3	6.2	N/A	9842	908	6	6.2	N/A	9008	834
9	6	N/A	9619	892	7	6.5	N/A	9786	903
Average Tensile Strength (kPa)				902	Average Tensile Strength (kPa)				872
Tensile Strength Ratio (%)				39.7	Tensile Strength Ratio (%)				71.6

Draindown (%)	Test Temp (deg C)	Sample Number		
		A	B	Average
	140	0.008	0.000	0.004
	155	0.008	0.000	0.004
	170	0.065	0.049	0.057

Aggregate Breakdown Sieve Analysis												
Sieve (mm)	Optimum Gradation	Marshall 35 Blows				Marshall 50 Blows				Marshall 75 Blows		
		2	1	4	Average	1	2	18	Average	3	4	5
19	100	100	100	100	100	100	100	100	100	100	100	100
12.5	90.0	91.2	92.5	92.5	92.1	91.2	93.6	92.5	92.4	91.2	92.3	92.0
9.5	52.0	71.5	73.9	73.4	72.9	72.2	74.9	77.4	74.8	74.7	77.4	76.5
4.75	20.0	37.7	41.8	42.1	40.5	39.3	43.2	44.1	42.2	39.4	45.9	43.6
2.36	17.0	27.1	30.5	30.3	29.3	28.3	31.9	31.8	30.7	28.8	33.1	31.5
1.18	15.0	23.1	25.0	24.9	24.3	24.0	26.1	25.9	25.3	24.5	27.4	26.3
0.6	13.0	19.4	20.3	20.4	20.0	19.8	21.2	21.0	20.7	20.1	21.4	21.0
0.3	12.0	16.1	16.6	16.7	16.5	16.5	17.3	17.1	17.0	16.7	17.5	17.2
0.15	11.0	13.6	13.6	13.6	13.6	13.8	14.1	14.0	14.0	13.8	14.1	14.0
0.75	10.0	10.9	10.8	10.6	10.8	11.1	11.1	11.0	11.1	11.0	11.1	11.0

Table E4.6: Results from Aggregate Gradation Optimization for Granite (2) using 100 Revolutions of the SGC
National Center for Asphalt Technology
SMA Trial Gradation Summary

GRADATION A--20% Passing 4.75-mm Sieve

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIALS: South Carolina Granite/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:								
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa)= 2.695		Effective Sp. Gr. of Agg. (Gse)= 2.687		Bulk Sp. Gr. of Agg. (Gsb) = 2.604		Percent Coarse Aggregate: 80				DATE: October 26, 1995				
									Bulk Specific Gravity of CA (Gca): 2.566				Unit wt. of CA in DRC (pcf): 96.20				
									Unit wt. of CA in DRC (kg/m ³): 1541.0								
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(I-J)	(100-K)	100(O-N)			
							(F-E)		(Gsb)	(Gsb)				O			
SCGRN-A1	6.3	101.2	4224.8	2475.0	4227.3	1752.3	2.411	2.438	86.8	14.8	150.4	1.1	13.2	91.6	29.6	39.9	0.741
SCGRN-A2	6.3	101.4	4218.4	2470.5	4220.9	1750.4	2.410	2.438	86.7	14.8	150.4	1.1	13.3	91.3	29.6	39.9	0.742
SCGRN-A3	6.3	101.1	4234.2	2482.0	4236.8	1754.8	2.413	2.438	86.8	14.8	150.6	1.0	13.2	92.2	29.5	39.9	0.740
												1.1	13.2	91.7	29.6	39.9	0.741

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

GRADATION B--24% Passing 4.75-mm Sieve

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIALS: South Carolina Granite/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:								
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa)= 2.695		Effective Sp. Gr. of Agg. (Gse)= 2.696		Bulk Sp. Gr. of Agg. (Gsb) = 2.608		Percent Coarse Aggregate: 76				DATE: October 26, 1995				
									Bulk Specific Gravity of CA (Gca): 2.566				Unit wt. of CA in DRC (pcf): 96.20				
									Unit wt. of CA in DRC (kg/m ³): 1541.0								
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(I-J)	(100-K)	100(O-N)			
							(F-E)		(Gsb)	(Gsb)				O			
SCGRN-B1	6.3	100.0	4221.0	2482.7	4222.0	1739.3	2.427	2.445	87.3	14.9	151.4	0.7	12.7	94.1	29.1	39.9	0.730
SCGRN-B2	6.3	100.0	4227.1	2490.5	4228.1	1737.6	2.433	2.445	87.5	15.0	151.8	0.5	12.5	96.0	28.9	39.9	0.725
SCGRN-B3	6.3	100.1	4223.7	2487.1	4224.8	1737.7	2.431	2.445	87.5	14.9	151.7	0.6	12.5	95.3	29.0	39.9	0.727
												0.6	12.6	95.1	29.0	39.9	0.727

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

GRADATION C--28% Passing 4.75-mm Sieve

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIALS: South Carolina Granite/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:								
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa)= 2.696		Effective Sp. Gr. of Agg. (Gse)= 2.696		Bulk Sp. Gr. of Agg. (Gsb) = 2.612		Percent Coarse Aggregate: 72				DATE: October 26, 1995				
									Bulk Specific Gravity of CA (Gca): 2.566				Unit wt. of CA in DRC (pcf): 96.20				
									Unit wt. of CA in DRC (kg/m ³): 1541.0								
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(I-J)	(100-K)	100(O-N)			
							(F-E)		(Gsb)	(Gsb)				O			
SCGRN-C1	6.3	99.9	4249.5	2507.0	4250.0	1743.0	2.438	2.445	87.7	15.0	152.1	0.3	12.3	97.7	28.8	39.9	0.722
SCGRN-C2	6.3	99.9	4232.3	2496.3	4233.1	1736.8	2.437	2.445	87.7	15.0	152.1	0.3	12.3	97.3	28.8	39.9	0.722
SCGRN-C3	6.3	100.0	4247.5	2503.8	4248.0	1744.2	2.435	2.445	87.6	15.0	152.0	0.4	12.4	96.8	28.9	39.9	0.724
												0.3	12.3	97.2	28.8	39.9	0.722

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

Table E4.7: Results from Asphalt Cement Optimization for Granite (2) using 100 Revolutions of the SGC
National Center for Asphalt Technology
SMA Mix Design Summary

OPTIMUM GRADATION--20% Passing 4.75mm Sieve

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIAL: South Carolina Granite/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate: 80		DATE: November 20, 1995	
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gs Effective Sp. Gr. of Agg. (Gse) Bulk Sp. Gr. of Agg. (Gsb) = 2.695 2.688 2.604											Bulk Specific Gravity of CA (Gca): 2.566		Unit wt. of CA in DRC (pcf): 96.20	
														Unit wt. of CA in DRC (kg/m3): 1541.0			
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUM	SPECIFIC GRAVITY		VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D (F-E)		(100-B) x I (Gsb)	B x I (Gb)	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N) O			
4.5-1	4.5	103.1	4159.4	2424.8	4176.4	1751.6	2.375	2.505	87.1	10.4	148.2	5.2	12.9	59.7	29.3	39.9	0.735
4.5-2	4.5	103.0	4176.3	2442.9	4193.7	1750.8	2.385	2.505	87.5	10.5	148.8	4.8	12.5	61.8	29.0	39.9	0.727
4.5-3	4.5	102.6	4171.0	2438.9	4185.5	1746.6	2.388	2.505	87.6	10.5	149.0	4.7	12.4	62.4	28.9	39.9	0.725
AVG												4.9	12.6	61.3	29.1	39.9	0.729
5.0-1	5.0	102.2	4192.0	2454.3	4200.5	1746.2	2.401	2.487	87.6	11.7	149.8	3.5	12.4	72.0	28.9	39.9	0.725
5.0-2	5.0	102.1	4196.0	2459.6	4202.6	1743.0	2.407	2.487	87.8	11.7	150.2	3.2	12.2	73.7	28.7	39.9	0.720
5.0-3	5.0	102.3	4195.2	2438.9	4202.5	1763.6	2.379	2.487	86.8	11.6	148.4	4.4	13.2	67.1	29.5	39.9	0.741
AVG												3.7	12.6	70.9	29.0	39.9	0.728
5.5-1	5.5	101.4	4216.8	2475.7	4220.3	1744.6	2.417	2.468	87.7	13.0	150.8	2.1	12.3	83.2	28.8	39.9	0.722
5.5-2	5.5	101.5	4210.8	2472.2	4214.6	1742.4	2.417	2.468	87.7	13.0	150.8	2.1	12.3	83.1	28.8	39.9	0.722
5.5-3	5.5	101.2	4220.8	2479.7	4224.2	1744.5	2.419	2.468	87.8	13.0	151.0	2.0	12.2	83.9	28.7	39.9	0.720
AVG												2.0	12.3	83.4	28.8	39.9	0.721

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement mm = millimeters Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

Table E4.8: Results from Asphalt Cement Optimization for Granite (2) using 75 Revolutions of the SGC
National Center for Asphalt Technology
SMA Mix Design Summary

OPTIMUM GRADATION--20% Passing 4.75mm Sieve

SHRP 75 REV

PROJECT: NCHRP 9-8			MATERIAL: South Carolina Granite/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:				Percent Coarse Aggregate: 80		DATE: November 26, 1995		
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (G) Effective Sp. Gr. of Agg. (Gse) Bulk Sp. Gr. of Agg. (Gsb)										Bulk Specific Gravity of CA (Gca): 2.566				
			2.695		2.688		2.604						Unit wt. of CA in DRC (pcf): 96.20				
													Unit wt. of CA in DRC (kg/m3): 1541.0				
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUM	SPECIFIC GRAV	VOLUMES			VOIDS						
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)			
						(F-E)	(F-E)		(Gsb)	(G)				O			
5.0-1	5.0	103.2	4170.9	2425.1	4179.6	1754.5	2.377	2.487	86.7	11.6	148.3	4.4	13.3	66.8	29.6	39.9	0.742
5.0-2	5.0	103.5	4179.3	2428.9	4187.8	1758.9	2.376	2.487	86.7	11.6	148.3	4.5	13.3	66.5	29.6	39.9	0.743
5.0-3	5.0	103.0	4183.6	2435.7	4192.0	1756.3	2.382	2.487	86.9	11.6	148.6	4.2	13.1	67.8	29.4	39.9	0.738
AVG												4.4	13.2	67.0	29.6	39.9	0.741
5.5-1	5.5	103.0	4201.5	2425.4	4207.3	1781.9	2.358	2.468	85.6	12.7	147.1	4.5	14.4	69.1	30.5	39.9	0.765
5.5-2	5.5	101.8	4203.6	2462.4	4208.0	1745.6	2.408	2.468	87.4	12.9	150.3	2.4	12.6	80.8	29.1	39.9	0.728
5.5-3	5.5	103.2	4208.2	2457.3	4215.8	1758.5	2.393	2.468	86.8	12.8	149.3	3.0	13.2	76.9	29.5	39.9	0.739
AVG												3.3	13.4	75.6	29.7	39.9	0.744
6.0-1	6.0	102.6	4216.3	2463.7	4219.9	1756.2	2.401	2.450	86.7	14.1	149.8	2.0	13.3	84.9	29.6	39.9	0.743
6.0-2	6.0	101.9	4204.3	2461.9	4207.2	1745.3	2.409	2.450	87.0	14.1	150.3	1.7	13.0	87.1	29.4	39.9	0.737
6.0-3	6.0	102.7	4210.5	2458.5	4213.9	1755.4	2.399	2.450	86.6	14.0	149.7	2.1	13.4	84.4	29.7	39.9	0.745
AVG												1.9	13.3	85.5	29.6	39.9	0.742

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement mm = millimeters Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

**Table E4.10: Various Test Results for Granite (2) SMA Mixtures Compacted with the SGC
NCHRP 9-8
SHRP SMA Mix Properties**

Marshall Stability				Marshall Flow	
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
Average			ERR	Average	
			ERR		

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
Average		ERR

Permeability						
	Specimen A		Specimen B		Average	
Blows	VTM	k(in/min)	VTM	k(in/min)	VTM	k(in/min)
10	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A
50	N/A	N/A	N/A	N/A	N/A	N/A

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number		
				Average
	25			ERR
	4			ERR
	40			ERR

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number		
				Average
	3600			ERR
	4500			ERR

Moisture Susceptability											
without Lime Conditioned					with 1% Lime Conditioned						
Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)						
Unconditioned					Unconditioned						
Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)						
Tensile Strength Ratio (%)					Tensile Strength Ratio (%)						

Draindown (%)	Test Temp (deg C)	Sample Number		
		A	B	Average
	140	0.016	0.016	0.016
	155	0.016	0.107	0.062
	170	0.008	0.008	0.008

Aggregate Breakdown Sieve Analysis														
Sieve (mm)	Optimum Gradation	SHRP 75 Revolutions					SHRP 100 Revolutions					SHRP 125 Revolutions		
		2	4	5	Average	1	2	3	Average	2	3	4	Average	
19	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
12.5	90.0	91.0	92.6	92.1	91.9	91.1	90.2	92.5	91.3	91.7	91.9	91.1	91.6	
9.5	52.0	65.3	65.1	65.6	65.3	65.9	64.6	65.9	65.5	66.8	66.0	65.6	66.1	
4.75	20.0	38.5	39.2	39.9	39.2	39.8	39.7	40.5	40.0	39.7	40.3	40.5	40.2	
2.36	17.0	27.9	28.7	29.0	28.5	29.1	28.6	29.7	29.1	29.2	29.2	29.9	29.4	
1.18	15.0	23.3	23.7	24.2	23.7	23.4	23.5	24.3	23.7	24.2	24.4	24.9	24.5	
0.6	13.0	19.0	19.3	19.8	19.4	19.3	19.0	19.6	19.3	19.8	19.9	20.2	20.0	
0.3	12.0	15.8	15.9	16.3	16.0	15.9	15.7	16.1	15.9	16.3	16.5	16.6	16.5	
0.15	11.0	13.2	13.3	13.4	13.3	13.3	13.1	13.4	13.3	13.6	13.7	13.8	13.7	
0.75	10.0	10.6	10.6	10.7	10.6	10.7	10.6	10.7	10.7	10.8	10.9	10.9	10.9	

Table E4.11: Voids in the Coarse Aggregate Test Results for Granite (2)
NCHRP 9-8
Marshall & SHRP SMA Mix Properties

Voids in th Course Aggregate (VCA) and Sieve Analysis																		
Sieve (mm)	Batched Gradation	Actual Tested Gradation	D.R.U.W. Method				Troxler SGC Method											
			D.R.U.W. (pcf)			average	75 Revolutions				100 Revolutions			125 Revolutions				
			96.2	96.6	95.8		average	75	100	125	average	100	125	150	average			
19	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
12.5	87.5	87.7	89.0	86.9	86.8	87.6	90.1	89.9	89.5	89.8	90.9	91.8	89.7	90.8	89.4	90.6	89.6	89.9
9.5	40	44	45.6	41.9	42.4	43.3	71.8	69.0	70.9	70.6	70.2	68.2	68.2	68.9	68.6	71.8	69.8	70.1
4.75	0	2.9	3.5	2.3	2.3	2.7	28.7	29.5	29.3	29.2	31.1	30.7	31.2	31.0	30.5	30.3	29.6	30.1
2.36		0.6	1.0	0.8	0.8	0.9	17.0	17.4	17.6	17.3	18.6	18.3	18.5	18.5	17.6	18.3	17.6	17.8
1.18		0.6	0.8	0.6	0.7	0.7	12.4	12.5	12.9	12.6	13.1	13.0	13.3	13.1	12.8	13.5	12.9	13.1
0.6		0.5	0.7	0.5	0.6	0.6	8.6	8.6	8.9	8.7	9.0	8.9	9.3	9.1	8.3	9.2	8.8	8.8
0.3		0.5	0.5	0.5	0.5	0.5	5.5	5.4	5.7	5.5	5.7	5.6	5.9	5.7	5.6	5.8	5.6	5.7
0.15		0.4	0.4	0.4	0.4	0.4	3.2	3.1	3.4	3.2	3.2	3.2	3.5	3.3	3.2	3.3	3.2	3.2
0.75		0.4	0.3	0.3	0.3	0.3	1.9	1.8	1.9	1.9	1.9	1.9	2.1	2.0	1.9	1.9	1.9	1.9
VCA (%)	N/A	N/A	39.9	39.6	40.1	39.9	26.3	26.3	26.0	26.2	24.9	24.9	24.6	24.8	24.2	24.6	24.5	24.4

Table E4.12: Results for Granite (2) Dense-Graded Mixture Design Compacted with 75-Blow Marshall
National Center for Asphalt Technology
Dense Mix Design Summary

Dense Mix Gradation

MARSHALL 75 BLOWS

PROJECT: NCHRP 9-8			MATERIALS: South Carolina Granite\Dolcito\Ergon AC-20						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate: 44		DATE: 2.566		
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa)= 2.689		Effective Sp. Gr. of Agg. (Gse)= 2.678		Bulk Sp. Gr. of Agg. (Gsb) = 2.641			Bulk Specific Gravity of CA (Gca): N/A					Unit wt. of CA in DRC (pcf): N/A		Unit wt. of CA in DRC (kg/m3): N/A	
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D		(100-B) x 1	B x 1	(1 x 62.4)	100(1-I/J)	(100-K)	100(O-N)				
						(F-E)	(F-E)		(Gsb)	(Gb)				O				
4.5-1	4.5	2.609	1249.8	717.1	1252.4	535.3	2.335	2.497	84.4	10.3	145.7	6.5	15.6	58.4	61.8	N/A	N/A	
4.5-2	4.5	2.607	1250.4	716.6	1252.4	535.8	2.334	2.497	84.4	10.2	145.6	6.5	15.6	58.2	61.8	N/A	N/A	
4.5-3	4.5	2.614	1253.7	716.3	1255.4	539.1	2.326	2.497	84.1	10.2	145.1	6.9	15.9	56.9	61.9	N/A	N/A	
Avg												6.6	15.7	57.8	61.8	N/A	N/A	
5.0-1	5.0	2.619	1254.6	720.2	1256.8	536.6	2.338	2.478	84.1	11.4	145.9	5.6	15.9	64.5	61.9	N/A	N/A	
5.0-2	5.0	2.629	1259.2	725.0	1261.0	536.0	2.349	2.478	84.5	11.5	146.6	5.2	15.5	66.5	61.7	N/A	N/A	
5.0-3	5.0	2.616	1255.1	721.3	1256.8	535.5	2.344	2.478	84.3	11.4	146.3	5.4	15.7	65.5	61.8	N/A	N/A	
Avg												5.4	15.7	65.5	61.8	N/A	N/A	
5.5-1	5.5	2.621	1265.4	729.8	1266.7	536.9	2.357	2.460	84.3	12.6	147.1	4.2	15.7	73.3	61.8	N/A	N/A	
5.5-2	5.5	2.599	1261.1	728.8	1262.0	533.2	2.365	2.460	84.6	12.7	147.6	3.8	15.4	75.0	61.7	N/A	N/A	
5.5-3	5.5	2.609	1264.5	730.0	1265.6	535.6	2.361	2.460	84.5	12.7	147.3	4.0	15.5	74.1	61.7	N/A	N/A	
Avg												4.0	15.5	74.2	61.7	N/A	N/A	

Computed By: S.BUCHANAN Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

Table E4.14: Results for Granite (2) Dense-Graded Design Compacted with Nmax=208 Revolutions of the SGC
National Center for Asphalt Technology
Dense Mix Design Summary

Dense Mix Gradation

SHRP N-MAX=208 REV

PROJECT: NCHRP 9-8			MATERIALS: South Carolina Granite(Dolcito)Ergon AC-20						COARSE AGGREGATE INFORMATION:										44	DATE:		
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa)= 2.689		Effective Sp. Gr. of Agg. (Gse)= 2.679		Bulk Sp. Gr. of Agg. (Gsb) = 2.641			Percent Coarse Aggregate: 2.566			Bulk Specific Gravity of CA (Gca): N/A			Unit wt. of CA in DRC (pcf): N/A			Unit wt. of CA in DRC (kg/m3): N/A			January 30, 1996
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS									
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc					
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S					
						(F-E)	D		(100-B) x I	B x I	(1 x 62.4)	100(1-I/J)	(100-K)	100(O-N)								
							(F-E)		(Gsb)	(Gb)				O								
4.5-1	4.5	99.4	4133.6	2404.7	4143.9	1739.2	2.377	2.498	85.9	10.4	148.3	4.8	14.1	65.6	61.1	N/A	N/A					
4.5-2	4.5	99.6	4150.5	2415.7	4157.3	1741.6	2.383	2.498	86.2	10.5	148.7	4.6	13.8	66.8	61.0	N/A	N/A					
Avg												4.7	13.9	66.2	61.0	N/A	N/A					
5.0-1	5.0	99	4155.2	2429.9	4157.8	1727.9	2.405	2.479	86.5	11.7	150.1	3.0	13.5	77.8	60.8	N/A	N/A					
5.0-2	5.0	99.5	4180.7	2447.2	4183.7	1736.5	2.408	2.479	86.6	11.7	150.2	2.9	13.4	78.5	60.8	N/A	N/A					
Avg												2.9	13.4	78.2	60.8	N/A	N/A					
5.5-1	5.5	98.5	4192.3	2469.4	4193.2	1723.8	2.432	2.461	87.0	13.0	151.8	1.2	13.0	91.0	60.6	N/A	N/A					
5.5-2	5.5	98.5	4189.3	2469.3	4190.3	1721.0	2.434	2.461	87.1	13.1	151.9	1.1	12.9	91.7	60.6	N/A	N/A					
Avg												1.1	12.9	91.4	60.6	N/A	N/A					

Computed By: S.BUCHANNAN Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

Table E5.1: Results from Aggregate Gradation Optimization for Dolomite using 50-Blow Marshall
National Center for Asphalt Technology
SMA Trial Gradation Summary

GRADATION A--20% PASSING 4.75-mm

MARSHALL 50 BLOWS

PROJECT: NCHRP 9-8			MATERIALS: Indiana Dolomite/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate:		DATE:		
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa)= 2.727		Effective Sp. Gr. of Agg. (Gse)= 2.581		Bulk Sp. Gr. of Agg. (Gsb)= 2.500								Bulk Specific Gravity of CA (Gca): 2.702		September 21, 1995	
										Unit wt. of CA in DRC (pcf): 91.10					Unit wt. of CA in DRC (kg/m ³): 1459.3			
Specimen Number	Asphalt Content (%)	Average Thickness (inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D (F-E)	J	(100-B) x I (Gsb)	B x I (Gsb)	(I x 62.4)	100(1-IJ)	(100-K)	100(O-N) O				
DOLO-A1	6.3	2.709	1222.2	682.4	1224.7	542.3	2.254	2.356	84.5	13.9	140.6	4.3	15.5	72.0	37.5	45.9	0.816	
DOLO-A2	6.3	2.716	1225.4	683.5	1227.2	543.7	2.254	2.356	84.5	13.9	140.6	4.3	15.5	72.1	37.5	45.9	0.816	
DOLO-A3	6.3	2.718	1226.8	686.0	1229.0	543.0	2.259	2.356	84.7	13.9	141.0	4.1	15.3	73.2	37.3	45.9	0.812	
												4.3	15.5	72.4	37.4	45.9	0.815	

Computed By: Michael H Huner Checked By: Todd Lynn

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gsb = Specific Gravity of Asphalt Cement
 Gse = Effective Specific Gravity of Aggregate Gc = Bulk Specific Gravity of Aggregate
 Gca = Bulk Specific Gravity of CA (Gca): 2.702
 Gce = Effective Specific Gravity of Aggregate
 Gcb = Specific Gravity of Asphalt Cement

GRADATION B--24% PASSING 4.75-mm

MARSHALL 50 BLOWS

PROJECT: NCHRP 9-8			MATERIALS: Indiana Dolomite/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate:		DATE:		
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa)= 2.731		Effective Sp. Gr. of Agg. (Gse)= 2.581		Bulk Sp. Gr. of Agg. (Gsb)= 2.501								Bulk Specific Gravity of CA (Gca): 76		September 21, 1995	
										Unit wt. of CA in DRC (pcf): 91.10					Unit wt. of CA in DRC (kg/m ³): 1459.3			
Specimen Number	Asphalt Content (%)	Average Thickness (inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D (F-E)	J	(100-B) x I (Gsb)	B x I (Gsb)	(I x 62.4)	100(1-IJ)	(100-K)	100(O-N) O				
DOLO-B1	6.3	2.649	1223.6	692.7	1224.9	532.2	2.299	2.356	86.2	14.1	143.5	2.4	13.8	82.5	36.2	45.9	0.788	
DOLO-B2	6.3	2.688	1223.8	687.4	1225.6	538.2	2.274	2.356	85.2	14.0	141.9	3.5	14.8	76.4	36.9	45.9	0.804	
DOLO-B3	6.3	2.635	1212.9	685.3	1214.2	528.9	2.293	2.356	86.0	14.1	143.1	2.7	14.0	81.0	36.4	45.9	0.792	
												2.9	14.2	80.0	36.5	45.9	0.795	

Computed By: Michael H Huner Checked By: Todd Lynn

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gsb = Specific Gravity of Asphalt Cement
 Gse = Effective Specific Gravity of Aggregate Gc = Bulk Specific Gravity of Aggregate
 Gca = Bulk Specific Gravity of CA (Gca): 76
 Gce = Effective Specific Gravity of Aggregate
 Gcb = Specific Gravity of Asphalt Cement

GRADATION C--28% PASSING 4.75-mm

MARSHALL 50 BLOWS

PROJECT: NCHRP 9-8			MATERIALS: Indiana Dolomite/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate:		DATE:		
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa)= 2.734		Effective Sp. Gr. of Agg. (Gse)= 2.581		Bulk Sp. Gr. of Agg. (Gsb)= 2.503								Bulk Specific Gravity of CA (Gca): 72		September 21, 1995	
										Unit wt. of CA in DRC (pcf): 91.10					Unit wt. of CA in DRC (kg/m ³): 1459.3			
Specimen Number	Asphalt Content (%)	Average Thickness (inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D (F-E)	J	(100-B) x I (Gsb)	B x I (Gsb)	(I x 62.4)	100(1-IJ)	(100-K)	100(O-N) O				
DOLO-C1	6.3	2.600	1226.4	701.2	1227.8	526.6	2.329	2.356	87.3	14.3	145.3	1.2	12.7	91.0	35.4	45.9	0.770	
DOLO-C2	6.3	2.604	1224.4	698.4	1226.0	527.6	2.321	2.356	87.0	14.3	144.8	1.5	13.0	88.5	35.6	45.9	0.775	
DOLO-C3	6.3	2.602	1229.5	704.0	1230.4	526.4	2.336	2.356	87.5	14.4	145.7	0.9	12.5	93.1	35.2	45.9	0.766	
												1.2	12.7	90.8	35.4	45.9	0.771	

Computed By: Michael H Huner Checked By: Todd Lynn

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gsb = Specific Gravity of Asphalt Cement
 Gse = Effective Specific Gravity of Aggregate Gc = Bulk Specific Gravity of Aggregate
 Gca = Bulk Specific Gravity of CA (Gca): 72
 Gce = Effective Specific Gravity of Aggregate
 Gcb = Specific Gravity of Asphalt Cement

Table E5.2: Results from Asphalt Cement Optimization for Dolomite using 50-Blow Marshall
National Center for Asphalt Technology
SMA Mix Design Summary

OPTIMUM GRADATION--20% Passing 4.75mm

MARSHALL 50 BLOW

PROJECT: NCHRP 9-8			MATERIAL: Indiana Dolomite/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate: 70		DATE: September 21, 1995	
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gs Effective Sp. Gr. of Agg. (Gse) Bulk Sp. Gr. of Agg. (Gsb) = 2.727 2.572 2.500											Bulk Specific Gravity of CA (Gca): 2.702		Unit wt. of CA in DRC (pcf): 91.10	
			WEIGHTS			MIX VOLUM	SPECIFIC GRAV		VOLUMES			VOIDS					
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	<u>D</u> (F-E)		<u>(100-B) x I</u> (Gsb)	<u>B x I</u> (Gb)	(I x 62.4)	100(I-I/J)	(100-K)	<u>100(O-N)</u> O			
6.3-1	6.3	2.709	1222.2	682.4	1224.7	542.3	2.254	2.349	84.5	13.9	140.6	4.1	15.5	73.9	45.3	45.9	0.986
6.3-2	6.3	2.716	1225.4	683.5	1227.2	543.7	2.254	2.349	84.5	13.9	140.6	4.1	15.5	73.9	45.3	45.9	0.986
6.3-3	6.3	2.718	1226.8	686.0	1229.0	543.0	2.259	2.349	84.7	13.9	141.0	3.8	15.3	75.1	45.2	45.9	0.983
AVG	6.3											4.0	15.5	74.3	45.2	45.9	0.985
6.8-1	6.8	2.743	1227	684.1	1229.3	545.2	2.251	2.333	83.9	14.9	140.4	3.5	16.1	78.0	45.7	45.9	0.994
6.8-2	6.8	2.704	1223.5	680.6	1225.3	544.7	2.246	2.333	83.7	14.9	140.2	3.7	16.3	77.1	45.8	45.9	0.996
6.8-3	6.8	2.716	1223.8	681.6	1226.1	544.5	2.248	2.333	83.8	14.9	140.2	3.7	16.2	77.4	45.7	45.9	0.996
AVG	6.8											3.6	16.2	77.5	45.7	45.9	0.995
7.3-1	7.3	2.715	1227.4	682.8	1228.8	546.0	2.248	2.317	83.4	16.0	140.3	3.0	16.6	82.1	46.0	45.9	1.002
7.3-2	7.3	2.713	1225.6	680.6	1227.4	546.8	2.241	2.317	83.1	16.0	139.9	3.3	16.9	80.7	46.2	45.9	1.005
7.3-3	7.3	2.721	1227.5	683.3	1228.7	545.4	2.251	2.317	83.5	16.0	140.4	2.9	16.5	82.7	45.9	45.9	1.000
AVG	7.3											3.0	16.7	81.8	46.0	45.9	1.002

Computed By: Michael H. Huner

Checked By: Todd Lynn

SSD = Saturated Surface Dry

gm = gram

pcf = pounds per cubic foot

Gmb = Bulk Specific Gravity of Compacted Mix

Gsb = Bulk Specific Gravity of Aggregate

Sp. Gr. = Specific Gravity

cc = cubic centimeter

in = inches

Gmm = Theoretical Maximum Specific Gravity of Mix

Gse = Effective Specific Gravity of Aggregate

TMD = Theoretical Maximum Density

AC = Asphalt Cement

Gsa = Apparent Specific Gravity of Aggregate

Gb = Specific Gravity of Asphalt Cement

**Table E5.3: Various Test Results for Dolomite SMA Mixtures Compacted with the Marshall Hammer
NCHRP 9-8
Marshall SMA Mix Properties**

Marshall Stability				Marshall Flow	
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
1	7784	0.89	6928	1	9.8
8	8118	0.89	7225	8	9.5
10	8563	0.93	7964	10	9.7
Average			7372	Average 9.7	

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
4	9564	862
15	9564	852
17	9230	836
Average		850

Permeability						
Blows	Specimen A		Specimen B		average	
	VTM	k(in/min)	VTM	k(in/min)	VTM	k(in/min)
10	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A
50	N/A	N/A	N/A	N/A	N/A	N/A

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number			Average
	25				ERR
	4				ERR
	40				ERR

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number			Average
	3600	7	16	18	58.1
	4500	51	62.7	60.5	59.5
		51.8	64.4	62.4	

Moisture Susceptibility										
without Lime					with 1% Lime					
Conditioned					Conditioned					
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	
3	6.3	66.1	8118	741	2	6.5	71.7	8618	759	
7	6	70.8	8618	765	4	6.6	71.4	8452	743	
8	6.1	70.4	8674	769	5	6.4	69.8	8452	749	
Average Tensile Strength (kPa)				521	Average Tensile Strength (kPa)				600	
Unconditioned					Unconditioned					
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	
2	5.9	N/A	9675	860	3	6.5	N/A	10120	899	
4	6.2	N/A	10676	938	7	6.5	N/A	9842	869	
6	5.9	N/A	10453	929	8	6.5	N/A	10787	948	
Average Tensile Strength (kPa)				825	Average Tensile Strength (kPa)				835	
Tensile Strength Ratio (%)				63.1	Tensile Strength Ratio (%)				71.8	

Drainow (%)	Test Temp (deg C)	Sample Number			Average
		A	B		
	140	0.008	0.000		0.008
	155	0.040	0.016		0.037
170	0.049	0.024		0.041	

Aggregate Breakdown Sieve Analysis					
Sieve (mm)	Optimum Gradation	Marshall 50 Blows			
		11	5	14	Average
19	100	100	100	100	100
12.5	90.0	92.8	93.4	94.4	93.5
9.5	52.0	60.6	60.2	61.6	60.8
4.75	20.0	38.5	37.7	39.3	38.5
2.36	17.0	23.2	23.3	23.8	23.4
1.18	15.0	18.9	18.9	19.3	19.0
0.6	13.0	15.9	16.2	16.6	16.2
0.3	12.0	14.4	14.7	15.0	14.7
0.15	11.0	12.7	13.4	13.7	13.3
0.75	10.0	10.5	11.3	11.5	11.1

Table E5.4: Results from Aggregate Gradation Optimization for Dolomite using 100 Revolutions of the SGC
National Center for Asphalt Technology
SMA Trial Gradation Summary

GRADATION A--20% Passing 4.75-mm Sieve

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIALS: Indiana Dolomite/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:										DATE: October 30, 1995								
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa})= 2.727		Effective Sp. Gr. of Agg. (G _{se})= 2.651		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.500			Percent Coarse Aggregate: 80										Bulk Specific Gravity of CA (G _{ca}): 2.452							
										Unit wt. of CA in DRC (pcf): 91.10										Unit wt. of CA in DRC (kg/m ³): 1459.3							
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS														
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc										
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S									
						(F-E)	D			(100-B) x 1			B x 1			(1 x 62.4)			100(1-I/J)			(100-K)			100(O-N)		
						(F-E)				(G)																	
DOLO-A1	6.3	110.6	4278.5	2417.1	4294.5	1877.4	2.279	2.410	85.4	14.0	142.2	5.4	14.6	62.7	30.3	40.4	0.750										
DOLO-A2	6.3	110.5	4265.0	2410.4	4284.9	1874.5	2.275	2.410	85.3	14.0	142.0	5.6	14.7	62.0	30.4	40.4	0.753										
DOLO-A3	6.3	110.4	4262.5	2404.9	4279.1	1874.2	2.274	2.410	85.2	14.0	141.9	5.6	14.8	61.9	30.5	40.4	0.754										
												5.6	14.7	62.2	30.4	40.4	0.752										

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gse = Effective Specific Gravity of Aggregate
 Gb = Specific Gravity of Asphalt Cement

GRADATION B--24% Passing 4.75-mm Sieve

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIALS: Indiana Dolomite/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:										DATE: November 8, 1995								
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa})= 2.731		Effective Sp. Gr. of Agg. (G _{se})= 2.655		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.501			Percent Coarse Aggregate: 76										Bulk Specific Gravity of CA (G _{ca}): 2.452							
										Unit wt. of CA in DRC (pcf): 91.10										Unit wt. of CA in DRC (kg/m ³): 1459.3							
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS														
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc										
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S									
						(F-E)	D			(100-B) x 1			B x 1			(1 x 62.4)			100(1-I/J)			(100-K)			100(O-N)		
						(F-E)				(G)																	
DOLO-B1	6.3	108.2	4309.3	2470.5	4320.3	1849.8	2.330	2.413	87.3	14.3	145.4	3.5	12.7	72.8	32.3	40.4	0.800										
DOLO-B2	6.3	108.4	4264.6	2437.3	4278.3	1841.0	2.316	2.413	86.8	14.2	144.5	4.0	13.2	69.6	32.7	40.4	0.809										
DOLO-B3	6.3	108.3	4246.1	2430.3	4268.0	1837.7	2.311	2.413	86.6	14.2	144.2	4.2	13.4	68.3	32.9	40.4	0.814										
												3.9	13.1	70.2	32.7	40.4	0.808										

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gse = Effective Specific Gravity of Aggregate
 Gb = Specific Gravity of Asphalt Cement

GRADATION C--28% Passing 4.75-mm Sieve

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIALS: Indiana Dolomite/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:										DATE: November 8, 1995								
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa})= 2.734		Effective Sp. Gr. of Agg. (G _{se})= 2.662		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.503			Percent Coarse Aggregate: 72										Bulk Specific Gravity of CA (G _{ca}): 2.452							
										Unit wt. of CA in DRC (pcf): 91.10										Unit wt. of CA in DRC (kg/m ³): 1459.3							
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS														
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc										
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S									
						(F-E)	D			(100-B) x 1			B x 1			(1 x 62.4)			100(1-I/J)			(100-K)			100(O-N)		
						(F-E)				(G)																	
DOLO-C1	6.3	106.4	4273.1	2462.9	4286.6	1823.7	2.343	2.419	87.8	14.4	146.2	3.1	12.2	74.2	35.5	40.4	0.879										
DOLO-C2	6.3	105.9	4261.7	2460.0	4274.1	1814.1	2.349	2.419	88.0	14.4	146.6	2.9	12.0	75.9	35.4	40.4	0.875										
DOLO-C3	6.3	106.0	4262.4	2458.5	4272.4	1813.9	2.350	2.419	88.1	14.4	146.6	2.9	11.9	76.0	35.3	40.4	0.874										
												3.0	12.0	75.4	35.4	40.4	0.876										

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gse = Effective Specific Gravity of Aggregate
 Gb = Specific Gravity of Asphalt Cement

Table E5.5: Results from Asphalt Cement Optimization for Dolomite using 100 Revolutions of the SGC
National Center for Asphalt Technology
SMA Mix Design Summary

OPTIMUM GRADATION--20% Passing 4.75mm Sieve

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIAL: Indiana Dolomite/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:				Percent Coarse Aggregate: 80			DATE: December 13, 1996	
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gs) Effective Sp. Gr. of Agg. (Gs) Bulk Sp. Gr. of Agg. (Gsb)= 2.720 2.627 2.517						Bulk Specific Gravity of CA (Gca): 2.452				Unit wt. of CA in DRC (pcf): 91.10			Unit wt. of CA in DRC (kg/m3): 1459.3	
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)			
						(F-E)	(F-E)		(Gsb)	(Gb)				O			
6.5-1	6.5	111.6	4281.5	2409.3	4293.8	1884.5	2.272	2.384	84.4	14.4	141.8	4.7	15.6	69.9	30.7	40.4	0.759
6.5-2	6.5	111.4	4260.7	2393.9	4274.0	1880.1	2.266	2.384	84.2	14.4	141.4	4.9	15.8	68.8	30.9	40.4	0.764
6.5-3	6.5	111.8	4261.3	2408.2	4286.7	1878.5	2.268	2.384	84.3	14.4	141.6	4.8	15.7	69.2	30.8	40.4	0.762
AVG												4.8	15.7	69.3	30.8	40.4	0.762
7.0-1	7.0	110.5	4290.4	2418.4	4296.4	1878.0	2.285	2.368	84.4	15.6	142.6	3.5	15.6	77.4	30.7	40.4	0.759
7.0-2	7.0	111.1	4268.5	2406.4	4278.6	1872.2	2.280	2.368	84.2	15.6	142.3	3.7	15.8	76.4	30.8	40.4	0.762
7.0-3	7.0	111.7	4290.2	2415.5	4301.9	1886.4	2.274	2.368	84.0	15.5	141.9	4.0	16.0	75.2	31.0	40.4	0.767
AVG												3.7	15.8	76.3	30.8	40.4	0.763
7.5-1	7.5	111.3	4286.7	2414.4	4293.9	1879.5	2.281	2.351	83.8	16.7	142.3	3.0	16.2	81.5	31.2	40.4	0.771
7.5-2	7.5	110.8	4287.8	2419.6	4295.7	1876.1	2.285	2.351	84.0	16.7	142.6	2.8	16.0	82.6	31.0	40.4	0.767
7.5-3	7.5	111.4	4266.4	2394.2	4274.6	1880.4	2.269	2.351	83.4	16.6	141.6	3.5	16.6	79.0	31.5	40.4	0.780
AVG												3.1	16.3	81.0	31.2	40.4	0.773

Computed By: G. FLOWERS Checked By: T.LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

**Table E5.6: Various Test Results for Dolomite SMA Mixtures Compacted with the SGC
NCHRP 9-8
SHRP SMA Mix Properties**

Marshall Stability				Marshall Flow	
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
Average			ERR	Average ERR	

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
Average		ERR

Permeability						
	Specimen A		Specimen B		Average	
Blows	VTM	k(in/min)	VTM	k(in/min)	VTM	k(in/min)
10	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A
50	N/A	N/A	N/A	N/A	N/A	N/A

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number		
				Average
	25			ERR
	4			ERR
	40			ERR

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number		
				Average
	3600			ERR
	4500			ERR

Moisture Susceptibility											
without Lime Conditioned					with 1% Lime Conditioned						
Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)						
Unconditioned					Unconditioned						
Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)						
Tensile Strength Ratio (%)					Tensile Strength Ratio (%)						

Draindown (%)	Test Temp (deg C)	Sample Number		
		A	B	Average
	140	0.008	0.032	0.006
	155	0.016	0.008	0.029
	170	0.024	0.000	0.020

Aggregate Breakdown Sieve Analysis					
Sieve (mm)	Optimum Gradation	SHRP 100 Revolutions			
		1	2	3	Average
19	100.0	100.0	100.0	100.0	100.0
12.5	90.0	91.3	92.1	92.0	91.8
9.5	52.0	59.1	57.5	59.0	58.5
4.75	20.0	29.7	29.4	30.0	29.7
2.36	17.0	21.5	20.8	22.0	21.4
1.18	15.0	18.2	17.4	18.7	18.1
0.6	13.0	15.8	15.0	16.3	15.7
0.3	12.0	14.5	13.7	15.0	14.4
0.15	11.0	13.2	12.4	13.7	13.1
0.75	10.0	11.1	10.3	11.6	11.0

**Table E5.7: Voids in the Coarse Aggregate Test Results for Dolomite
NCHRP 9-8
Marshall & SHRP SMA Mix Properties**

Voids in th Course Aggregate (VCA) and Sieve Analysis																		
Sieve (mm)	Batched Gradation	Actual Tested Gradation	D.R.U.W. Method				Troxler SGC Method											
			D.R.U.W. (pcf)			average	75 Revolutions				100 Revolutions				125 Revolutions			
			91.0	91.2	91.2		91.1				average				average			
19	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
12.5	87.5	91.3	92.7	92.2	91.2	92.0	93.1	92.8	92.2	92.7	92.9	92.6	92.0	92.5	91.5	92.4	93.1	92.3
9.5	40	40.9	43.9	43.3	43.0	43.4	48.9	48.9	49.5	49.1	49.9	50.0	51.0	50.3	48.7	48.7	48.4	48.6
4.75	0	6.8	8.4	7.9	6.4	7.6	20.8	20.3	20.9	20.7	20.5	22.1	21.9	21.5	22.1	22.6	22.4	22.4
2.36		0.4	0.7	0.7	0.8	0.7	7.5	7.0	7.5	7.3	7.6	8.1	8.0	7.9	8.0	8.4	7.7	8.0
1.18		0.3	0.6	0.6	0.7	0.6	5.2	4.4	4.9	4.8	5.0	5.2	5.1	5.1	5.2	5.6	4.9	5.2
0.6		0.3	0.6	0.6	0.7	0.6	3.9	3.2	3.8	3.6	3.8	3.8	3.7	3.8	3.9	4.1	3.5	3.8
0.3		0.3	0.6	0.6	0.7	0.6	3.3	2.5	3.1	3.0	3.1	3.0	3.0	3.0	3.1	3.3	2.7	3.0
0.15		0.3	0.5	0.5	0.7	0.6	2.8	2.1	2.7	2.5	2.6	2.6	2.5	2.6	2.7	2.3	1.8	2.3
0.75		0.3	0.5	0.5	0.6	0.5	2.4	1.7	2.2	2.1	2.2	2.1	2.1	2.1	2.2	2.3	1.8	2.1
VCA (%)	N/A	N/A	40.5	40.4	40.4	40.4	30.3	31.0	30.6	30.6	30.3	29.9	29.7	30.0	28.8	28.8	29.3	29.0

Table E5.10: Results for Dolomite Dense-Graded Mixture Design Compacted with Nmax=208 Revolutions of the SGC
National Center for Asphalt Technology
Dense Mix Design Summary

Dense Mix Gradation

SHRP N-MAX=208 REV

PROJECT: NCHRP 9-8			MATERIALS: Dolomite\Dolcito\Ergon AC-20						COARSE AGGREGATE INFORMATION:										44 DATE: January 30, 1996		
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa})= 2.738		Effective Sp. Gr. of Agg. (G _{se})= 2.722		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.486			Percent Coarse Aggregate: 2.702			Bulk Specific Gravity of CA (G _{ca}): N/A			Unit wt. of CA in DRC (pcf): N/A			Unit wt. of CA in DRC (kg/m ³): N/A		
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS								
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (G _{mb})	TMD (G _{mm})	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc				
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S				
						(F-E)	D		(100-B) x I	B x I	(1 x 62.4)	100(1-I/J)	(100-K)	100(O-N)							
4.5-1	4.5	104.9	4239.8	2439.8	4260.9	1821.1	2.328	2.457	89.4	10.2	145.3	5.2	10.6	50.4	63.8	N/A	N/A				
4.5-2	4.5	105.0	4264.3	2455.4	4278.6	1823.2	2.339	2.457	89.8	10.3	145.9	4.8	10.2	52.6	63.6	N/A	N/A				
Avg												5.0	10.4	51.5	63.7	N/A	N/A				
5.0-1	5.0	104.8	4282.2	2473.4	4292.1	1818.7	2.355	2.439	90.0	11.5	146.9	3.5	10.0	65.5	63.6	N/A	N/A				
5.0-2	5.0	104.6	4285.1	2477.7	4293.0	1815.3	2.361	2.439	90.2	11.5	147.3	3.2	9.8	67.2	63.5	N/A	N/A				
Avg												3.3	9.9	66.3	63.5	N/A	N/A				
5.5-1	5.5	103.5	4289.6	2488.6	4292.3	1803.7	2.378	2.421	90.4	12.8	148.4	1.8	9.6	81.6	63.4	N/A	N/A				
5.5-2	5.5	103.7	4302.6	2499.1	4305.5	1806.4	2.382	2.421	90.5	12.8	148.6	1.6	9.5	82.9	63.3	N/A	N/A				
Avg												1.7	9.5	82.2	63.4	N/A	N/A				

Computed By: S.BUCHANNAN
 SSD = Saturated Surface Dry
 Sp. Gr. = Specific Gravity
 TMD = Theoretical Maximum Density
 gm = gram
 cc = cubic centimeter
 AC = Asphalt Cement
 pcf = pounds per cubic foot
 in = inches
 Checked By: T. LYNN
 G_{mb} = Bulk Specific Gravity of Compacted Mix
 G_{mm} = Theoretical Maximum Specific Gravity of Mix
 G_{sa} = Apparent Specific Gravity of Aggregate
 G_b = Bulk Specific Gravity of Aggregate
 G_{se} = Effective Specific Gravity of Aggregate
 G_c = Specific Gravity of Asphalt Cement

Table E6.1: Results from Aggregate Gradation Optimization for Limestone (2) using 50-Blow Marshall Hammer
National Center for Asphalt Technology
SMA Trial Gradation Summary

GRADATION A--20% Passing 4.75-mm Sieve

MARSHALL 50 BLOW

PROJECT: NCHRP9-8			MATERIALS: Texas Limestone/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:										
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa}) = 2.689		Effective Sp. Gr. of Agg. (G _{se}) = 2.542		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.505			Percent Coarse Aggregate: 80					DATE: December 5, 1995				
										Bulk Specific Gravity of CA (G _{ca}): 2.463					Unit wt. of CA in DRC (pcf): 92.90				
										Unit wt. of CA in DRC (kg/m ³): 1488.1									
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS						
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc		
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S		
						(F-E)	D		(100-B) x I	B x I	(1 x 62.4)	100(1-I/J)	(100-K)	O					
						(F-E)	(F-E)		(Gsb)	(Gb)									
TXLMS-A1	6.3	2.652	1217.5	686.0	1219.4	533.4	2.283	2.325	85.4	14.0	142.4	1.8	14.6	87.5	30.5	39.5	0.773		
TXLMS-A2	6.3	2.626	1210.6	682.4	1212.0	529.6	2.286	2.325	85.5	14.0	142.6	1.7	14.5	88.4	30.4	39.5	0.770		
TXLMS-A3	6.3	2.644	1217.3	683.9	1219.1	535.2	2.274	2.325	85.1	14.0	141.9	2.2	14.9	85.4	30.8	39.5	0.779		
												1.9	14.7	87.1	30.6	39.5	0.774		

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

GRADATION B--24% Passing 4.75-mm Sieve

MARSHALL 50 BLOW

PROJECT: NCHRP9-8			MATERIALS: Texas Limestone/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:										
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa}) = 2.691		Effective Sp. Gr. of Agg. (G _{se}) = 2.539		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.504			Percent Coarse Aggregate: 76					DATE: December 5, 1995				
										Bulk Specific Gravity of CA (G _{ca}): 2.463					Unit wt. of CA in DRC (pcf): 92.90				
										Unit wt. of CA in DRC (kg/m ³): 1488.1									
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS						
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc		
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S		
						(F-E)	D		(100-B) x I	B x I	(1 x 62.4)	100(1-I/J)	(100-K)	O					
						(F-E)	(F-E)		(Gsb)	(Gb)									
TXLMS-B1	6.3	2.570	1193.0	673.1	1194.2	521.1	2.289	2.323	85.6	14.1	142.9	1.4	14.4	89.9	30.3	39.5	0.767		
TXLMS-B2	6.3	2.587	1216.7	691.8	1217.5	525.7	2.314	2.323	86.6	14.2	144.4	0.4	13.4	97.3	29.6	39.5	0.748		
TXLMS-B3	6.3	2.583	1219.3	693.0	1219.9	526.9	2.314	2.323	86.6	14.2	144.4	0.4	13.4	97.1	29.6	39.5	0.748		
												0.7	13.7	94.8	29.8	39.5	0.755		

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

GRADATION C--28% Passing 4.75-mm Sieve

MARSHALL 50 BLOW

PROJECT: NCHRP9-8			MATERIALS: Texas Limestone/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:										
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa}) = 2.693		Effective Sp. Gr. of Agg. (G _{se}) = 2.544		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.502			Percent Coarse Aggregate: 72					DATE: December 5, 1995				
										Bulk Specific Gravity of CA (G _{ca}): 2.463					Unit wt. of CA in DRC (pcf): 92.90				
										Unit wt. of CA in DRC (kg/m ³): 1488.1									
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS						
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc		
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S		
						(F-E)	D		(100-B) x I	B x I	(1 x 62.4)	100(1-I/J)	(100-K)	O					
						(F-E)	(F-E)		(Gsb)	(Gb)									
TXLMS-C1	6.3	2.561	1213.5	691.3	1214.4	523.1	2.320	2.327	86.8	14.3	144.8	0.3	13.2	97.7	29.4	39.5	0.744		
TXLMS-C2	6.3	2.559	1219.9	696.0	1220.4	524.4	2.326	2.327	87.0	14.3	145.2	0.0	13.0	99.8	29.2	39.5	0.739		
TXLMS-C3	6.3	2.567	1213.8	691.7	1214.5	522.8	2.322	2.327	86.8	14.3	144.9	0.2	13.2	98.3	29.3	39.5	0.742		
												0.2	13.1	98.6	29.3	39.5	0.742		

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

Table E6.2: Results from Asphalt Cement Optimization for Limestone (2) using 50-Blow Marshall Hammer
National Center for Asphalt Technology
SMA Trial Gradation Summary

OPTIMUM GRADATION--20% PASSING 4.75mm SIEVE

MARSHALL 50 BLOW

PROJECT: NCHRP9-8			MATERIAL: Texas Limestone/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate: 80		DATE: FEBRUARY 13, 1996	
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gs Effective Sp. Gr. of Agg. (Gs Bulk Sp. Gr. of Agg. (Gsb) = 2.689 2.554 2.505)											Bulk Specific Gravity of CA (Gca): 2.463			
														Unit wt. of CA in DRC (pcf): 92.90			
														Unit wt. of CA in DRC (kg/m3): 1488.1			
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUM	SPECIFIC GRAVITY			VOLUMES			VOIDS				
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D (F-E)		(100-B) x I (Gsb)	B x I (Gb)	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)			
5.0-1	5.0	2.724	1205.2	674.6	1213.4	538.8	2.237	2.376	84.8	10.9	139.6	5.9	15.2	61.4	31.0	39.5	0.784
5.0-2	5.0	2.717	1210.3	678.2	1218.4	540.2	2.240	2.376	85.0	10.9	139.8	5.7	15.0	62.1	30.9	39.5	0.781
5.0-3	5.0	2.702	1204.7	673.3	1210.0	536.7	2.245	2.376	85.1	10.9	140.1	5.5	14.9	62.8	30.7	39.5	0.778
AVG												5.7	15.0	62.1	30.9	39.5	0.781
5.5-1	5.5	2.701	1211.1	675.3	1215.6	540.3	2.242	2.360	84.6	12.0	139.9	5.0	15.4	67.5	31.2	39.5	0.789
5.5-2	5.5	2.699	1210.8	676.5	1214.6	538.1	2.250	2.360	84.9	12.1	140.4	4.7	15.1	69.2	30.9	39.5	0.783
5.5-3	5.5	2.677	1203.4	675.3	1207.0	531.7	2.263	2.360	85.4	12.1	141.2	4.1	14.6	72.0	30.5	39.5	0.772
AVG												4.6	15.1	69.6	30.9	39.5	0.782
6.0-1	6.0	2.698	1204.2	670.7	1208.5	537.8	2.239	2.343	84.0	13.1	139.7	4.4	16.0	72.3	31.6	39.5	0.800
6.0-2	6.0	2.700	1216.6	681.2	1220.1	538.9	2.258	2.343	84.7	13.2	140.9	3.6	15.3	76.1	31.1	39.5	0.786
6.0-3	6.0	2.699	1212.1	678.1	1215.9	537.8	2.254	2.343	84.6	13.2	140.6	3.8	15.4	75.3	31.2	39.5	0.789
6.0-4	6.0	2.653	1211.0	682.3	1213.0	530.7	2.282	2.343	85.6	13.4	142.4	2.6	14.4	81.9	30.3	39.5	0.767
6.0-5	6.0	2.668	1215.7	682.2	1217.9	535.7	2.269	2.343	85.2	13.3	141.6	3.1	14.8	78.8	30.7	39.5	0.777
AVG												3.5	15.2	76.9	31.0	39.5	0.784
6.5-1	6.5	2.656	1224.3	691.5	1226.2	534.7	2.290	2.327	85.5	14.5	142.9	1.6	14.5	89.0	30.5	39.5	0.771
6.5-2	6.5	2.674	1222.4	684.5	1223.9	539.4	2.266	2.327	84.6	14.4	141.4	2.6	15.4	83.1	31.2	39.5	0.789
6.5-3	6.5	2.662	1222.7	688.3	1224.3	536.0	2.281	2.327	85.1	14.5	142.3	2.0	14.9	86.7	30.7	39.5	0.777
AVG												2.1	14.9	86.3	30.8	39.5	0.779

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

**Table E6.3: Various Test Results for Limestone (2) SMA Mixtures Compacted with the Marshall Hammer
NCHRP 9-8
Marshall SMA Mix Properties**

Marshall Stability				Marshall Flow	
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
6	8007	0.93	7447	6	12.0
10	8452	0.93	7860	10	12.0
13	8229	0.93	7653	13	14.0
Average			7653	Average 12.7	

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
9	10898	998
15	9564	880
16	9341	869
Average		916

Permeability						
Blows	Specimen A		Specimen B		average	
	VTM	k(in/min)	VTM	k(in/min)	VTM	k(in/min)
10						
20						
30						
40						
50						

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number		
				Average
ERR	25			ERR
	4			ERR
	40			ERR

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number		
				Average
ERR	3600			ERR
	4500			ERR

Moisture Susceptibility									
without Lime					with 1% Lime				
Conditioned					Conditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
20BLOW	6.5	63.9	4448	382	18	6.5	69.7	6450	561
1	6.6	73.8	4748	413	21	6.2	72.8	6083	530
10	6.2	63.9	5393	468	25	6.1	71.6	6450	560
Average Tensile Strength (kPa)				421	Average Tensile Strength (kPa)				550
Unconditioned					Unconditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
25BLOW	6.2		9341	812	20	6.1		10787	943
6	6.6		9953	865	22	6.2		10120	882
9	6.5		8563	741	26	6.4		10398	907
Average Tensile Strength (kPa)				806	Average Tensile Strength (kPa)				911
Tensile Strength Ratio (%)				52.2	Tensile Strength Ratio (%)				60.4

Draindown (%)	Test Temp (deg C)	Sample Number		
		A	B	Average
0.013	140	0.017	0.041	0.013
	155	0.000	0.008	0.021
	170	0.057	0.008	0.037

Aggregate Breakdown Sieve Analysis					
Sieve (mm)	Optimum Gradation	Marshall 50 Blows			
		2	7	8	Average
19	100	100	100	100	100
12.5	90.0	92.9	92.9	93.2	93.0
9.5	52.0	60.2	63.5	63.3	62.3
4.75	20.0	33.9	34.3	34.5	34.2
2.36	17.0	23.3	23.0	23.5	23.3
1.18	15.0	19.5	19.3	19.8	19.5
0.6	13.0	16.6	16.3	16.7	16.5
0.3	12.0	14.9	14.7	15.0	14.9
0.15	11.0	13.3	13.1	13.4	13.3
0.75	10.0	11.2	10.9	11.2	11.1

Table E6.4: Results from Aggregate Gradation Optimization for Limestone (2) using 100 Revolutions of the SGC
National Center for Asphalt Technology
SMA Trial Gradation Summary

GRADATION A--20% Passing 4.75-mm Sieve

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIALS: Texas Limestone/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:				Percent Coarse Aggregate:				DATE:			
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa})= 2.689		Effective Sp. Gr. of Agg. (G _{se})= 2.602		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.505						Bulk Specific Gravity of CA (G _{ca}): 2.643		Unit wt. of CA in DRC (pcf): 92.90		Unit wt. of CA in DRC (kg/m ³): 1488.1		80 OCTOBER 26,1995	
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS								
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (G _{mb})	TMD (G _{mm})	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc			
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S			
						(F-E)	D	J	(100-B) x I	B x I	(1 x 62.4)	100(1-I/J)	(100-K)	100(O-N)						
						(F-E)	(F-E)		(G _b)	(G _b)				O						
TXLMS-A1	6.3	3.827	3889.9	2224.4	3892.0	1667.6	2.333	2.372	87.3	14.3	145.6	1.7	12.7	87.0	33.8	43.6	0.775			
TXLMS-A2	6.3	3.862	3859.0	2197.8	3865.1	1667.3	2.315	2.372	86.6	14.2	144.4	2.4	13.4	81.9	34.4	43.6	0.787			
TXLMS-A3	6.3	3.858	3873.1	2206.3	3877.7	1671.4	2.317	2.372	86.7	14.2	144.6	2.3	13.3	82.7	34.3	43.6	0.785			
																	83.9	34.2	43.6	0.783

Computed By: S. BUCHANAN Checked By: T. LYNN
 SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot G_{mb} = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches G_{mm} = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement G_{sa} = Apparent Specific Gravity of Aggregate G_{se} = Effective Specific Gravity of Aggregate
 G_{sb} = Specific Gravity of Asphalt Cement

GRADATION B--24% Passing 4.75-mm Sieve

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIALS: Texas Limestone/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:				Percent Coarse Aggregate:				DATE:			
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa})= 2.691		Effective Sp. Gr. of Agg. (G _{se})= 2.616		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.504						Bulk Specific Gravity of CA (G _{ca}): 2.643		Unit wt. of CA in DRC (pcf): 92.90		Unit wt. of CA in DRC (kg/m ³): 1488.1		76 OCTOBER 26,1995	
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS								
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (G _{mb})	TMD (G _{mm})	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc			
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S			
						(F-E)	D	J	(100-B) x I	B x I	(1 x 62.4)	100(1-I/J)	(100-K)	100(O-N)						
						(F-E)	(F-E)		(G _b)	(G _b)				O						
TXLMS-B1	6.3	3.752	3878.8	2229.5	3880.2	1650.7	2.350	2.383	87.9	14.4	146.6	1.4	12.1	88.5	33.4	43.6	0.764			
TXLMS-B2	6.3	3.74	3871.4	2230.4	3872.9	1642.5	2.357	2.383	88.2	14.5	147.1	1.1	11.8	90.8	33.2	43.6	0.760			
TXLMS-B3	6.3	3.768	3869.8	2226.7	3872.0	1645.3	2.352	2.383	88.0	14.5	146.8	1.3	12.0	89.2	33.3	43.6	0.763			
																	89.5	33.3	43.6	0.762

Computed By: S. BUCHANAN Checked By: T. LYNN
 SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot G_{mb} = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches G_{mm} = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement G_{sa} = Apparent Specific Gravity of Aggregate G_{se} = Effective Specific Gravity of Aggregate
 G_{sb} = Specific Gravity of Asphalt Cement

GRADATION C--28% Passing 4.75-mm Sieve

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIALS: Texas Limestone/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:				Percent Coarse Aggregate:				DATE:			
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa})= 2.693		Effective Sp. Gr. of Agg. (G _{se})= 2.607		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.502						Bulk Specific Gravity of CA (G _{ca}): 2.643		Unit wt. of CA in DRC (pcf): 92.90		Unit wt. of CA in DRC (kg/m ³): 1488.1		72 OCTOBER 26,1995	
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS								
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (G _{mb})	TMD (G _{mm})	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc			
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S			
						(F-E)	D	J	(100-B) x I	B x I	(1 x 62.4)	100(1-I/J)	(100-K)	100(O-N)						
						(F-E)	(F-E)		(G _b)	(G _b)				O						
TXLMS-C1	6.3	3.693	3864.5	2232.2	3865.1	1632.9	2.367	2.376	88.5	14.5	147.7	0.4	11.5	96.6	32.9	43.6	0.753			
TXLMS-C2	6.3	3.697	3875.6	2243.2	3876.5	1633.3	2.373	2.376	88.8	14.6	148.1	0.1	11.2	98.8	32.7	43.6	0.749			
TXLMS-C3	6.3	3.721	3878.9	2243.3	3880.9	1637.6	2.369	2.376	88.6	14.6	147.8	0.3	11.4	97.3	32.8	43.6	0.752			
																	97.6	32.8	43.6	0.752

Computed By: S. BUCHANAN Checked By: T. LYNN
 SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot G_{mb} = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches G_{mm} = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement G_{sa} = Apparent Specific Gravity of Aggregate G_{se} = Effective Specific Gravity of Aggregate
 G_{sb} = Specific Gravity of Asphalt Cement

Table E6.5: Results from Asphalt Cement Optimization for Limestone (2) using 100 Revolutions of the SGC
National Center for Asphalt Technology
SMA Trial Gradation Summary

OPTIMUM GRADATION--20% Passing 4.75mm Sieve

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIAL: Texas Limestone/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:							Percent Coarse Aggregate: 80		DATE: December 14, 1995	
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gs Effective Sp. Gr. of Agg. (Gse)- Bulk Sp. Gr. of Agg. (Gsb) = 2.689 2.598 2.505													Bulk Specific Gravity of CA (Gca): 2.643			
																Unit wt. of CA in DRC (pcf): 92.90			
																Unit wt. of CA in DRC (kg/m3): 1488.1			
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUM	SPECIFIC GRAVITY		VOLUMES			VOIDS							
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc		
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S		
						(F-E)	D (F-E)		(100-B) x I (Gsb)	B x I (Gb)	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N) O					
5.3-1	5.3	99.6	3879.8	2201.6	3893.6	1692.0	2.293	2.402	86.7	11.9	143.1	4.5	13.3	65.9	34.3	43.6	0.785		
5.3-2	5.3	99.5	3840.9	2176.7	3858.1	1681.4	2.284	2.402	86.4	11.8	142.5	4.9	13.6	64.1	34.5	43.6	0.791		
5.3-3	5.3	99.2	3852.0	2186.5	3869.7	1683.2	2.288	2.402	86.5	11.8	142.8	4.7	13.5	65.0	34.4	43.6	0.788		
AVG												4.7	13.5	65.0	34.4	43.6	0.788		
5.8-1	5.8	99.4	3852.7	2182.4	3865.2	1682.8	2.289	2.385	86.1	13.0	142.9	4.0	13.9	71.2	34.7	43.6	0.796		
5.8-2	5.8	99.2	3850.6	2185.3	3860.4	1675.1	2.299	2.385	86.4	13.0	143.4	3.6	13.6	73.3	34.5	43.6	0.790		
5.8-3	5.8	99.5	3863.2	2191.5	3876.8	1685.3	2.292	2.385	86.2	13.0	143.0	3.9	13.8	71.8	34.6	43.6	0.794		
AVG												3.8	13.8	72.1	34.6	43.6	0.793		
6.3-1	6.3	3.827	3889.9	2224.4	3892.0	1667.6	2.333	2.369	87.3	14.3	145.6	1.5	12.7	88.0	33.8	43.6	0.775		
6.3-2	6.3	3.862	3859.0	2197.8	3865.1	1667.3	2.315	2.369	86.6	14.2	144.4	2.3	13.4	82.9	34.4	43.6	0.787		
6.3-3	6.3	3.858	3873.1	2206.3	3877.7	1671.4	2.317	2.369	86.7	14.2	144.6	2.2	13.3	83.6	34.3	43.6	0.785		
AVG												2.0	13.2	84.8	34.2	43.6	0.783		

Computed By: G. FLOWERS

Checked By: T. LYNN

SSD = Saturated Surface Dry

gm = gram

pcf = pounds per cubic foot

Gmb = Bulk Specific Gravity of Compacted Mix

Gsb = Bulk Specific Gravity of Aggregate

Sp. Gr. = Specific Gravity

cc = cubic centimeter

in = inches

Gmm = Theoretical Maximum Specific Gravity of Mix

Gse = Effective Specific Gravity of Aggregate

TMD = Theoretical Maximum Density

AC = Asphalt Cement

Gsa = Apperant Specific Gravity of Aggregate

Gb = Specific Gravity of Asphalt Cement

**Table E6.6: Various Test Results for Limestone (2) SMA Mixtures Compacted with the SGC
NCHRP 9-8
SHRP SMA Mix Properties**

Marshall Stability				Marshall Flow	
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
Average			ERR	Average	
			ERR		

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
Average		ERR

Permeability						
	Specimen A		Specimen B		Average	
Blows	VTM	k(in/min)	VTM	k(in/min)	VTM	k(in/min)
10	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A
50	N/A	N/A	N/A	N/A	N/A	N/A

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number		
				Average
	25			ERR
	4			ERR
	40			ERR

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number		
				Average
	3600			ERR
	4500			ERR

Moisture Susceptibility											
without Lime Conditioned					with 1% Lime Conditioned						
Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)						
Unconditioned					Unconditioned						
Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)						
Tensile Strength Ratio (%)					Tensile Strength Ratio (%)						

Draindown (%)	Test Temp (deg C)	Sample Number		
		A	B	Average
	140	0.000	0.000	0.004
	155	0.016	0.008	0.008
	170	0.008	0.041	0.017

Aggregate Breakdown Sieve Analysis						
Sieve (mm)	Optimum Gradation	SHRP 100 Revolutions				Average
		1	2	3		
19	100.0	100.0	100.0	100.0	100.0	
12.5	90.0	93.2	92.5	92.6	92.8	
9.5	52.0	58.5	58.3	59.0	58.6	
4.75	20.0	31.0	30.9	31.4	31.1	
2.36	17.0	22.7	22.2	22.5	22.5	
1.18	15.0	19.5	18.9	19.3	19.2	
0.6	13.0	16.9	16.3	16.7	16.6	
0.3	12.0	15.2	14.8	15.2	15.1	
0.15	11.0	13.6	13.2	13.7	13.5	
0.75	10.0	11.2	10.8	11.4	11.1	

Table E6.7: Voids in the Coarse Aggregate Test Results for Limestone (2)

**NCHRP 9-8
Marshall & SHRP SMA Mix Properties**

Voids in th Course Aggregate (VCA) and Sieve Analysis																		
Sieve (mm)	Batched Gradation	Actual Tested Gradation	D.R.U.W. Method				Troxler SGC Method											
			D.R.U.W. (pcf)			average	75 Revolutions				100 Revolutions				125 Revolutions			
			92.9	92.9	92.9		92.9	75	75	75	average	100	100	100	average	125	125	125
19	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
12.5	87.5	85.0	87.0	90.6	88.6	88.7	85.8	89.5	87.0	88.7	88.9	91.4	87.2	89.2	89.8	83.7	92.2	88.6
9.5	40.0	42.8	43.6	43.8	43.8	43.7	48.3	49.3	49.1	48.9	49.2	49.7	50.2	49.7	49.5	48.7	48.4	48.9
4.75	0.0	5.2	4.6	4.6	4.9	4.7	14.5	16.1	16.0	15.5	15.8	18.2	15.0	16.3	16.5	16.5	16.8	16.6
2.36		1.0	0.7	0.8	0.8	0.8	6.3	6.5	6.3	6.4	6.7	7.5	6.6	6.9	7.0	7.0	7.4	7.1
1.18		0.9	0.7	0.8	0.8	0.8	4.3	4.4	4.4	4.4	4.7	5.3	4.6	4.9	5.0	4.9	5.2	5.0
0.6		0.9	0.7	0.8	0.8	0.8	3.2	3.2	3.2	3.2	3.3	3.8	3.3	3.5	3.6	3.5	3.7	3.6
0.3		0.8	0.7	0.7	0.8	0.7	2.4	2.2	2.4	2.3	2.5	2.9	2.5	2.6	2.8	2.7	2.8	2.8
0.15		0.8	0.6	0.7	0.7	0.7	1.9	1.9	1.9	1.9	1.9	2.2	1.9	2.0	2.2	2.0	2.1	2.1
0.75		0.8	0.4	0.6	0.7	0.6	1.5	1.5	1.5	1.5	1.4	1.7	1.4	1.5	1.7	1.6	1.7	1.7
VCA (%)	N/A	N/A	43.6	43.6	43.6	43.6	29.5	29.8	29.7	29.7	28.8	28.5	28.9	28.7	28.4	27.7	27.3	27.8

Table E6.8: Results for Limestone (2) Dense-Graded Mixture Design Compacted with 75-Blow Marshall Hammer
National Center for Asphalt Technology
Dense Mix Design Summary

Dense Mix Gradation

MARSHALL 75 BLOWS

PROJECT: NCHRP 9-8			MATERIALS: Texas Limestone\Ergon AC-20						COARSE AGGREGATE INFORMATION:									
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa})= 2.677		Effective Sp. Gr. of Agg. (G _{se})= 2.570		Bulk Sp. Gr. of Agg. (G _{sb})= 2.439		Percent Coarse Aggregate: 44			Bulk Specific Gravity of CA (G _{ca}): 2.463			DATE: January 29, 1996			
									Unit wt. of CA in DRC (pcf): N/A			Unit wt. of CA in DRC (kg/m ³): N/A						
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (G _{mb})	TMD (G _{mm})	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)				
							(F-E)		(Gsb)	(Gb)				O				
4.5-1	4.5	--	1203.3	677.8	1204.7	526.9	2.284	2.407	89.4	10.0	142.5	5.1	10.6	51.6	61.0	N/A	N/A	
4.5-2	4.5	--	1197.4	673.4	1199.1	525.7	2.278	2.407	89.2	10.0	142.1	5.4	10.8	50.4	61.1	N/A	N/A	
4.5-3	4.5	--	1202.0	676.4	1203.5	527.1	2.280	2.407	89.3	10.0	142.3	5.3	10.7	50.9	61.1	N/A	N/A	
Avg												5.2	10.7	51.0	61.1	N/A	N/A	
5.0-1	5.0	--	1208.7	685.1	1209.6	524.5	2.304	2.390	89.8	11.2	143.8	3.6	10.2	65.1	60.9	N/A	N/A	
5.0-2	5.0	--	1208.0	682.3	1208.9	526.6	2.294	2.390	89.4	11.2	143.1	4.0	10.6	62.3	61.1	N/A	N/A	
5.0-3	5.0	--	1203.2	681.6	1203.9	522.3	2.304	2.390	89.7	11.2	143.7	3.6	10.3	64.8	60.9	N/A	N/A	
Avg												3.7	10.4	64.1	61.0	N/A	N/A	
5.5-1	5.5	--	1206.5	686.5	1207.0	520.5	2.318	2.373	89.8	12.4	144.6	2.3	10.2	77.1	60.9	N/A	N/A	
5.5-2	5.5	--	1215.2	691.9	1215.7	523.8	2.320	2.373	89.9	12.4	144.8	2.2	10.1	77.8	60.8	N/A	N/A	
5.5-3	5.5	--	1215.7	692.6	1216.2	523.6	2.322	2.373	90.0	12.5	144.9	2.2	10.0	78.4	60.8	N/A	N/A	
Avg												2.3	10.1	77.7	60.8	N/A	N/A	

Computed By: S.BUCHANAN	Checked By: T. LYNN
SSD = Saturated Surface Dry Sp. Gr. = Specific Gravity TMD = Theoretical Maximum Density	gm = gram cc = cubic centimeter AC = Asphalt Cement
	pcf = pounds per cubic foot in = inches
	G _{mb} = Bulk Specific Gravity of Compacted Mix G _{mm} = Theoretical Maximum Specific Gravity of Mix G _{sa} = Apparent Specific Gravity of Aggregate
	G _{sb} = Bulk Specific Gravity of Aggregate G _{se} = Effective Specific Gravity of Aggregate G _b = Specific Gravity of Asphalt Cement

Table E6.10: Results for Limestone (2) Dense-Graded Mixture Design Compacted with Nmax=208 Revolutions of the SGC
National Center for Asphalt Technology
Dense Mix Design Summary

Dense Mix Gradation

SHRP N-MAX=208 REV

PROJECT: NCHRP 9-8			MATERIALS: Texas Limestone\Dolcito\Ergon AC-20						COARSE AGGREGATE INFORMATION:									
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa})= 2.677		Effective Sp. Gr. of Agg. (G _{se})= 2.679		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.641			Percent Coarse Aggregate: 44			DATE: January 30, 1996					
										Bulk Specific Gravity of CA (G _{ca}): 2.463			Unit wt. of CA in DRC (pcf): N/A		Unit wt. of CA in DRC (kg/m ³): N/A			
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (G _{mb})	TMD (G _{mm})	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D		(100-B) x I	B x I	(1 x 62.4)	100(1-I/J)	(100-K)	100(O-N)				
						(F-E)	(F-E)		(Gsb)	(G _b)			O					
4.5-1	4.5	99.4	4133.6	2404.7	4143.9	1739.2	2.377	2.498	85.9	10.4	148.3	4.8	14.1	65.6	59.5	N/A	N/A	
4.5-2	4.5	99.6	4150.5	2415.7	4157.3	1741.6	2.383	2.498	86.2	10.5	148.7	4.6	13.8	66.8	59.3	N/A	N/A	
Avg												4.7	13.9	66.2	59.4	N/A	N/A	
5.0-1	5.0	99.0	4155.2	2429.9	4157.8	1727.9	2.405	2.479	86.5	11.7	150.1	3.0	13.5	77.8	59.2	N/A	N/A	
5.0-2	5.0	99.5	4180.7	2447.2	4183.7	1736.5	2.408	2.479	86.6	11.7	150.2	2.9	13.4	78.5	59.1	N/A	N/A	
Avg												2.9	13.4	78.2	59.2	N/A	N/A	
5.5-1	5.5	98.5	4192.3	2469.4	4193.2	1723.8	2.432	2.461	87.0	13.0	151.8	1.2	13.0	91.0	58.9	N/A	N/A	
5.5-2	5.5	98.5	4189.3	2469.3	4190.3	1721.0	2.434	2.461	87.1	13.1	151.9	1.1	12.9	91.7	58.9	N/A	N/A	
Avg												1.1	12.9	91.4	58.9	N/A	N/A	

Computed By: S.BUCHANNAN Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot G_{mb} = Bulk Specific Gravity of Compacted Mix G_{sb} = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches G_{mm} = Theoretical Maximum Specific Gravity of Mix G_{se} = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement G_{sa} = Apparent Specific Gravity of Aggregate G_b = Specific Gravity of Asphalt Cement

Table E7.1: Results from Aggregate Gradation Optimization for Slag using 50-Blow Marshall Hammer
National Center for Asphalt Technology
SMA Trial Gradation Summary

GRADATION A - - 20% Passing 4.75 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP 9-8			MATERIALS: Slag/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:				Percent Coarse Aggregate:			DATE:	
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa)= 2.596		Effective Sp. Gr. of Agg. (Gse)= 2.442		Bulk Sp. Gr. of Agg. (Gsb) = 2.380						Bulk Specific Gravity of CA (Gca): 2.288			February 1, 1996	
			Unit wt. of CA in DRC (pcf): 81.30										Unit wt. of CA in DRC (kg/m ³): 1302.3				
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(1-IJ)	(100-K)	100(O-N)			
						(F-E)	(F-E)		(Gsb)	(Gsb)		O					
SLAG-A1	6.6	--	1176.0	624.3	1180.3	556.0	2.115	2.238	83.0	13.6	132.0	5.5	17.0	67.7	30.9	43.0	0.719
SLAG-A2	6.6	--	1175.1	626.1	1178.5	552.4	2.127	2.238	83.5	13.7	132.7	4.9	16.5	70.0	99.9	43.0	2.323
SLAG-A3	6.6	--	1178.8	622.2	1178.2	556.0	2.120	2.238	83.2	13.7	132.3	5.3	16.8	68.6	99.9	43.0	2.321
												5.2	16.8	68.8	76.9	43.0	1.788

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gse = Effective Specific Gravity of Aggregate
 Gsb = Bulk Specific Gravity of Aggregate Gca = Bulk Specific Gravity of CA
 Gc = Specific Gravity of Asphalt Cement

GRADATION B - - 24% Passing 4.75 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP9-8			MATERIALS: Slag/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:				Percent Coarse Aggregate:			DATE:	
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa)= 2.608		Effective Sp. Gr. of Agg. (Gse)= 2.437		Bulk Sp. Gr. of Agg. (Gsb) = 2.397						Bulk Specific Gravity of CA (Gca): 2.288			February 1, 1996	
			Unit wt. of CA in DRC (pcf): 81.30										Unit wt. of CA in DRC (kg/m ³): 1302.3				
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(1-IJ)	(100-K)	100(O-N)			
						(F-E)	(F-E)		(Gsb)	(Gsb)		O					
SLAG-B1	6.6	--	1178.3	636.1	1181.3	545.2	2.161	2.234	84.8	13.9	134.9	3.3	15.2	78.5	32.9	43.0	0.766
SLAG-B2	6.6	--	1171.7	634.8	1174.4	539.6	2.171	2.234	85.2	14.0	135.5	2.8	14.8	81.1	99.9	43.0	2.323
SLAG-B3	6.6	--	1176.4	636.0	1179.3	543.3	2.165	2.234	85.0	13.9	135.1	3.1	15.0	79.5	99.9	43.0	2.321
												3.0	15.0	79.7	77.6	43.0	1.803

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gse = Effective Specific Gravity of Aggregate
 Gsb = Bulk Specific Gravity of Aggregate Gca = Bulk Specific Gravity of CA
 Gc = Specific Gravity of Asphalt Cement

GRADATION C - - 28% Passing 4.75 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP9-8			MATERIALS: Slag/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:				Percent Coarse Aggregate:			DATE:	
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa)= 2.620		Effective Sp. Gr. of Agg. (Gse)= 2.447		Bulk Sp. Gr. of Agg. (Gsb) = 2.414						Bulk Specific Gravity of CA (Gca): 2.288			February 1, 1996	
			Unit wt. of CA in DRC (pcf): 81.30										Unit wt. of CA in DRC (kg/m ³): 1302.3				
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(1-IJ)	(100-K)	100(O-N)			
						(F-E)	(F-E)		(Gsb)	(Gsb)		O					
SLAG-C1	6.6	--	1176.1	638.1	1177.8	539.7	2.179	2.242	85.5	14.0	136.0	2.8	14.5	80.6	36.0	43.0	0.836
SLAG-C2	6.6	--	1176.4	643.3	1178.8	535.5	2.197	2.242	86.2	14.1	137.1	2.0	13.8	85.4	99.9	43.0	2.323
SLAG-C3	6.6	--	1182.9	646.1	1185.7	539.6	2.192	2.242	86.0	14.1	136.8	2.2	14.0	84.1	99.9	43.0	2.321
												2.3	14.1	83.4	78.6	43.0	1.827

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gse = Effective Specific Gravity of Aggregate
 Gsb = Bulk Specific Gravity of Aggregate Gca = Bulk Specific Gravity of CA
 Gc = Specific Gravity of Asphalt Cement

Table E7.2: Results from Asphalt Cement Optimization for Slag using 50-Blow Marshall Hammer
National Center for Asphalt Technology
SMA Mix Design Summary

OPTIMUM GRADATION - - 20% Passing 4.75 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP 9-8			MATERIAL: Slag/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate:			80	DATE:	
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gs Effective Sp. Gr. of Agg. (Gse) Bulk Sp. Gr. of Agg. (Gsb)											Bulk Specific Gravity of CA (Gca):			2.288	FEBRUARY 1, 1996	
			2.596		2.469		2.380							Unit wt. of CA in DRC (pcf):			81.30		
															Unit wt. of CA in DRC (kg/m ³):			1302.3	
Specimen Number	Asphalt Content (%)	Average Thickness (inches)	WEIGHTS			MIX VOLUM	SPECIFIC GRAVITY		VOLUMES			VOIDS							
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc		
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S		
						(F-E)	$\frac{D}{(F-E)}$		$\frac{(100-B) \times I}{(Gsb)}$	$\frac{B \times I}{(Gb)}$	(I x 62.4)	100(1-I/J)	(100-K)	$\frac{100(O-N)}{O}$					
7.0-1	7.0	2.766	1163.3	623.2	1170.8	547.6	2.124	2.247	83.0	14.5	132.6	5.5	17.0	67.8	30.9	43.0	0.719		
7.0-2	7.0	2.814	1170.3	621.5	1176.6	555.1	2.108	2.247	82.4	14.4	131.6	6.2	17.6	64.9	31.4	43.0	0.731		
7.0-3	7.0	2.825	1176.3	625.9	1180.8	554.9	2.120	2.247	82.8	14.5	132.3	5.7	17.2	67.0	31.1	43.0	0.722		
AVG												5.8	17.3	66.5	31.1	43.0	0.724		
7.5-1	7.5	2.778	1174.1	628.1	1177.9	549.8	2.136	2.233	83.0	15.6	133.3	4.4	17.0	74.3	30.9	43.0	0.719		
7.5-2	7.5	2.812	1176.6	623.2	1180.0	556.8	2.113	2.233	82.1	15.5	131.9	5.4	17.9	70.0	31.7	43.0	0.736		
7.5-3	7.5	2.793	1172.5	625.6	1177.0	551.4	2.126	2.233	82.6	15.6	132.7	4.8	17.4	72.5	31.2	43.0	0.726		
AVG												4.8	17.4	72.3	31.3	43.0	0.727		
8.0-1	8.0	2.812	1183.3	626.8	1186.7	559.9	2.113	2.219	81.7	16.5	131.9	4.8	18.3	74.0	32.0	43.0	0.744		
8.0-2	8.0	2.835	1183.0	625.4	1186.2	560.8	2.109	2.219	81.5	16.5	131.6	4.9	18.5	73.3	32.1	43.0	0.747		
8.0-3	8.0	2.838	1172.5	618.8	1172.5	553.7	2.118	2.219	81.9	16.5	132.1	4.6	18.1	74.8	31.9	43.0	0.741		
AVG												4.7	18.3	74.1	32.0	43.0	0.744		
7.0-1	7.0	0.000	0.0	0.0	0.0	0.0	ERR	2.247	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	43.0	ERR	
7.0-2	7.0	0.000	0.0	0.0	0.0	0.0	ERR	2.247	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	43.0	ERR
7.0-3	7.0	0.000	0.0	0.0	0.0	0.0	ERR	2.247	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	43.0	ERR
AVG												ERR	ERR	ERR	ERR	ERR	ERR	43.0	ERR
7.5-1	7.5	0.000	0.0	0.0	0.0	0.0	ERR	2.233	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	43.0	ERR
7.5-2	7.5	0.000	0.0	0.0	0.0	0.0	ERR	2.233	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	43.0	ERR
7.5-3	7.5	0.000	0.0	0.0	0.0	0.0	ERR	2.233	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	43.0	ERR
AVG												ERR	ERR	ERR	ERR	ERR	ERR	43.0	ERR

Computed By: G. FLOWERS

Checked By: T. LYNN

SSD = Saturated Surface Dry
 Sp. Gr. = Specific Gravity
 TMD = Theoretical Maximum Density

gm = gram
 cc = cubic centimeter
 AC = Asphalt Cement
 pcf = pounds per cubic foot
 in = inches

Gmb = Bulk Specific Gravity of Compacted Mix
 Gmm = Theoretical Maximum Specific Gravity of Mix
 Gsa = Apparent Specific Gravity of Aggregate

Gsb = Bulk Specific Gravity of Aggregate
 Gse = Effective Specific Gravity of Aggregate
 Gb = Specific Gravity of Asphalt Cement

**Table E7.3: Various Test Results for Slag SMA Mixtures Compacted with the Marshall Hammer
NCHRP 9-8
Marshall SMA Mix Properties**

Marshall Stability				Marshall Flow	
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
4	11565	0.89	10293	4	15.0
5	11343	0.89	10095	5	12.0
6	9786	0.89	8710	6	17.0
Average			9699	Average 14.7	

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
2	10231	898
7	10008	884
14	9119	814
Average		865

Permeability						
	Specimen A		Specimen B		average	
Blows	VTM	k(in/min)	VTM	k(in/min)	VTM	k(in/min)
10	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A
50	N/A	N/A	N/A	N/A	N/A	N/A

Moisture Susceptibility									
without Lime					with 1% Lime				
Conditioned					Conditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
55BLOW	5.7	65.2	7562	669	5.9	60.5	7896	7896	702
2	7.0	71.2	6939	606	5.7	75.6	6784	6784	603
10	5.8	69.2	7784	686	6.2	57.1	8118	8118	725
Average Tensile Strength (kPa)				654	Average Tensile Strength (kPa)				677
Unconditioned					Unconditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
1	6.4	N/A	10676	942	1	5.9	N/A	10342	923
4	5.6	N/A	12566	1107	2	6.3	N/A	11565	1032
5	6.7	N/A	11743	1027	7	5.8	N/A	11788	1051
Average Tensile Strength (kPa)				1025	Average Tensile Strength (kPa)				1002
Tensile Strength Ratio (%)				63.8	Tensile Strength Ratio (%)				67.5

Aggregate Breakdown Sieve Analysis					
Sieve (mm)	Optimum Gradation	Marshall 50 Blows			
		8	18	30	Average
19	100	100	100	100	100
12.5	90.0	92.5	91.8	91.4	91.9
9.5	52.0	67.0	66.0	65.9	66.3
4.75	20.0	32.9	34.0	33.1	33.3
2.36	17.0	24.5	24.9	25.0	24.8
1.18	15.0	19.9	20.1	20.4	20.1
0.6	13.0	16.4	16.6	16.9	16.6
0.3	12.0	14.3	14.4	14.7	14.5
0.15	11.0	12.2	12.3	12.7	12.4
0.75	10.0	9.8	9.9	10.2	10.0

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number		
				Average
	25			ERR
	4			ERR
40			ERR	

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number		
				Average
	3600			ERR
	4500			ERR

Draindown (%)	Test Temp (deg C)	Sample Number		
		A	B	Average
	140	0.008	0.008	0.008
	155	0.042	0.000	0.042
170	0.016	0.008	0.016	

Table E7.4: Results from Aggregate Gradation Optimization for Slag using 100 Revolutions of the SGC
National Center for Asphalt Technology
SMA Trial Gradation Summary

GRADATION A--20% Passing 4.75-mm Sieve

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIALS: Slag/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate:		DATE:		
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa)= 2.596		Effective Sp. Gr. of Agg. (Gsc)= 2.524		Bulk Sp. Gr. of Agg. (Gsb) = 2.380								80		January 24, 1996	
															2.288			
															81.30			
															1302.3			
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D	J	(100-B) x I	B x I	(1 x 62.4)	100(1-U)	(100-K)	100(O-N)				
						(F-E)	(F-E)		(Gsb)	(Gb)				O				
SLAG7.5-A1	7.5	105.1	3757.9	1996.1	3770.8	1774.7	2.117	2.275	82.3	15.5	132.1	6.9	17.7	60.9	31.5	43.0	0.732	
SLAG7.5-A2	7.5	105.2	3734.3	1993.0	3754.4	1761.4	2.120	2.275	82.4	15.5	132.3	6.8	17.6	61.3	31.4	43.0	0.731	
SLAG7.5-A3	7.5	105.2	3730.5	1980.0	3748.4	1768.4	2.110	2.275	82.0	15.4	131.6	7.3	18.0	59.6	31.8	43.0	0.738	
												7.0	17.8	60.6	31.6	43.0	0.734	

Computed By: G.FLOWERS Checked By: T.LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

GRADATION B--24% Passing 4.75-mm Sieve

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIALS: Slag/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate:		DATE:		
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa)= 2.608		Effective Sp. Gr. of Agg. (Gsc)= 2.489		Bulk Sp. Gr. of Agg. (Gsb) = 2.397								76		January 24, 1996	
															2.288			
															81.30			
															1302.3			
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D	J	(100-B) x I	B x I	(1 x 62.4)	100(1-U)	(100-K)	100(O-N)				
						(F-E)	(F-E)		(Gsb)	(Gb)				O				
SLAG7.5-B1	7.5	103.2	3712.6	1994.4	3725.9	1731.5	2.144	2.248	83.3	15.7	133.8	4.6	16.7	72.3	30.7	43.0	0.712	
SLAG7.5-B2	7.5	102.5	3729.6	2014.1	3739.6	1725.5	2.161	2.248	84.0	15.8	134.9	3.8	16.0	75.9	30.1	43.0	0.699	
SLAG7.5-B3	7.5	103.6	3714.5	2002.1	3728.8	1726.7	2.151	2.248	83.6	15.7	134.2	4.3	16.4	73.7	30.4	43.0	0.707	
												4.3	16.4	74.0	30.4	43.0	0.706	

Computed By: G.FLOWERS Checked By: T.LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

GRADATION C--28% Passing 4.75-mm Sieve

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIALS: Slag/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate:		DATE:		
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa)= 2.620		Effective Sp. Gr. of Agg. (Gsc)= 2.514		Bulk Sp. Gr. of Agg. (Gsb) = 2.414								72		January 24, 1996	
															2.288			
															81.30			
															1302.3			
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D	J	(100-B) x I	B x I	(1 x 62.4)	100(1-U)	(100-K)	100(O-N)				
						(F-E)	(F-E)		(Gsb)	(Gb)				O				
SLAG7.5-C1	7.5	100.4	3742.8	2042.8	3748.3	1705.5	2.195	2.267	85.3	16.1	136.9	3.2	14.7	78.3	29.0	43.0	0.675	
SLAG7.5-C2	7.5	100.0	3728.4	2045.9	3737.0	1691.1	2.205	2.267	85.7	16.1	137.6	2.7	14.3	80.8	28.7	43.0	0.667	
SLAG7.5-C3	7.5	99.9	3706.9	2025.5	3714.0	1688.5	2.195	2.267	85.3	16.1	137.0	3.2	14.7	78.5	29.0	43.0	0.674	
												3.0	14.6	79.2	28.9	43.0	0.672	

Computed By: G.FLOWERS Checked By: T.LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

Table E7.5: Results from Asphalt Cement Optimization for Slag using 100 Revolutions of the SGC
National Center for Asphalt Technology
SMA Mix Design Summary

OPTIMUM GRADATION--20% Passing 4.75mm Sieve

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIAL: Slag/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate: 80		DATE: December 13, 1995	
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gs Effective Sp. Gr. of Agg. (Gse) Bulk Sp. Gr. of Agg. (Gsb) = 2.596 2.524 2.380											Bulk Specific Gravity of CA (Gca): 2.288			
														Unit wt. of CA in DRC (pcf): 81.30			
														Unit wt. of CA in DRC (kg/m ³): 1302.3			
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUM	SPECIFIC GRAV	VOLUMES			VOIDS						
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)			
						(F-E)	(Gsb)		(G)	(G)							
7.5-1	7.5	105.1	3757.9	1996.1	3770.8	1774.7	2.117	2.275	82.3	15.5	132.1	6.9	17.7	60.9	31.5	43.0	0.732
7.5-2	7.5	105.2	3734.3	1993.0	3754.4	1761.4	2.120	2.275	82.4	15.5	132.3	6.8	17.6	61.3	31.4	43.0	0.731
7.5-3	7.5	105.2	3730.5	1980.0	3748.4	1768.4	2.110	2.275	82.0	15.4	131.6	7.3	18.0	59.6	31.8	43.0	0.738
AVG												7.0	17.8	60.6	31.6	43.0	0.734
8.0-1	8.0	104.6	3723.4	1983.4	3740.1	1756.7	2.120	2.260	81.9	16.5	132.3	6.2	18.1	65.6	31.8	43.0	0.740
8.0-2	8.0	104.4	3761.8	2008.1	3772.3	1764.2	2.132	2.260	82.4	16.6	133.1	5.7	17.6	67.8	31.4	43.0	0.730
8.0-3	8.0	104.7	3743.0	1991.8	3755.8	1764.0	2.122	2.260	82.0	16.6	132.4	6.1	18.0	66.0	31.7	43.0	0.738
AVG												6.0	17.9	66.5	31.7	43.0	0.736
8.5-1	8.5	103.1	3771.2	2017.9	3778.4	1760.5	2.142	2.245	82.4	17.8	133.7	4.6	17.6	74.0	31.5	43.0	0.731
8.5-2	8.5	104.7	3759.6	1993.1	3767.8	1774.7	2.118	2.245	81.4	17.6	132.2	5.6	18.6	69.6	32.2	43.0	0.749
8.5-3	8.5	104.0	3750.3	1996.9	3759.3	1762.4	2.128	2.245	81.8	17.6	132.8	5.2	18.2	71.3	31.9	43.0	0.742
AVG												5.2	18.1	71.6	31.9	43.0	0.741
9.0-1	9.0	103.7	3758.2	1995.3	3776.7	1781.4	2.110	2.231	80.7	18.5	131.6	5.4	19.3	71.9	32.9	43.0	0.764
9.0-2	9.0	103.8	3756.8	1993.8	3768.3	1774.5	2.117	2.231	80.9	18.6	132.1	5.1	19.1	73.3	32.6	43.0	0.759
9.0-3	9.0	103.5	3755.4	1993.0	3763.8	1770.8	2.121	2.231	81.1	18.6	132.3	4.9	18.9	73.9	32.5	43.0	0.756
AVG												5.2	19.1	73.0	32.7	43.0	0.760
9.5-1	9.5	102.1	3771.5	2008.8	3778.1	1769.3	2.132	2.216	81.1	19.8	133.0	3.8	18.9	79.8	32.5	43.0	0.757
9.5-4	9.5	104.6	3777.1	2001.7	3783.2	1781.5	2.120	2.216	80.6	19.7	132.3	4.3	19.4	77.6	32.9	43.0	0.765
9.5-5	9.5	104.2	3729.8	1977.2	3737.8	1760.6	2.118	2.216	80.6	19.6	132.2	4.4	19.4	77.3	33.0	43.0	0.766
AVG												4.2	19.3	78.2	32.8	43.0	0.763
10.0-1	10.0	105.4	3779.3	1990.2	3788.3	1798.1	2.102	2.202	79.5	20.5	131.2	4.6	20.5	77.8	33.9	43.0	0.787
10.0-2	10.0	104.4	3758.3	1981.2	3765.2	1784.0	2.107	2.202	79.7	20.6	131.5	4.3	20.3	78.6	33.7	43.0	0.783
10.0-3	10.0	104.9	3782.0	1995.0	3787.5	1792.5	2.110	2.202	79.8	20.6	131.7	4.2	20.2	79.2	33.6	43.0	0.781
AVG												4.4	20.4	78.5	33.7	43.0	0.784

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

Table E7.6: Various Test Results for Slag SMA Mixtures Compacted with the SGC
NCHRP 9-8
SHRP SMA Mix Properties

Marshall Stability			Marshall Flow		
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
Average			ERR	Average	ERR

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
Average		ERR

Permeability						
	Specimen A		Specimen B		Average	
Blows	VTM	k(in/min)	VTM	k(in/min)	VTM	k(in/min)
10	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A
50	N/A	N/A	N/A	N/A	N/A	N/A

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number		
				Average
	25			ERR
	4			ERR
	40			ERR

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number		
				Average
	3600			ERR
	4500			ERR

Moisture Susceptibility											
without Lime Conditioned					with 1% Lime Conditioned						
Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)						
Unconditioned					Unconditioned						
Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)						
Tensile Strength Ratio (%)					Tensile Strength Ratio (%)						

Draindown (%)	Test Temp (deg C)	Sample Number		
		A	B	Average
	140	0.008	0.000	0.008
	155	0.000	0.008	0.000
	170	0.025	0.016	0.025

Aggregate Breakdown Sieve Analysis					
Sieve (mm)	Optimum Gradation	SHRP 100 Revolutions			
		1	2	3	Average
19	100.0	100.0	100.0	100.0	100.0
12.5	90.0	89.6	90.9	92.0	90.8
9.5	52.0	62.5	64.3	63.7	63.5
4.75	20.0	29.3	30.0	29.9	29.7
2.36	17.0	22.7	23.2	23.5	23.1
1.18	15.0	18.8	19.3	19.7	19.3
0.6	13.0	15.7	16.0	16.7	16.1
0.3	12.0	13.7	13.9	14.6	14.1
0.15	11.0	11.8	11.8	12.8	12.1
0.75	10.0	9.5	9.4	10.4	9.8

**Table E7.7: Voids in the Coarse Aggregate Test Results for Slag
NCHRP 9-8
Marshall & SHRP SMA Mix Properties**

Voids in th Course Aggregate (VCA) and Sieve Analysis																		
Sieve (mm)	Batched Gradation	Actual Tested Gradation	D.R.U.W. Method				Troxler SGC Method											
			D.R.U.W. (pcf)			average	75 Revolutions				100 Revolutions			125 Revolutions				
			82.0	81.8	80.1		81.3				average				average			
19	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
12.5	87.5	88.1	86.3	87.0	86.6	86.6	90.7	86.5	90.1	86.6	90.2	90.4	90.0	90.2	90.8	89.7	90.4	90.3
9.5	40	46.5	41.8	43.7	40.5	42.0	57.4	56.5	58.2	57.4	60.2	58.0	58.6	58.9	59.4	58.7	58.3	58.8
4.75	0	2.3	2.0	1.9	2.0	2.0	13.9	14.5	14.1	14.2	16.4	14.5	16.3	15.7	16.7	16.5	16.3	16.5
2.36		1.2	1.3	1.1	1.2	1.2	11.8	7.6	7.7	9.0	9.3	7.9	9.5	8.9	9.2	9.1	8.7	9.0
1.18		1.1	1.2	1.1	1.1	1.1	4.9	5.1	5.0	5.0	6.6	5.0	6.7	6.1	6.0	6.1	5.7	5.9
0.6		1.1	1.2	1.0	1.1	1.1	3.4	3.5	3.4	3.4	4.9	3.5	4.9	4.4	4.1	4.2	3.8	4.0
0.3		1.1	1.1	1.0	1.0	1.0	2.4	2.5	2.4	2.4	3.6	2.4	3.7	3.2	2.8	2.9	2.7	2.8
0.15		1.1	1.1	0.9	0.9	1.0	1.7	1.7	1.6	1.7	2.6	1.6	2.7	2.3	1.9	2.0	1.8	1.9
0.75		0.9	0.8	0.8	0.8	0.8	1.2	1.2	1.1	1.2	1.9	1.1	1.9	1.6	1.3	1.4	1.3	1.3
VCA (%)	N/A	N/A	42.5	42.7	43.9	43.0	32.7	31.6	31.6	32.0	30.0	30.0	29.9	30.0	28.9	29.0	29.0	29.0

Table E7.8: Results for Slag Dense-Graded Mixture Design Compacted with 75-Blow Marshall Hammer
National Center for Asphalt Technology
Dense Mix Design Summary

Dense Mix Gradation

MARSALL 75 BLOWS

PROJECT: NCHRP 9-8			MATERIALS: Slag\Dolcito\Ergon AC-20						COARSE AGGREGATE INFORMATION:									
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa})= 2.707		Effective Sp. Gr. of Agg. (G _{se})= 2.605		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.541			Percent Coarse Aggregate: 44			DATE: January 29, 1996					
										Bulk Specific Gravity of CA (G _{ca}): 2.288			Unit wt. of CA in DRC (pcf): N/A					
										Unit wt. of CA in DRC (kg/m ³): N/A								
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (G _{mb})	TMD (G _{mm})	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D		(100-B) x 1	B x 1	(1 x 62.4)	100(1-IJ)	(100-K)	100(O-N)	O			
							(F-E)		(Gsb)	(G _b)								
6.0-1	6.0	2.744	1269.4	709.2	1270.1	560.9	2.263	2.385	83.7	13.2	141.2	5.1	16.3	68.7	59.1	N/A	N/A	
6.0-2	6.0	2.755	1268.2	705.5	1268.8	563.3	2.251	2.385	83.3	13.2	140.5	5.6	16.7	66.5	59.3	N/A	N/A	
6.0-3	6.0	2.771	1265.0	701.4	1266.1	564.7	2.240	2.385	82.9	13.1	139.8	6.1	17.1	64.6	59.5	N/A	N/A	
Avg												5.6	16.7	66.6	59.3	N/A	N/A	
6.5-1	6.5	2.778	1275.2	707.7	1276.0	568.3	2.244	2.368	82.6	14.2	140.0	5.2	17.4	69.9	59.7	N/A	N/A	
6.5-2	6.5	2.736	1275.9	715.3	1276.3	561.0	2.274	2.368	83.7	14.4	141.9	4.0	16.3	75.8	59.1	N/A	N/A	
6.5-3	6.5	2.75	1277.1	713.9	1278.2	564.3	2.263	2.368	83.3	14.4	141.2	4.4	16.7	73.5	59.3	N/A	N/A	
Avg												4.5	16.8	73.1	59.4	N/A	N/A	
7.0-1	7.0	2.75	1277.7	715.5	1278.2	562.7	2.271	2.352	83.1	15.5	141.7	3.4	16.9	79.6	59.4	N/A	N/A	
7.0-2	7.0	2.759	1278.3	715.6	1278.9	563.3	2.269	2.352	83.1	15.5	141.6	3.5	16.9	79.4	59.4	N/A	N/A	
7.0-3	7.0	2.748	1280.1	717.6	1280.7	563.1	2.273	2.352	83.2	15.5	141.9	3.3	16.8	80.2	59.3	N/A	N/A	
Avg												3.4	16.9	79.7	59.4	N/A	N/A	

Computed By: S.BUCHANAN	Checked By: T. LYNN
SSD = Saturated Surface Dry Sp. Gr. = Specific Gravity TMD = Theoretical Maximum Density	gm = gram cc = cubic centimeter AC = Asphalt Cement
pcf = pounds per cubic foot in = inches	G _{mb} = Bulk Specific Gravity of Compacted Mix G _{mm} = Theoretical Maximum Specific Gravity of Mix G _{sa} = Apparent Specific Gravity of Aggregate
	G _{sb} = Bulk Specific Gravity of Aggregate G _{se} = Effective Specific Gravity of Aggregate G _b = Specific Gravity of Asphalt Cement

**Table E7.10: Results for Slag Dense-Graded Mixture Design Compacted with Nmax=208 Revolutions of the SGC
National Center for Asphalt Technology
Dense Mix Design Summary**

Dense Mix Gradation

SHRP N-MAX=208 REV

PROJECT: NCHRP 9-8			MATERIALS: Slag\Dolcito\Ergon AC-20						COARSE AGGREGATE INFORMATION:									
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa)= 2.707		Effective Sp. Gr. of Agg. (Gse)= 2.643		Bulk Sp. Gr. of Agg. (Gsb) = 2.541			Percent Coarse Aggregate: 44			DATE: January 30, 1996					
										Bulk Specific Gravity of CA (Gca): 2.288			Unit wt. of CA in DRC (pcf): N/A					
										Unit wt. of CA in DRC (kg/m ³): N/A								
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)				
							(F-E)		(Gsb)	(Gb)				O				
4.5-1	4.5	108.2	4275.6	2403.7	4279.5	1875.8	2.279	2.380	85.7	10.0	142.2	4.2	14.3	70.5	58.1	N/A	N/A	
4.5-2	4.5	107.9	4267.3	2403.7	4273.0	1869.3	2.283	2.380	85.8	10.0	142.4	4.1	14.2	71.3	58.1	N/A	N/A	
Avg												4.2	14.3	70.9	58.1	N/A	N/A	
5.0-1	5.0	107.6	4329.7	2466.2	4331.8	1865.6	2.321	2.321	86.8	11.3	144.8	0.0	13.2	99.9	57.6	N/A	N/A	
5.0-2	5.0	108	4285.2	2420.0	4288.6	1868.6	2.293	2.321	85.7	11.2	143.1	1.2	14.3	91.6	58.1	N/A	N/A	
Avg												0.6	13.7	95.8	57.9	N/A	N/A	
5.5-1	5.5	106.9	4280.9	2432.2	4282.8	1850.6	2.313	2.347	86.0	12.4	144.3	1.4	14.0	89.7	58.0	N/A	N/A	
5.5-2	5.5	108	4328.2	2459.9	4331.4	1871.5	2.313	2.347	86.0	12.4	144.3	1.5	14.0	89.6	58.0	N/A	N/A	
Avg												1.4	14.0	89.6	58.0	N/A	N/A	

Computed By: S.BUCHANNAN Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

Table E8.1: Results from Aggregate Gradation Optimization for Gravel using 50-Blow Marshall Hammer
National Center for Asphalt Technology
SMA Trial Gradation Summary

GRADATION A--20% Passing 4.75-mm

MARSHALL 50 BLOW

PROJECT: NCHRP 9-8			MATERIALS: New York Gravel/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:			Percent Coarse Aggregate:			DATE:		
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa})		Effective Sp. Gr. of Agg. (G _{se})		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.594			Bulk Specific Gravity of CA (G _{ca}): 2.556			Unit wt. of CA in DRC (pcf): 100.60		October 23, 1995		
			2.707		2.628					Unit wt. of CA in DRC (kg/m ³): 1611.5							
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (G _{mb})	TMD (G _{mm})	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D (F-E)	J	K (100-B) x I (Gsb)	L (B x I (G _b))	M (I x 62.4)	N (100(1-IJ))	O (100-K)	P (100(O-N))	Q	R	S
GRAV-A1	6.3	2.749	1212.9	678.8	1216.5	537.7	2.256	2.392	81.5	13.9	140.8	5.7	18.5	69.2	33.8	36.9	0.917
GRAV-A2	6.3	2.722	1218.5	684.8	1220.1	535.3	2.276	2.392	82.2	14.0	142.0	4.8	17.8	72.8	33.2	36.9	0.901
GRAV-A3	6.3	2.752	1218.5	682.0	1220.8	538.8	2.262	2.392	81.7	13.9	141.1	5.5	18.3	70.2	33.7	36.9	0.913
												5.3	18.2	70.7	33.6	36.9	0.910

Computed By: G. FLOWERS Checked By: T. LYNN
SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot G_{mb} = Bulk Specific Gravity of Compacted Mix G_{sb} = Bulk Specific Gravity of Aggregate
Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches G_{mm} = Theoretical Maximum Specific Gravity of Mix G_{se} = Effective Specific Gravity of Aggregate
TMD = Theoretical Maximum Density AC = Asphalt Cement G_{sa} = Apparent Specific Gravity of Aggregate G_b = Specific Gravity of Asphalt Cement

GRADATION B--24% Passing 4.75-mm

MARSHALL 50 BLOW

PROJECT: NCHRP 9-8			MATERIALS: New York Gravel/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:			Percent Coarse Aggregate:			DATE:		
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa})		Effective Sp. Gr. of Agg. (G _{se})		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.596			Bulk Specific Gravity of CA (G _{ca}): 2.556			Unit wt. of CA in DRC (pcf): 100.60		October 23, 1995		
			2.707		2.612					Unit wt. of CA in DRC (kg/m ³): 1611.5							
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (G _{mb})	TMD (G _{mm})	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D (F-E)	J	K (100-B) x I (Gsb)	L (B x I (G _b))	M (I x 62.4)	N (100(1-IJ))	O (100-K)	P (100(O-N))	Q	R	S
GRAV-B1	6.3	2.654	1219.9	695.9	1221.5	525.6	2.321	2.380	83.8	14.3	144.8	2.5	16.2	84.7	31.9	36.9	0.866
GRAV-B2	6.3	2.666	1220.2	693.2	1221.8	528.6	2.308	2.380	83.4	14.2	144.0	3.0	16.6	81.9	32.3	36.9	0.876
GRAV-B3	6.3	2.648	1220.3	696.9	1221.9	525.0	2.324	2.380	84.0	14.3	145.0	2.3	16.0	85.4	31.8	36.9	0.863
												2.6	16.3	84.0	32.0	36.9	0.868

Computed By: G. FLOWERS Checked By: T. LYNN
SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot G_{mb} = Bulk Specific Gravity of Compacted Mix G_{sb} = Bulk Specific Gravity of Aggregate
Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches G_{mm} = Theoretical Maximum Specific Gravity of Mix G_{se} = Effective Specific Gravity of Aggregate
TMD = Theoretical Maximum Density AC = Asphalt Cement G_{sa} = Apparent Specific Gravity of Aggregate G_b = Specific Gravity of Asphalt Cement

GRADATION C--28% Passing 4.75-mm

MARSHALL 50 BLOW

PROJECT: NCHRP 9-8			MATERIALS: New York Gravel/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:			Percent Coarse Aggregate:			DATE:		
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa})		Effective Sp. Gr. of Agg. (G _{se})		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.597			Bulk Specific Gravity of CA (G _{ca}): 2.556			Unit wt. of CA in DRC (pcf): 100.60		October 23, 1995		
			2.707		2.619					Unit wt. of CA in DRC (kg/m ³): 1611.5							
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (G _{mb})	TMD (G _{mm})	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D (F-E)	J	K (100-B) x I (Gsb)	L (B x I (G _b))	M (I x 62.4)	N (100(1-IJ))	O (100-K)	P (100(O-N))	Q	R	S
GRAV-C1	6.3	2.594	1224.2	703.0	1225.2	522.2	2.344	2.385	84.7	14.4	146.3	1.7	15.3	88.9	31.2	36.9	0.847
GRAV-C2	6.3	2.577	1218.6	700.5	1219.3	518.8	2.349	2.385	84.8	14.4	146.6	1.5	15.2	90.0	31.1	36.9	0.843
GRAV-C3	6.3	2.586	1220.4	700.4	1221.2	520.8	2.343	2.385	84.6	14.4	146.2	1.7	15.4	88.6	31.3	36.9	0.848
												1.7	15.3	89.2	31.2	36.9	0.846

Computed By: G. FLOWERS Checked By: T. LYNN
SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot G_{mb} = Bulk Specific Gravity of Compacted Mix G_{sb} = Bulk Specific Gravity of Aggregate
Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches G_{mm} = Theoretical Maximum Specific Gravity of Mix G_{se} = Effective Specific Gravity of Aggregate
TMD = Theoretical Maximum Density AC = Asphalt Cement G_{sa} = Apparent Specific Gravity of Aggregate G_b = Specific Gravity of Asphalt Cement

**Table E8.3: Various Test Results for Gravel SMA Mixtures Compacted with the Marshall Hammer
NCHRP 9-8
Marshall SMA Mix Properties**

Marshall Stability				Marshall Flow	
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
3	7340	0.93	6826	3	24.0
6	5671	0.93	5274	6	17.0
9	6672	0.93	6205	9	23.0
Average			6102	Average 21.3	

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
5	9564	871
7	9786	893
8	9786	889
Average		884

Permeability						
Blows	Specimen A		Specimen B		average	
	VTM	k(in/min)	VTM	k(in/min)	VTM	k(in/min)
10						
20						
30						
40						
50						

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number		
				Average
ERR	25			ERR
	4			ERR
	40			ERR

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number		
				Average
ERR	3600			ERR
	4500			ERR

Moisture Susceptibility										
without Lime Conditioned					with 1% Lime Conditioned					
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	
2	5.4	73	3281	281	1	6.5	78.3	3281	283	
7	5.5	75.9	3447	292	3	5.8	72.7	3559	305	
8	5.9	67.5	3670	312	5	6.7	72	3781	319	
Average Tensile Strength (kPa)				295	Average Tensile Strength (kPa)				302	
Unconditioned					Unconditioned					
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	
1	5.4		7729	664	4	5.9		7228	618	
3	5.5		6784	579	9	6.5		6561	552	
6	5.7		6895	588	10	6.7		6784	571	
Average Tensile Strength (kPa)				610	Average Tensile Strength (kPa)				580	
Tensile Strength Ratio (%)				48	Tensile Strength Ratio (%)				52	

Draindown (%)	Test Temp (deg C)	Sample Number		
		A	B	Average
0.004	140	0.000	0.008	0.004
	155	0.064	0.072	0.068
	170	0.041	0.008	0.025

Aggregate Breakdown Sieve Analysis					
Sieve (mm)	Optimum Gradation	Marshall 50 Blows			
		2	10	11	Average
19	100	100	100	100	100
12.5	90.1	93.3	91.7	91.6	92.2
9.5	52.6	62.2	62.9	60.7	61.9
4.75	21.0	26.9	26.1	27.3	26.8
2.36	17.9	19.6	19.1	19.6	19.4
1.18	15.8	17.6	16.5	16.8	17.0
0.6	13.4	14.8	14.3	14.6	14.6
0.3	12.4	13.7	13.3	13.6	13.5
0.15	11.1	12.5	12.1	12.3	12.3
0.75	10.0	10.4	10.1	10.3	10.3

Table E8.4: Results from Aggregate Gradation Optimization for Gravel using 100 Revolutions of the SGC
National Center for Asphalt Technology
SMA Trial Gradation Summary

GRADATION A--20% Passing 4.75-mm Sieve

SHRP 100 REV

PROJECT: NCHRP9-8			MATERIALS: New York Gravel/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate: 80		DATE: 2.556			
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa)= 2.707		Effective Sp. Gr. of Agg. (Gse)= 2.639		Bulk Sp. Gr. of Agg. (Gsb) = 2.595			Bulk Specific Gravity of CA (Gca): 100.60					Unit wt. of CA in DRC (pcf): 1611.5		Unit wt. of CA in DRC (kg/m3): 1611.5		
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME			SPECIFIC GRAVITIES			VOLUMES			VOIDS				
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc		
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S		
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)					
						(F-E)	(F-E)		(Gsb)	(Gb)			O						
GRAV-A1	6.3	110.4	4250.6	2403.3	4263.8	1860.5	2.285	2.401	82.5	14.0	142.6	4.8	17.5	72.3	33.0	36.9	0.894		
GRAV-A2	6.3	109.9	4216.0	2364.8	4225.8	1861.0	2.265	2.401	81.8	13.9	141.4	5.6	18.2	69.0	33.6	36.9	0.910		
GRAV-A3	6.3	109.7	4207.1	2360.4	4218.1	1857.7	2.265	2.401	81.8	13.9	141.3	5.7	18.2	68.9	33.6	36.9	0.910		
												5.4	18.0	70.0	33.4	36.9	0.905		

Computed By: G. FLOWERS Checked By: T. LYNN
 SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

GRADATION B--24% Passing 4.75-mm Sieve

SHRP 100 REV

PROJECT: NCHRP9-8			MATERIALS: New York Gravel/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate: 76		DATE: 2.556			
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa)= 2.708		Effective Sp. Gr. of Agg. (Gse)= 2.643		Bulk Sp. Gr. of Agg. (Gsb) = 2.597			Bulk Specific Gravity of CA (Gca): 100.60					Unit wt. of CA in DRC (pcf): 1611.5		Unit wt. of CA in DRC (kg/m3): 1611.5		
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME			SPECIFIC GRAVITIES			VOLUMES			VOIDS				
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc		
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S		
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)					
						(F-E)	(F-E)		(Gsb)	(Gb)			O						
GRAV-B1	6.3	105.2	4231.0	2432.4	4235.4	1803.0	2.347	2.404	84.7	14.4	146.4	2.4	15.3	84.4	31.2	36.9	0.845		
GRAV-B2	6.3	105.4	4231.1	2437.5	4235.3	1797.8	2.353	2.404	85.0	14.5	146.9	2.1	15.0	86.0	31.0	36.9	0.840		
GRAV-B3	6.3	106.2	4246.7	2442.6	4251.0	1808.4	2.348	2.404	84.8	14.4	146.5	2.3	15.2	84.8	31.1	36.9	0.844		
												2.3	15.2	85.1	31.1	36.9	0.843		

Computed By: G. FLOWERS Checked By: T. LYNN
 SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

GRADATION C--28% Passing 4.75-mm Sieve

SHRP 100 REV

PROJECT: NCHRP9-8			MATERIALS: New York Gravel/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate: 72		DATE: 2.556			
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa)= 2.708		Effective Sp. Gr. of Agg. (Gse)= 2.633		Bulk Sp. Gr. of Agg. (Gsb) = 2.598			Bulk Specific Gravity of CA (Gca): 100.60					Unit wt. of CA in DRC (pcf): 1611.5		Unit wt. of CA in DRC (kg/m3): 1611.5		
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME			SPECIFIC GRAVITIES			VOLUMES			VOIDS				
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc		
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S		
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)					
						(F-E)	(F-E)		(Gsb)	(Gb)			O						
GRAV-C1	6.3	102.7	4255.8	2473.1	4257.0	1783.9	2.386	2.396	86.1	14.7	148.9	0.4	13.9	96.9	30.0	36.9	0.814		
GRAV-C2	6.3	102.7	4235.5	2459.3	4237.3	1778.0	2.382	2.396	86.0	14.6	148.6	0.6	14.0	95.9	30.1	36.9	0.817		
GRAV-C3	6.3	103.0	4209.9	2441.8	4212.9	1771.1	2.377	2.396	85.8	14.6	148.3	0.8	14.2	94.4	30.3	36.9	0.821		
												0.6	14.0	95.7	30.2	36.9	0.817		

Computed By: G. FLOWERS Checked By: T. LYNN
 SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

Table E8.5: Results from Asphalt Cement Optimization for Gravel using 100 Revolutions of the SGC
National Center for Asphalt Technology
SMA Mix Design Summary

OPTIMUM GRADATION -- 20% Passing 4.75 mm Sieve

SHRP 100 REV

PROJECT: NCHRP9-8			MATERIAL: New York Gravel/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate: 80		DATE: December 5, 1995	
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gs Effective Sp. Gr. of Agg. (Gse)- Bulk Sp. Gr. of Agg. (Gsb) = 2.707 2.643 2.595											Bulk Specific Gravity of CA (Gca): 2.556			
														Unit wt. of CA in DRC (pcf): 100.60			
														Unit wt. of CA in DRC (kg/m3): 1611.5			
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUM	SPECIFIC GRAVITIES		VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	$\frac{D}{(F-E)}$		$\frac{(100-B) \times I}{(Gsb)}$	$\frac{B \times I}{(Gb)}$	(I x 62.4)	100(1-I/J)	(100-K)	$\frac{100(O-N)}{O}$			
6.5-1	6.5	108.8	4218.1	2384.0	4225.2	1841.2	2.291	2.397	82.5	14.5	143.0	4.4	17.5	74.7	33.0	36.9	0.893
6.5-2	6.5	108.8	4197.6	2362.8	4206.9	1844.1	2.276	2.397	82.0	14.4	142.0	5.0	18.0	72.0	33.4	36.9	0.905
6.5-3	6.5	109.4	4248.4	2408.0	4256.5	1848.5	2.298	2.397	82.8	14.6	143.4	4.1	17.2	76.0	32.7	36.9	0.888
AVG												4.5	17.5	74.2	33.0	36.9	0.895
7.0-1	7.0	109.7	4224.8	2373.4	4230.9	1857.5	2.274	2.380	81.5	15.5	141.9	4.4	18.5	76.0	33.8	36.9	0.916
7.0-2	7.0	109.2	4225.0	2385.2	4231.4	1846.2	2.288	2.380	82.0	15.6	142.8	3.8	18.0	78.6	33.4	36.9	0.905
7.0-3	7.0	108.8	4232.0	2393.4	4237.0	1843.6	2.296	2.380	82.3	15.7	143.2	3.6	17.7	80.0	33.2	36.9	0.899
AVG												3.9	18.1	78.2	33.5	36.9	0.907
7.5-1	7.5	108.5	4229.9	2396.4	4234.1	1837.7	2.302	2.363	82.0	16.8	143.6	2.6	18.0	85.6	33.4	36.9	0.904
7.5-2	7.5	108.3	4248.0	2403.3	4250.9	1847.6	2.299	2.363	82.0	16.8	143.5	2.7	18.0	85.0	33.4	36.9	0.906
7.5-3	7.5	108.0	4213.6	2380.6	4217.7	1837.1	2.294	2.363	81.8	16.8	143.1	2.9	18.2	83.9	33.6	36.9	0.911
AVG												2.7	18.1	84.8	33.5	36.9	0.907

Computed By: G. FLOWERS

Checked By: T. LYNN

SSD = Saturated Surface Dry

gm = gram

pcf = pounds per cubic foot

Gmb = Bulk Specific Gravity of Compacted Mix

Gsb = Bulk Specific Gravity of Aggregate

Sp. Gr. = Specific Gravity

cc = cubic centimeter

in = inches

Gmm = Theoretical Maximum Specific Gravity of Mix

Gse = Effective Specific Gravity of Aggregate

TMD = Theoretical Maximum Density

AC = Asphalt Cement

Gsa = Apparent Specific Gravity of Aggregate

Gb = Specific Gravity of Asphalt Cement

Table E8.6: Various Test Results for Gravel SMA Mixtures Compacted with the SGC
NCHRP 9-8
SHRP SMA Mix Properties

Marshall Stability				Marshall Flow	
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
Average			ERR	Average ERR	

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
Average		ERR

Permeability						
	Specimen A		Specimen B		Average	
Blows	VTM	k(in/min)	VTM	k(in/min)	VTM	k(in/min)
10	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A
50	N/A	N/A	N/A	N/A	N/A	N/A

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number		
				Average
	25			ERR
	4			ERR
	40			ERR

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number		
				Average
	3600			ERR
	4500			ERR

Moisture Susceptibility											
without Lime Conditioned					with 1% Lime Conditioned						
Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)						
Unconditioned					Unconditioned						
Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. (%)	Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)						
Tensile Strength Ratio (%)					Tensile Strength Ratio (%)						

Draindown (%)	Test Temp (deg C)	Sample Number		
		A	B	Average
	140	0.008	0.033	0.021
	155	0.082	0.008	0.045
	170	0.024	0.042	0.033

Aggregate Breakdown Sieve Analysis					
Sieve (mm)	Optimum Gradation	SHRP 100 Revolutions			
		1	2	3	Average
19	100.0	100.0	100.0	100.0	100.0
12.5	90.0	90.2	90.0	89.9	90.0
9.5	52.0	57.3	57.5	59.2	58.0
4.75	20.0	23.9	24.3	24.4	24.2
2.36	17.0	18.4	19.0	18.7	18.7
1.18	15.0	15.8	16.1	16.0	16.0
0.6	13.0	13.9	14.2	14.1	14.1
0.3	12.0	12.9	13.1	13.1	13.0
0.15	11.0	11.9	12.1	12.0	12.0
0.75	10.0	10.0	10.2	10.2	10.1

Table E8.7: Voids in the Coarse Aggregate Test Results for Gravel

**NCHRP 9-8
Marshall & SHRP SMA Mix Properties**

Voids in th Course Aggregate (VCA) and Sieve Analysis																		
Sieve (mm)	Batched Gradation	Actual Tested Gradation	D.R.U.W. Method				Troxler SGC Method											
			D.R.U.W. (pcf)			average	75 Revolutions				100 Revolutions			125 Revolutions				
			100.4	99.8	101.5		100.6	100	100	100	average	100	100	100	average	100	100	100
19	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
12.5	87.5	88.4	87.5	88.1	88.6	88.1	91.4	91.2	90.2	90.9	91.1	91.3	96.1	92.8	91.7	90.8	91.0	91.2
9.5	40	42.5	42.6	43.0	45.0	43.5	48.4	49.0	48.5	48.6	48.7	49.0	47.9	48.5	49.7	49.4	49.6	49.6
4.75	0	2.3	2.4	2.7	2.2	2.4	5.5	6.3	5.8	5.9	6.8	6.5	7.5	6.9	6.8	7.2	7.0	7.0
2.36		0.3	0.4	0.5	0.4	0.4	1.8	2.3	1.7	1.9	2.4	2.5	4.0	3.0	2.8	2.9	3.0	2.9
1.18		0.3	0.4	0.4	0.4	0.4	1.1	1.4	1.5	1.3	1.5	1.7	2.1	1.8	2.1	2.1	2.1	2.1
0.6		0.3	0.4	0.4	0.4	0.4	0.8	1.1	1.1	1.0	1.1	1.3	1.5	1.3	1.6	1.6	1.7	1.6
0.3		0.3	0.4	0.4	0.4	0.4	0.6	0.9	0.9	0.8	0.9	1.1	1.2	1.1	1.4	1.4	1.4	1.4
0.15		0.3	0.3	0.4	0.4	0.4	0.5	0.7	0.7	0.6	0.7	0.9	1.0	0.9	1.2	1.2	1.3	1.2
0.75		0.3	0.3	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.8	0.6	1.0	9.0	1.0	3.7
VCA (%)	N/A	N/A		37.0	37.4	36.3	36.9	34.4	34.6	34.7	34.6	33.5	34.0	34.0	33.8	33.3	33.3	33.3

Table E8.8: Results for Gravel Dense-Graded Mixture Design Compacted with 75-Blow Marshall Hammer
National Center for Asphalt Technology
Dense Mix Design Summary

Dense Mix Gradation

MARSHALL 75 BLOWS

PROJECT: NCHRP 9-8			MATERIALS: New York Gravel(Dolcito)Ergon AC-20						COARSE AGGREGATE INFORMATION:										44	DATE:
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa})= 2.698		Effective Sp. Gr. of Agg. (G _{se})= 2.623		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.589		Percent Coarse Aggregate: 2.556										January 29, 1995	
									Unit wt. of CA in DRC (pcf): N/A											
									Unit wt. of CA in DRC (kg/m ³): N/A											
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS							
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (G _{mb})	TMD (G _{mm})	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc			
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S			
						(F-E)	D		(100-B) x I	B x I	(1 x 62.4)	100(1-I/J)	(100-K)	100(O-N)						
							(F-E)		(Gsb)	(G _b)				O						
4.5-1	4.5	2.681	1248.2	704.6	1250.2	545.6	2.288	2.451	84.4	10.0	142.8	6.6	15.6	57.4	62.4	N/A	N/A			
4.5-2	4.5	2.679	1245.3	704.0	1245.3	541.3	2.301	2.451	84.9	10.1	143.6	6.1	15.1	59.5	62.2	N/A	N/A			
4.5-3	4.5	2.69	1251.8	707.4	1251.8	544.4	2.299	2.451	84.8	10.1	143.5	6.2	15.2	59.3	62.2	N/A	N/A			
Avg												6.3	15.3	58.8	62.3	N/A	N/A			
5.0-1	5.0	2.655	1259.1	719.3	1259.7	540.4	2.330	2.433	85.5	11.4	145.4	4.2	14.5	70.8	61.9	N/A	N/A			
5.0-2	5.0	2.645	1252.5	714.3	1253.1	538.8	2.325	2.433	85.3	11.3	145.1	4.5	14.7	69.7	62.0	N/A	N/A			
5.0-3	5.0	2.636	1254.3	713.4	1254.9	541.5	2.316	2.433	85.0	11.3	144.5	4.8	15.0	68.0	62.1	N/A	N/A			
Avg												4.5	14.7	69.5	62.0	N/A	N/A			
5.5-1	5.5	2.661	1261.1	722.8	1261.4	538.6	2.341	2.416	85.5	12.6	146.1	3.1	14.5	78.9	61.9	N/A	N/A			
5.5-2	5.5	2.645	1259.1	721.8	1259.9	538.1	2.340	2.416	85.4	12.6	146.0	3.1	14.6	78.5	61.9	N/A	N/A			
5.5-3	5.5	2.673	1263.6	723.5	1264.4	540.9	2.336	2.416	85.3	12.5	145.8	3.3	14.7	77.7	62.0	N/A	N/A			
Avg												3.2	14.6	78.4	61.9	N/A	N/A			

Computed By: S.BUCHANAN Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

Table E8.10: Results for Gravel Dense-Graded Mixture Design Compacted with Nmax=208 Revolutions of the SGC
National Center for Asphalt Technology
Dense Mix Design Summary

Dense Mix Gradation

SHRP N-MAX=208 REV

PROJECT: NCHRP 9-8			MATERIALS: Ney York Gravel\Dolcito\Ergon AC-20						COARSE AGGREGATE INFORMATION:									
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa)= 2.698		Effective Sp. Gr. of Agg. (Gse)= 2.653		Bulk Sp. Gr. of Agg. (Gsb) = 2.589		Percent Coarse Aggregate: 44			Bulk Specific Gravity of CA (Gca): 2.556			DATE: January 30, 1996			
			Unit wt. of CA in DRC (pcf): N/A		Unit wt. of CA in DRC (kg/m3): N/A													
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS						
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D		(100-B) x 1	B x 1	(1 x 62.4)	100(1-I/J)	(100-K)	100(O-N)				
						(F-E)			(Gsb)	(Gb)								
5.0-1	5.0	100.8	4175.2	2423.7	4179.6	1755.9	2.378	2.458	87.3	11.6	148.4	3.3	12.7	74.4	61.1	N/A	N/A	
5.0-2	5.0	100.9	4174.8	2422.2	4178.7	1756.5	2.377	2.458	87.2	11.6	148.3	3.3	12.8	74.2	61.1	N/A	N/A	
Avg												3.3	12.8	74.3	61.1	N/A	N/A	
5.5-1	5.5	99.9	4194.2	2452.4	4195.4	1743.0	2.406	2.440	87.8	12.9	150.2	1.4	12.2	88.7	60.9	N/A	N/A	
5.5-2	5.5	100.1	4198.1	2453.9	4199.0	1745.1	2.406	2.440	87.8	12.9	150.1	1.4	12.2	88.5	60.9	N/A	N/A	
Avg												1.4	12.2	88.6	60.9	N/A	N/A	
6.0-1	6.0	100.1	4221.0	2473.6	4221.3	1747.7	2.415	2.422	87.7	14.1	150.7	0.3	12.3	97.7	60.9	N/A	N/A	
6.0-2	6.0	100.3	4223.7	2473.4	4224.2	1750.8	2.412	2.422	87.6	14.1	150.5	0.4	12.4	96.8	61.0	N/A	N/A	
Avg												0.3	12.4	97.3	60.9	N/A	N/A	

Computed By: S.BUCHANNAN Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

Appendix F - Mix Design for Mortar

Table F1.1: Results from Mortar Work
National Center for Asphalt Technology
SMA Mix Design Summary
Mortar Mix "A"

OPTIMUM GRADATION - - 20% Passing 4.75 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP 9-8			MATERIALS: Labstock Granite/10% Traprock/Ergon AC-20/No Fiber						COARSE AGGREGATE INFORMATION:										
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa) 2.762		Effective Sp. Gr. of Agg. (Gse) 2.737		Bulk Sp. Gr. of Agg. (Gsb) 2.722		Percent Coarse Aggregate: 80			Bulk Specific Gravity of CA (Gca): 2.688		Unit wt. of CA in DRC (pcf): 100.93		Unit wt. of CA in DRC (kg/m ³): 1616.7		DATE: February 1, 1996	
Specimen Number	Asphalt Content (%)	Average Thickness (inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS							
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc		
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S		
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)					
							(F-E)		(Gsb)	(Gb)				O					
5.5-1	5.5	2.545	1198.1	699.8	1200.8	501.0	2.391	2.507	83.0	12.8	149.2	4.6	17.0	72.8	32.7	39.8	0.822		
5.5-2	5.5	2.571	1201.2	701.2	1204.1	502.9	2.389	2.507	82.9	12.8	149.0	4.7	17.1	72.3	32.8	39.8	0.825		
5.5-3	5.5	2.547	1200.2	703.2	1202.5	499.3	2.404	2.507	83.5	12.9	150.0	4.1	16.5	75.1	32.4	39.8	0.814		
AVG												4.5	16.9	73.4	32.6	39.8	0.820		
6.0-1	6.0	2.548	1207.9	704.0	1209.6	505.6	2.389	2.488	82.5	14.0	149.1	4.0	17.5	77.3	33.2	39.8	0.833		
6.0-2	6.0	2.568	1215.1	708.1	1217.6	509.5	2.385	2.488	82.4	14.0	148.8	4.1	17.6	76.5	33.3	39.8	0.836		
6.0-3	6.0	2.578	1215.2	707.2	1217.0	509.8	2.384	2.488	82.3	14.0	148.7	4.2	17.7	76.3	33.3	39.8	0.837		
AVG												4.1	17.6	76.7	33.3	39.8	0.836		
6.5-1	6.5	2.567	1212.2	707.3	1214.2	506.9	2.391	2.469	82.1	15.2	149.2	3.1	17.9	82.4	33.5	39.8	0.841		
6.5-2	6.5	2.550	1209.2	706.4	1210.8	504.4	2.397	2.469	82.3	15.2	149.6	2.9	17.7	83.6	33.3	39.8	0.837		
6.5-3	6.5	2.533	1203.7	703.9	1205.3	501.4	2.401	2.469	82.5	15.2	149.8	2.8	17.5	84.2	33.2	39.8	0.834		
AVG												2.9	17.7	83.4	33.3	39.8	0.837		

Computed By: G. FLOWERS

Checked By: T. LYNN

SSD = Saturated Surface Dry
 Sp. Gr. = Specific Gravity
 TMD = Theoretical Maximum Density

gm = gram
 cc = cubic centimeter
 AC = Asphalt Cement
 pcf = pounds per cubic foot
 in = inches

Gmb = Bulk Specific Gravity of Compacted Mix
 Gmm = Theoretical Maximum Specific Gravity of Mix
 Gsa = Apparent Specific Gravity of Aggregate

Gsb = Bulk Specific Gravity of Aggregate
 Gse = Effective Specific Gravity of Aggregate
 Gb = Specific Gravity of Asphalt Cement

Table F1.3: Results from Mortar Work
National Center for Asphalt Technology
SMA Mix Design Summary
Mortar Mix "A"

OPTIMUM GRADATION - - 20% Passing 4.75 mm Sieve

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIAL: Labstock Granite/10% Traprock/Ergon AC-20/No Fiber					COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate: 80			DATE: 80			
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (G Effective Sp. Gr. of Agg. (Gse) Bulk Sp. Gr. of Agg. (Gsb) 2.762 2.763 2.722					Bulk Specific Gravity of CA (Gca): 2.688			Unit wt. of CA in DRC (pcf): 100.93			Unit wt. of CA in DRC (kg/m3): 1616.7			DATE: January 24, 1996		
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME	VOLUMES			VOIDS									
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc		
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S		
						(F-E)	D	$\frac{(100-B) \times I}{(Gsb)}$			$\frac{B \times I}{(1 \times 62.4)}$			$\frac{100(O-N)}{O}$					
5.0-1	5.0	102.6	4196.6	2449.7	4185.8	1736.1	2.417	2.547	84.4	11.8	150.8	5.1	15.6	67.5	31.7	39.8	0.795		
5.0-2	5.0	103.0	4160.9	2440.4	4171.0	1730.6	2.404	2.547	83.9	11.7	150.0	5.6	16.1	65.2	32.0	39.8	0.805		
5.0-3	5.0	103.2	4179.9	2460.5	4194.7	1734.2	2.410	2.547	84.1	11.8	150.4	5.4	15.9	66.3	31.9	39.8	0.800		
AVG												5.3	15.9	66.3	31.8	39.8	0.800		
5.5-1	5.5	103.2	4173.1	2448.0	4185.9	1737.9	2.401	2.527	83.4	12.9	149.8	5.0	16.6	70.1	32.5	39.8	0.816		
5.5-2	5.5	102.5	4185.5	2469.8	4197.3	1727.5	2.423	2.527	84.1	13.0	151.2	4.1	15.9	74.1	31.9	39.8	0.801		
5.5-3	5.5	102.9	4183.4	2455.4	4196.0	1740.6	2.403	2.527	83.4	12.9	150.0	4.9	16.6	70.5	32.4	39.8	0.814		
AVG												4.7	16.4	71.5	32.2	39.8	0.810		
6.0-1	6.0	102.2	4166.8	2448.1	4177.1	1729.0	2.410	2.508	83.2	14.1	150.4	3.9	16.8	76.8	32.6	39.8	0.819		
6.0-2	6.0	102.4	4212.8	2476.6	4221.0	1744.4	2.415	2.508	83.4	14.1	150.7	3.7	16.6	77.8	32.4	39.8	0.815		
6.0-3	6.0	101.3	4148.6	2432.7	4156.3	1723.6	2.407	2.508	83.1	14.1	150.2	4.0	16.9	76.2	32.7	39.8	0.821		
AVG												3.9	16.8	76.9	32.6	39.8	0.818		
6.5-1	6.5	103.3	4173.7	2431.6	4183.1	1751.5	2.383	2.488	81.9	15.1	148.7	4.2	18.1	76.6	33.7	39.8	0.847		
6.5-2	6.5	102.5	4200.4	2466.9	4205.6	1738.7	2.416	2.488	83.0	15.3	150.7	2.9	17.0	82.9	32.8	39.8	0.824		
6.5-3	6.5	102.9	4190.7	2453.4	4195.5	1742.1	2.406	2.488	82.6	15.3	150.1	3.3	17.4	80.8	33.1	39.8	0.831		
AVG												3.5	17.5	80.1	33.2	39.8	0.834		

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

Table F1.4: Various Test Results for Mortars Compacted With the SGC

National Center for Asphalt Technology

SMA Mix Design Summary

Mortar Mix "A"

Marshall Stability			Marshall Flow		
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
Average			Average		

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
Average		

Permeability						
Blows	Specimen A		Specimen B		average	
	VTM	k (in/min)	VTM	k (in/min)	VTM	k (in/min)
10	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A
50	N/A	N/A	N/A	N/A	N/A	N/A

Moisture Susceptibility									
without Lime					with 1% Lime				
Conditioned					Conditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)				
Unconditioned					Unconditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
		N/A					N/A		
		N/A					N/A		
		N/A					N/A		
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)				
Tensile Strength Ratio (%)					Tensile Strength Ratio (%)				

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number		
	25			Average
	4			
	40			

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number		
	3600			Average
	4500			

Draindown (%)	Test Temp (deg C)	Sample Number		
		A	B	Average
	140	0.000	0.033	0.017
155	0.000	0.082	0.041	
170	0.000	0.000	0.000	

Table F2.1: Results from Mortar Work
National Center for Asphalt Technology
SMA Mix Design Summary
Mortar Mix "B"

OPTIMUM GRADATION - - 20% Passing 4.75 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP 9-8			MATERIAL: Labstock Granite/10% Traprock/MAC 20-HD(Styrelf)/No Fiber						COARSE AGGREGATE INFORMATION:			Percent Coarse Aggregate:			80		DATE:	
AC Sp. Gr. (G _b) = 1.026			Apparent Sp. Gr. of Agg. (G _s Effective Sp. Gr. of Agg. (G _{se})		Bulk Sp. Gr. of Agg. (G _{sb})					Bulk Specific Gravity of CA (G _{ca}):			2.688		February 2, 1996			
			2.762		2.746		2.722			Unit wt. of CA in DRC (pcf):			100.93					
			WEIGHTS			MIX VOLUME	SPECIFIC GRAVIT		VOLUMES			VOIDS						
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (G _{mb})	TMD (G _{mm})	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D				(100-B) x I	B x I	(I x 62.4)	100(I-I/J)	(100-K)	100(O-N)	O	
						(F-E)	(F-E)				(G _{sb})	(G _b)						
6.5-1	6.5	2.570	1206.7	701.7	1208.8	507.1	2.380	2.477	81.7	15.1	148.5	3.9	18.3	78.6	33.8	39.8	0.849	
6.5-2	6.5	2.581	1220.7	707.3	1222.3	515.0	2.370	2.477	81.4	15.0	147.9	4.3	18.6	76.9	34.0	39.8	0.855	
6.5-3	6.5	2.573	1208.7	703.3	1211.0	507.7	2.381	2.477	81.8	15.1	148.6	3.9	18.2	78.8	33.8	39.8	0.848	
AVG												4.0	18.4	78.1	33.9	39.8	0.851	
7.0-1	7.0	2.510	1167.3	674.0	1169.7	495.7	2.355	2.458	80.5	16.1	146.9	4.2	19.5	78.5	34.8	39.8	0.875	
7.0-2	7.0	2.602	1200.9	690.2	1203.3	513.1	2.340	2.458	80.0	16.0	146.0	4.8	20.0	76.2	35.2	39.8	0.885	
7.0-3	7.0	2.576	1216.1	709.9	1217.6	507.7	2.395	2.458	81.8	16.3	149.5	2.5	18.2	86.0	33.7	39.8	0.847	
AVG												3.8	19.2	80.2	34.6	39.8	0.869	
7.5-1	7.5	2.484	1139.4	652.9	1136.3	483.4	2.357	2.440	80.1	17.2	147.1	3.4	19.9	83.0	35.1	39.8	0.882	
7.5-2	7.5	2.659	1231.5	709.8	1233.6	523.8	2.351	2.440	79.9	17.2	146.7	3.6	20.1	82.0	35.3	39.8	0.886	
7.5-3	7.5	2.590	1215.7	705.1	1217.5	512.4	2.373	2.440	80.6	17.3	148.0	2.7	19.4	85.8	34.7	39.8	0.872	
AVG												3.3	19.8	83.6	35.0	39.8	0.880	

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

Table F2.2: Various Test Results for Mortars Compacted With the Marshall Hammer

National Center for Asphalt Technology

SMA Mix Design Summary

Mortar Mix "B"

Marshall Stability			Marshall Flow		
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
Average			Average		

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
Average		

Permeability						
Blows	Specimen A		Specimen B		average	
	VTM	k (in/min)	VTM	k(in/min)	VTM	k(in/min)
10	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A
50	N/A	N/A	N/A	N/A	N/A	N/A

Moisture Susceptibility									
without Lime					with 1% Lime				
Conditioned					Conditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)				
Unconditioned					Unconditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
		N/A					N/A		
		N/A					N/A		
		N/A					N/A		
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)				
Tensile Strength Ratio (%)					Tensile Strength Ratio (%)				

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number		
				Average
	25			
4				
40				

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number		
				Average
	3600			
4500				

Draindown (%)	Test Temp (deg C)	Sample Number		
		A	B	Average
	140	0.000	0.033	0.017
155	0.000	0.082	0.041	
170	0.000	0.000	0.000	

Table F2.1: Results from Mortar Work
National Center for Asphalt Technology
SMA Mix Design Summary
Mortar Mix "B"

OPTIMUM GRADATION - - 20% Passing 4.75 mm Sieve

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIAL: Labstock Granite/10% Traprock/MAC 20-HD(Styrelf)/No Fiber						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate: 80		DATE: January 26, 1996	
AC Sp. Gr. (Gb) = 1.026			Apparent Sp. Gr. of Agg. (Gs Effective Sp. Gr. of Agg. (Gse) 2.762		Bulk Sp. Gr. of Agg. (Gsb) 2.766		Bulk Sp. Gr. of Agg. (Gsb) 2.722							Bulk Specific Gravity of CA (Gca): 2.688		Unit wt. of CA in DRC (pcf): 100.93	
			WEIGHTS			MIX VOLUME	SPECIFIC GRAVIT		VOLUMES			VOIDS					
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	$\frac{D}{(F-E)}$		$\frac{(100-B) \times I}{(Gsb)}$	$\frac{B \times I}{(Gb)}$	(I x 62.4)	100(1-I/J)	(100-K)	$\frac{100(O-N)}{O}$			
5.0-1	5.0	102.6	4106.3	2410.6	4128.0	1717.4	2.391	2.550	83.4	11.7	149.2	6.2	16.6	62.4	32.4	39.8	0.814
5.0-2	5.0	103.3	4162.8	2454.2	4174.9	1720.7	2.419	2.550	84.4	11.8	151.0	5.1	15.6	67.1	31.6	39.8	0.794
5.0-3	5.0	102.5	4165.6	2449.2	4176.0	1726.8	2.412	2.550	84.2	11.8	150.5	5.4	15.8	65.9	31.8	39.8	0.799
AVG												5.6	16.0	65.1	31.9	39.8	0.802
5.5-1	5.5	102.1	4154.4	2433.5	4161.7	1728.2	2.404	2.530	83.5	12.9	150.0	5.0	16.5	69.9	32.4	39.8	0.814
5.5-2	5.5	102.6	4159.3	2438.6	4168.8	1730.2	2.404	2.530	83.5	12.9	150.0	5.0	16.5	69.9	32.4	39.8	0.814
5.5-3	5.5	102.8	4138.6	2433.8	4149.0	1715.2	2.413	2.530	83.8	12.9	150.6	4.6	16.2	71.5	32.1	39.8	0.808
AVG												4.9	16.4	70.4	32.3	39.8	0.812
6.0-1	6.0	102.1	4122.1	2415.9	4132.4	1716.5	2.401	2.511	82.9	14.0	149.9	4.3	17.1	74.5	32.8	39.8	0.825
6.0-2	6.0	103.1	4143.8	2409.4	4156.2	1746.8	2.372	2.511	81.9	13.9	148.0	5.5	18.1	69.5	33.6	39.8	0.845
6.0-3	6.0	102.9	4207.7	2475.1	4219.6	1744.5	2.412	2.511	83.3	14.1	150.5	3.9	16.7	76.5	32.5	39.8	0.817
AVG												4.6	17.3	73.5	33.0	39.8	0.829
6.5-1	6.5	102.4	4175.5	2447.2	4180.5	1733.3	2.409	2.491	82.7	15.3	150.3	3.3	17.3	80.8	33.0	39.8	0.828
6.5-2	6.5	102.3	4151.0	2425.1	4157.2	1732.1	2.397	2.491	82.3	15.2	149.5	3.8	17.7	78.5	33.3	39.8	0.837
6.5-3	6.5	102.0	4154.2	2432.8	4160.4	1727.6	2.405	2.491	82.6	15.2	150.0	3.5	17.4	80.0	33.1	39.8	0.831
AVG												3.5	17.4	79.8	33.1	39.8	0.832

Computed By: G. FLOWERS

Checked By: T. LYNN

SSD = Saturated Surface Dry
 Sp. Gr. = Specific Gravity
 TMD = Theoretical Maximum Density

gm = gram
 cc = cubic centimeter
 AC = Asphalt Cement
 pcf = pounds per cubic foot
 in = inches

Gmb = Bulk Specific Gravity of Compacted Mix
 Gmm = Theoretical Maximum Specific Gravity of Mix
 Gsa = Apparent Specific Gravity of Aggregate

Gsb = Bulk Specific Gravity of Aggregate
 Gse = Effective Specific Gravity of Aggregate
 Gb = Specific Gravity of Asphalt Cement

Table F4.4: Various Test Results for Mortars Compacted With the SGC
National Center for Asphalt Technology
SMA Mix Design Summary
Mortar Mix "B"

Marshall Stability			Marshall Flow		
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
Average			Average		

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
Average		

Permeability						
Blows	Specimen A		Specimen B		average	
	VTM	k (in/min)	VTM	k(in/min)	VTM	k(in/min)
10	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A
50	N/A	N/A	N/A	N/A	N/A	N/A

Moisture Susceptibility									
without Lime					with 1% Lime				
Conditioned					Conditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)				
Unconditioned					Unconditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
		N/A					N/A		
		N/A					N/A		
		N/A					N/A		
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)				
Tensile Strength Ratio (%)					Tensile Strength Ratio (%)				

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number		
				Average
	25			
	4			
40				

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number		
				Average
	3600			
	4500			

Draindown (%)	Test Temp (deg C)	Sample Number		
		A	B	Average
	140	0.000	0.033	0.017
	155	0.000	0.082	0.041
170	0.000	0.000	0.000	

Table F3.1: Results from Mortar Work
National Center for Asphalt Technology
SMA Mix Design Summary
Mortar Mix "C"

OPTIMUM GRADATION - - 20% Passing 4.75 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP 9-8			MATERIAL: Labstock Granite/10% Traprock/Ergon AC-20/Vestoplast/No Fiber						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate: 80		DATE: February 2, 1996		
AC Sp. Gr. (Gb) = 1.011			Apparent Sp. Gr. of Agg. (Gs Effective Sp. Gr. of Agg. (Gse) 2.762		Bulk Sp. Gr. of Agg. (Gsb) 2.757		2.722							Bulk Specific Gravity of CA (Gca): 2.688		Unit wt. of CA in DRC (pcf): 100.93		
			WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS						
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)				
						(F-E)	(F-E)		(Gsb)	(G)	(G)				O			
6.5-1	6.5	2.567	1196.3	691.9	1198.5	506.6	2.361	2.479	81.1	15.2	147.4	4.7	18.9	75.0	34.3	39.8	0.862	
6.5-2	6.5	2.594	1216.2	704.6	1218.9	514.3	2.365	2.479	81.2	15.2	147.6	4.6	18.8	75.5	34.2	39.8	0.859	
6.5-3	6.5	2.582	1187.2	683.5	1190.5	507.0	2.342	2.479	80.4	15.1	146.1	5.5	19.6	71.8	34.8	39.8	0.876	
AVG												4.9	19.1	74.1	34.4	39.8	0.865	
7.0-1	7.0	2.632	1234.9	717.1	1237.1	520.0	2.375	2.460	81.1	16.4	148.2	3.4	18.9	81.7	34.3	39.8	0.861	
7.0-2	7.0	2.593	1212.5	701.7	1215.2	513.5	2.361	2.460	80.7	16.3	147.3	4.0	19.3	79.3	34.6	39.8	0.871	
7.0-3	7.0	2.613	1213.7	703.2	1216.0	512.8	2.367	2.460	80.9	16.4	147.7	3.8	19.1	80.3	34.5	39.8	0.867	
AVG												3.7	19.1	80.5	34.5	39.8	0.866	
7.5-1	7.5	2.624	1226.9	709.8	1228.8	519.0	2.364	2.441	80.3	17.5	147.5	3.1	19.7	84.0	34.9	39.8	0.878	
7.5-2	7.5	2.611	1220.6	707.1	1222.8	515.7	2.367	2.441	80.4	17.6	147.7	3.0	19.6	84.5	34.8	39.8	0.876	
7.5-3	7.5	2.581	1207.0	700.6	1209.3	508.7	2.373	2.441	80.6	17.6	148.1	2.8	19.4	85.6	34.7	39.8	0.872	
AVG												3.0	19.5	84.7	34.8	39.8	0.875	
0.0-1	0.0	0.0	0.0	0.0	0.0	0.0	0.000	2.757	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513	
0.0-2	0.0	0.0	0.0	0.0	0.0	0.0	0.000	2.757	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513	
0.0-3	0.0	0.0	0.0	0.0	0.0	0.0	0.000	2.757	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513	
AVG												100.0	100.0	0.0	100.0	39.8	2.513	
0.0-1	0.0	0.0	0.0	0.0	0.0	0.0	0.000	2.757	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513	
0.0-2	0.0	0.0	0.0	0.0	0.0	0.0	0.000	2.757	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513	
0.0-3	0.0	0.0	0.0	0.0	0.0	0.0	0.000	2.757	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513	
AVG												100.0	100.0	0.0	100.0	39.8	2.513	

Computed By: G. FLOWERS

Checked By: T. LYNN

SSD = Saturated Surface Dry

gm = gram

pcf = pounds per cubic foot

Gmb = Bulk Specific Gravity of Compacted Mix

Gsb = Bulk Specific Gravity of Aggregate

Sp. Gr. = Specific Gravity

cc = cubic centimeter

in = inches

Gmm = Theoretical Maximum Specific Gravity of Mix

Gse = Effective Specific Gravity of Aggregate

TMD = Theoretical Maximum Density

AC = Asphalt Cement

Gsa = Apparent Specific Gravity of Aggregate

Gb = Specific Gravity of Asphalt Cement

Table F3.2: Various Test Results for Mortars Compacted With the Marshall Hammer

National Center for Asphalt Technology

SMA Mix Design Summary

Mortar Mix "C"

Marshall Stability			Marshall Flow		
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
Average			Average		

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
Average		

Permeability						
Blows	Specimen A		Specimen B		average	
	VTM	k (in/min)	VTM	k(in/min)	VTM	k(in/min)
10	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A
50	N/A	N/A	N/A	N/A	N/A	N/A

Moisture Susceptability									
without Lime					with 1% Lime				
Conditioned					Conditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)				
Unconditioned					Unconditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
		N/A					N/A		
		N/A					N/A		
		N/A					N/A		
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)				
Tensile Strength Ratio (%)					Tensile Strength Ratio (%)				

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number		
				Average
	25			
4				
40				

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number		
				Average
	3600			
4500				

Draindown (%)	Test Temp (deg C)	Sample Number		
		A	B	Average
	140	0.000	0.033	0.017
155	0.000	0.082	0.041	
170	0.000	0.000	0.000	

Table F3.3: Results from Mortar Work
National Center for Asphalt Technology
SMA Mix Design Summary
Mortar Mix "C"

OPTIMUM GRADATION - - 20% Passing 4.75 mm Sieve

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIALS Labstock Granite/10% Traprock/Ergon AC-20/Vestoplast/No Fibe						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate: 80		DATE: 80		
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gs Effective Sp. Gr. of Agg. (Gse)			Bulk Sp. Gr. of Agg. (Gsb)								Bulk Specific Gravity of CA (Gca): 2.688		January 26, 1996		
			2.762			2.761								Unit wt. of CA in DRC (pcf): 100.93				
			2.722								Unit wt. of CA in DRC (kg/m3): 1616.7							
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVIT		VOLUMES			VOIDS						
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D				(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)		
						(F-E)	(Gsb)	(Gb)				O						
5.0-1	5.0	103.1	4165.9	2446.2	4178.3	1732.1	2.405	2.546	83.9	11.7	150.1	5.5	16.1	65.6	32.0	39.8	0.804	
5.0-2	5.0	103.5	4180.7	2460.2	4195.3	1735.1	2.409	2.546	84.1	11.8	150.4	5.4	15.9	66.4	31.9	39.8	0.801	
5.0-3	5.0	104.1	4203.9	2491.1	4219.0	1727.9	2.433	2.546	84.9	11.9	151.8	4.4	15.1	70.6	31.2	39.8	0.784	
AVG												5.1	15.7	67.5	31.7	39.8	0.796	
5.5-1	5.5	102.5	4182.8	2455.3	4191.4	1736.1	2.409	2.526	83.6	12.9	150.3	4.6	16.4	71.8	32.2	39.8	0.810	
5.5-2	5.5	103.3	4173.4	2442.4	4182.8	1740.4	2.398	2.526	83.3	12.9	149.6	5.1	16.7	69.7	32.6	39.8	0.818	
5.5-3	5.5	103.8	4185.2	2451.3	4198.7	1747.4	2.395	2.526	83.2	12.9	149.5	5.2	16.8	69.2	32.6	39.8	0.820	
AVG												5.0	16.7	70.2	32.5	39.8	0.816	
6.0-1	6.0	102.8	4143.4	2411.5	4150.6	1739.1	2.382	2.507	82.3	13.9	148.7	5.0	17.7	72.1	33.3	39.8	0.838	
6.0-2	6.0	102.3	4184.8	2454.9	4193.4	1738.5	2.407	2.507	83.1	14.1	150.2	4.0	16.9	76.5	32.7	39.8	0.821	
6.0-3	6.0	102.2	4124.4	2414.8	4139.2	1724.4	2.392	2.507	82.6	14.0	149.2	4.6	17.4	73.7	33.1	39.8	0.831	
AVG												4.5	17.3	74.1	33.0	39.8	0.830	
6.5-1	6.5	102.2	4137.5	2414.6	4144.3	1729.7	2.392	2.487	82.2	15.2	149.3	3.8	17.8	78.5	33.4	39.8	0.840	
6.5-2	6.5	103.0	4187.3	2448.4	4194.3	1745.9	2.398	2.487	82.4	15.2	149.7	3.6	17.6	79.7	33.3	39.8	0.836	
6.5-3	6.5	102.8	4193.2	2456.0	4200.9	1744.9	2.403	2.487	82.5	15.2	150.0	3.4	17.5	80.6	33.1	39.8	0.832	
AVG												3.6	17.6	79.6	33.3	39.8	0.836	

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

Table F3.4: Various Test Results for Mortars Compacted With the SGC
National Center for Asphalt Technology
SMA Mix Design Summary
Mortar Mix "C"

Marshall Stability			Marshall Flow		
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
Average			Average		

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
Average		

Permeability						
Blows	Specimen A		Specimen B		average	
	VTM	k (in/min)	VTM	k (in/min)	VTM	k (in/min)
10	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A
50	N/A	N/A	N/A	N/A	N/A	N/A

Moisture Susceptibility									
without Lime					with 1% Lime				
Conditioned					Conditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)				
Unconditioned					Unconditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
		N/A					N/A		
		N/A					N/A		
		N/A					N/A		
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)				
Tensile Strength Ratio (%)					Tensile Strength Ratio (%)				

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number		
				Average
	25			
	4			
40				

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number		
				Average
	3600			
4500				

Draindown (%)	Test Temp (deg C)	Sample Number		
		A	B	Average
	140	0.000	0.033	0.017
	155	0.000	0.082	0.041
170	0.000	0.000	0.000	

Table F4.1: Results from Mortar Work
National Center for Asphalt Technology
SMA Mix Design Summary
Mortar Mix "D"

OPTIMUM GRADATION - - 20% Passing 4.75 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP 9-8			MATERIAL: Labstock Granite/10% Traprock/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:				Percent Coarse Aggregate: 80		DATE: 2.688		
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gs Effective Sp. Gr. of Agg. (Gse) 2.762		Bulk Sp. Gr. of Agg. (Gsb) 2.726		Bulk Sp. Gr. of Agg. (Gsb) 2.722						Unit wt. of CA in DRC (pcf): 100.93		Unit wt. of CA in DRC (kg/m3): 1616.7		
Specimen Number	Asphalt Content (%)	Average Thickness (inches)	WEIGHTS			MIX VOLUM	SPECIFIC GRAVITIES		VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)			
							(F-E)		(Gsb)	(Gsb)				O			
5.5-1	5.5	2.606	1209.9	703.9	1216.2	512.3	2.362	2.498	82.0	12.7	147.4	5.5	18.0	69.6	33.6	39.8	0.844
5.5-2	5.5	2.594	1218.9	710.5	1223.7	513.2	2.375	2.498	82.5	12.7	148.2	4.9	17.5	71.9	33.2	39.8	0.834
5.5-3	5.5	2.549	1211.2	704.7	1215.2	510.5	2.373	2.498	82.4	12.7	148.0	5.0	17.6	71.4	33.3	39.8	0.836
AVG												5.1	17.7	71.0	33.3	39.8	0.838
6.0-1	6.0	2.594	1222.2	711.1	1224.7	513.6	2.380	2.480	82.2	13.9	148.5	4.0	17.8	77.4	33.4	39.8	0.840
6.0-2	6.0	2.581	1218.0	708.9	1220.4	511.5	2.381	2.480	82.2	13.9	148.6	4.0	17.8	77.7	33.4	39.8	0.839
6.0-3	6.0	2.579	1221.1	711.1	1223.4	512.3	2.384	2.480	82.3	14.0	148.7	3.9	17.7	78.1	33.3	39.8	0.837
AVG												4.0	17.8	77.7	33.4	39.8	0.839
6.5-1	6.5	2.553	1222.6	711.9	1223.8	511.9	2.388	2.461	82.0	15.1	149.0	2.9	18.0	83.6	33.5	39.8	0.843
6.5-2	6.5	2.544	1221.7	712.6	1222.8	510.2	2.395	2.461	82.3	15.2	149.4	2.7	17.7	84.8	33.4	39.8	0.838
6.5-3	6.5	2.566	1229.9	717.5	1231.1	513.6	2.395	2.461	82.3	15.2	149.4	2.7	17.7	84.8	33.4	39.8	0.838
AVG												2.8	17.8	84.4	33.4	39.8	0.840
0.0-1	0.0	0.0	0.0	0.0	0.0	0.0	0.000	2.726	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513
0.0-2	0.0	0.0	0.0	0.0	0.0	0.0	0.000	2.726	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513
0.0-3	0.0	0.0	0.0	0.0	0.0	0.0	0.000	2.726	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513
AVG												100.0	100.0	0.0	100.0	39.8	2.513
0.0-1	0.0	0.0	0.0	0.0	0.0	0.0	0.000	2.726	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513
0.0-2	0.0	0.0	0.0	0.0	0.0	0.0	0.000	2.726	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513
0.0-3	0.0	0.0	0.0	0.0	0.0	0.0	0.000	2.726	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513
AVG												100.0	100.0	0.0	100.0	39.8	2.513

Computed By: G. FLOWERS

Checked By: T. LYNN

SSD = Saturated Surface Dry

gm = gram

pcf = pounds per cubic foot

Gmb = Bulk Specific Gravity of Compacted Mix

Gsb = Bulk Specific Gravity of Aggregate

Sp. Gr. = Specific Gravity

cc = cubic centimeter

in = inches

Gmm = Theoretical Maximum Specific Gravity of Mix

Gse = Effective Specific Gravity of Aggregate

TMD = Theoretical Maximum Density

AC = Asphalt Cement

Gsa = Apparent Specific Gravity of Aggregate

Gb = Specific Gravity of Asphalt Cement

Table F4.2: Various Test Results for Mortars Compacted With the Marshall Hammer
National Center for Asphalt Technology
SMA Mix Design Summary
Mortar Mix "D"

Marshall Stability			Marshall Flow		
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
Average			Average		

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
Average		

Permeability						
Blows	Specimen A		Specimen B		average	
	VTM	k (in/min)	VTM	k (in/min)	VTM	k (in/min)
10	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A
50	N/A	N/A	N/A	N/A	N/A	N/A

Moisture Susceptability									
without Lime					with 1% Lime				
Conditioned					Conditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)				
Unconditioned					Unconditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
		N/A					N/A		
		N/A					N/A		
		N/A					N/A		
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)				
Tensile Strength Ratio (%)					Tensile Strength Ratio (%)				

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number		
				Average
	25			
4				
40				

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number		
				Average
	3600			
4500				

Draindown (%)	Test Temp (deg C)	Sample Number		
		A	B	Average
	140	0.000	0.033	0.017
155	0.000	0.082	0.041	
170	0.000	0.000	0.000	

Table F4.3: Results from Mortar Work
National Center for Asphalt Technology
SMA Mix Design Summary
Mortar Mix "D"

OPTIMUM GRADATION - - 20% Passing 4.75 mm Sieve

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIAL: Labstock Granite/10% Traprock/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:										Percent Coarse Aggregate: 80		DATE: 80	
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (C Effective Sp. Gr. of Agg. (Gsc) 2.762			Bulk Sp. Gr. of Agg. (Gsb) 2.757			Unit Weight (pcf) 100.93			Unit wt. of CA in DRC (kg/m3): 1616.7			January 24, 1996							
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS										
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc					
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S					
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)								
							(F-E)		(Gsb)	(Gb)				O								
5.0-1	5.0	104.7	4181.0	2456.9	4215.3	1758.4	2.378	2.542	83.0	11.6	148.4	6.5	17.0	62.0	32.8	39.8	0.824					
5.0-2	5.0	104.9	4192.1	2466.6	4226.3	1759.7	2.382	2.542	83.1	11.6	148.7	6.3	16.9	62.7	32.6	39.8	0.820					
5.0-3	5.0	104.5	4190.8	2470.1	4223.6	1753.5	2.390	2.542	83.4	11.7	149.1	6.0	16.6	63.9	32.4	39.8	0.815					
AVG												6.2	16.8	62.9	32.6	39.8	0.820					
5.5-1	5.5	104.8	4230.0	2487.5	4253.1	1765.6	2.396	2.523	83.2	12.9	149.5	5.0	16.8	70.1	32.6	39.8	0.820					
5.5-2	5.5	104.4	4217.9	2482.1	4235.0	1752.9	2.406	2.523	83.5	12.9	150.1	4.6	16.5	72.0	32.3	39.8	0.812					
5.5-3	5.5	104.1	4219.5	2476.7	4240.7	1764.0	2.392	2.523	83.0	12.8	149.3	5.2	17.0	69.5	32.7	39.8	0.822					
AVG												4.9	16.7	70.5	32.6	39.8	0.818					
6.0-1	6.0	104.5	4257.4	2494.1	4269.9	1775.8	2.397	2.503	82.8	14.0	149.6	4.2	17.2	75.5	32.9	39.8	0.827					
6.0-2	6.0	103.4	4238.7	2492.0	4247.9	1755.9	2.414	2.503	83.4	14.1	150.6	3.6	16.6	78.6	32.5	39.8	0.816					
6.0-3	6.0	103.7	4221.7	2475.2	4232.3	1757.1	2.403	2.503	83.0	14.1	149.9	4.0	17.0	76.4	32.8	39.8	0.824					
AVG												3.9	17.0	76.8	32.7	39.8	0.822					
6.5-1	6.5	103.5	4237.8	2492.2	4243.7	1751.5	2.420	2.484	83.1	15.3	151.0	2.6	16.9	84.6	32.7	39.8	0.821					
6.5-2	6.5	103.5	4243.7	2485.8	4250.4	1764.6	2.405	2.484	82.6	15.3	150.1	3.2	17.4	81.7	33.1	39.8	0.831					
6.5-3	6.5	102.8	4236.7	2486.7	4240.4	1753.7	2.416	2.484	83.0	15.3	150.7	2.7	17.0	83.9	32.8	39.8	0.824					
AVG												2.8	17.1	83.4	32.8	39.8	0.825					

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

Table F4.4: Various Test Results for Mortars Compacted With the SGC
National Center for Asphalt Technology
SMA Mix Design Summary
Mortar Mix "D"

Marshall Stability			Marshall Flow		
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
Average			Average		

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
Average		

Permeability						
Blows	Specimen A		Specimen B		average	
	VTM	k (in/min)	VTM	k(in/min)	VTM	k(in/min)
10	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A
50	N/A	N/A	N/A	N/A	N/A	N/A

Moisture Susceptability									
without Lime					with 1% Lime				
Conditioned					Conditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)				
Unconditioned					Unconditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
		N/A					N/A		
		N/A					N/A		
		N/A					N/A		
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)				
Tensile Strength Ratio (%)					Tensile Strength Ratio (%)				

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number		
				Average
	25			
4				
40				

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number		
				Average
	3600			
4500				

Draindown (%)	Test Temp (deg C)	Sample Number		
		A	B	Average
	140	0.000	0.033	0.017
155	0.000	0.082	0.041	
170	0.000	0.000	0.000	

Table F5.1: Results from Mortar Work
National Center for Asphalt Technology
SMA Mix Design Summary
Mortar Mix "E"

OPTIMUM GRADATION - - 20% Passing 4.75 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP 9-8			MATERIAL: Labstock Granite/10% Traprock/Ergon AC-20/Rock Wool						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate: 80		DATE: 80	
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (G Effective Sp. Gr. of Agg. (Gse) Bulk Sp. Gr. of Agg. (Gsb) 2.762 2.745 2.722											Bulk Specific Gravity of CA (Gca): 2.688		February 5, 1996	
			WEIGHTS			MIX VOLUME	SPECIFIC GRAVITY	VOLUMES					VOIDS				
Specimen Number	Asphalt Content (%)	Average Thickness (inches)	In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D (F-E)		(100-B) x I (Gsb)	B x I (Gb)	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N) O			
5.5-1	5.5	2.583	1217.4	711.2	1219.5	508.3	2.395	2.513	83.1	12.9	149.5	4.7	16.9	72.1	32.6	39.8	0.820
5.5-2	5.5	2.574	1215.8	708.2	1217.5	509.3	2.387	2.513	82.9	12.8	149.0	5.0	17.1	70.7	32.9	39.8	0.826
5.5-3	5.5	2.536	1218.9	713.4	1220.6	507.2	2.403	2.513	83.4	12.9	150.0	4.4	16.6	73.6	32.4	39.8	0.814
AVG												4.7	16.8	72.1	32.6	39.8	0.820
6.0-1	6.0	2.552	1221.1	715.5	1222.9	507.4	2.407	2.494	83.1	14.1	150.2	3.5	16.9	79.3	32.7	39.8	0.821
6.0-2	6.0	2.556	1220.2	711.2	1222.0	510.8	2.389	2.494	82.5	14.0	149.1	4.2	17.5	75.9	33.2	39.8	0.834
6.0-3	6.0	2.554	1219.1	710.0	1220.6	510.6	2.388	2.494	82.5	14.0	149.0	4.3	17.5	75.7	33.2	39.8	0.834
AVG												4.0	17.3	76.9	33.0	39.8	0.830
6.5-1	6.5	2.545	1224.7	714.9	1226.0	511.1	2.396	2.475	82.3	15.2	149.5	3.2	17.7	82.0	33.3	39.8	0.837
6.5-2	6.5	2.558	1224.9	715.3	1226.2	510.9	2.398	2.475	82.4	15.2	149.6	3.1	17.6	82.2	33.3	39.8	0.836
6.5-3	6.5	2.588	1223.1	714.0	1224.7	510.7	2.395	2.475	82.3	15.2	149.4	3.2	17.7	81.7	33.4	39.8	0.838
AVG												3.2	17.7	82.0	33.3	39.8	0.837
0.0-1	0.0	0.0	0.0	0.0	0.0	0.0	0.000	2.745	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513
0.0-2	0.0	0.0	0.0	0.0	0.0	0.0	0.000	2.745	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513
0.0-3	0.0	0.0	0.0	0.0	0.0	0.0	0.000	2.745	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513
AVG												100.0	100.0	0.0	100.0	39.8	2.513
0.0-1	0.0	0.0	0.0	0.0	0.0	0.0	0.000	2.745	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513
0.0-2	0.0	0.0	0.0	0.0	0.0	0.0	0.000	2.745	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513
0.0-3	0.0	0.0	0.0	0.0	0.0	0.0	0.000	2.745	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513
AVG												100.0	100.0	0.0	100.0	39.8	2.513

Computed By: G. FLOWERS

Checked By: T. LYNN

SSD = Saturated Surface Dry

gm = gram

pcf = pounds per cubic foot

Gmb = Bulk Specific Gravity of Compacted Mix

Gsb = Bulk Specific Gravity of Aggregate

Sp. Gr. = Specific Gravity

cc = cubic centimeter

in = inches

Gmm = Theoretical Maximum Specific Gravity of Mix

Gse = Effective Specific Gravity of Aggregate

TMD = Theoretical Maximum Density

AC = Asphalt Cement

Gsa = Apparent Specific Gravity of Aggregate

Gb = Specific Gravity of Asphalt Cement

Table F5.2: Various Test Results for Mortars Compacted With the Marshall Hammer

National Center for Asphalt Technology

SMA Mix Design Summary

Mortar Mix "E"

Marshall Stability			Marshall Flow		
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
Average			Average		

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
Average		

Permeability						
Blows	Specimen A		Specimen B		average	
	VTM	k (in/min)	VTM	k(in/min)	VTM	k(in/min)
10	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A
50	N/A	N/A	N/A	N/A	N/A	N/A

Moisture Susceptability									
without Lime					with 1% Lime				
Conditioned					Conditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)				
Unconditioned					Unconditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
		N/A					N/A		
		N/A					N/A		
		N/A					N/A		
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)				
Tensile Strength Ratio (%)					Tensile Strength Ratio (%)				

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number		
				Average
	25			
4				
40				

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number		
				Average
	3600			
4500				

Draindown (%)	Test Temp (deg C)	Sample Number		
		A	B	Average
	140	0.000	0.033	0.017
155	0.000	0.082	0.041	
170	0.000	0.000	0.000	

Table F5.3: Results from Mortar Work
National Center for Asphalt Technology
SMA Mix Design Summary
Mortar Mix "E"

OPTIMUM GRADATION - - 20% Passing 4.75 mm Sieve

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIAL: Labstock Granite/10% Traprock/Ergon AC-20/Rock Wool						COARSE AGGREGATE INFORMATION:								DATE: January 24, 1996	
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gs Effective Sp. Gr. of Agg. (Gse)		Bulk Sp. Gr. of Agg. (Gsb)				Percent Coarse Aggregate: 80		Bulk Specific Gravity of CA (Gca): 2.688		Unit wt. of CA in DRC (pcf): 100.93		Unit wt. of CA in DRC (kg/m ³): 1616.7			
			2.762		2.763				2.722									
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITY		VOLUMES			VOIDS						
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(I-J)	(100-K)	100(O-N)				
						(F-E)	(F-E)		(Gsb)	(Gb)				O				
5.0-1	5.0	103.9	4162.5	2451.6	4181.8	1730.2	2.406	2.547	84.0	11.7	150.1	5.6	16.0	65.4	32.0	39.8	0.804	
5.0-2	5.0	103.6	4190.5	2464.1	4204.5	1740.4	2.408	2.547	84.0	11.7	150.2	5.5	16.0	65.7	31.9	39.8	0.802	
5.0-3	5.0	103.8	4192.2	2464.3	4213.4	1749.1	2.397	2.547	83.6	11.7	149.6	5.9	16.4	63.9	32.2	39.8	0.810	
AVG												5.6	16.1	65.0	32.0	39.8	0.805	
5.5-1	5.5	103.1	4205.3	2473.2	4215.9	1742.7	2.413	2.528	83.8	12.9	150.6	4.5	16.2	72.1	32.1	39.8	0.807	
5.5-2	5.5	103.1	4209.7	2481.7	4219.1	1737.4	2.423	2.528	84.1	13.0	151.2	4.1	15.9	74.0	31.9	39.8	0.800	
5.5-3	5.5	103.3	4212.5	2474.5	4221.5	1747.0	2.411	2.528	83.7	12.9	150.5	4.6	16.3	71.8	32.2	39.8	0.809	
AVG												4.4	16.1	72.6	32.1	39.8	0.806	
6.0-1	6.0	103.2	4264.9	2512.0	4270.0	1758.0	2.426	2.508	83.8	14.2	151.4	3.3	16.2	79.8	32.1	39.8	0.807	
6.0-2	6.0	101.9	4230.8	2498.7	4235.1	1736.4	2.437	2.508	84.1	14.3	152.0	2.9	15.9	82.0	31.8	39.8	0.800	
6.0-3	6.0	103.1	4223.1	2482.7	4231.1	1748.4	2.415	2.508	83.4	14.1	150.7	3.7	16.6	77.7	32.4	39.8	0.815	
AVG												3.3	16.2	79.9	32.1	39.8	0.807	

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

Table F5.4: Various Test Results for Mortars Compacted With the SGC
National Center for Asphalt Technology
SMA Mix Design Summary
Mortar Mix "E"

Marshall Stability			Marshall Flow		
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
Average			Average		

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
Average		

Permeability						
Blows	Specimen A		Specimen B		average	
	VTM	k (in/min)	VTM	k(in/min)	VTM	k(in/min)
10	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A
50	N/A	N/A	N/A	N/A	N/A	N/A

Moisture Susceptibility									
without Lime					with 1% Lime				
Conditioned					Conditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)				
Unconditioned					Unconditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
		N/A					N/A		
		N/A					N/A		
		N/A					N/A		
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)				
Tensile Strength Ratio (%)					Tensile Strength Ratio (%)				

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number		
	25			Average
	4			
	40			

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number		
	3600			Average
	4500			

Draindown (%)	Test Temp (deg C)	Sample Number		
		A	B	Average
	140	0.000	0.033	0.017
155	0.000	0.082	0.041	
170	0.000	0.000	0.000	

Table F6.1: Results from Mortar Work
National Center for Asphalt Technology
SMA Mix Design Summary
Mortar Mix "F"

OPTIMUM GRADATION - - 20% Passing 4.75 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP 9-8			MATERIAL: Labstock Granite/8% Whimpey/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:										DATE: 80 February 5, 1996	
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G Effective Sp. Gr. of Agg. (G _{se}) = 2.745		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.705				Percent Coarse Aggregate: 80			Bulk Specific Gravity of CA (G _{ca}): 2.688			Unit wt. of CA in DRC (pcf): 100.93			Unit wt. of CA in DRC (kg/m ³): 1616.7		
Specimen Number	Asphalt Content (%)	Average Thickness (inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAV		VOLUMES			VOIDS								
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc			
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S			
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)						
5.5-1	5.5	2.557	1208.0	703.2	1212.9	509.7	2.370	2.482	82.8	12.7	147.9	4.5	17.2	73.8	33.3	39.8	0.838			
5.5-2	5.5	2.565	1214.5	706.6	1217.7	511.1	2.376	2.482	83.0	12.8	148.3	4.3	17.0	74.9	33.2	39.8	0.834			
5.5-3	5.5	2.566	1212.4	705.5	1215.4	509.9	2.378	2.482	83.1	12.8	148.4	4.2	16.9	75.2	33.1	39.8	0.832			
AVG												4.3	17.0	74.6	33.2	39.8	0.835			
6.0-1	6.0	2.574	1218.1	707.2	1220.1	512.9	2.375	2.464	82.5	13.9	148.2	3.6	17.5	79.4	33.6	39.8	0.843			
6.0-2	6.0	2.558	1218.0	707.4	1219.1	511.7	2.380	2.464	82.7	13.9	148.5	3.4	17.3	80.5	33.4	39.8	0.840			
6.0-3	6.0	2.553	1221.8	712.2	1223.1	510.9	2.391	2.464	83.1	14.0	149.2	2.9	16.9	82.7	33.1	39.8	0.832			
AVG												3.3	17.2	80.9	33.4	39.8	0.838			
6.5-1	6.5	2.574	1219.3	706.4	1221.0	514.6	2.369	2.445	81.9	15.0	147.9	3.1	18.1	82.9	34.1	39.8	0.856			
6.5-2	6.5	2.566	1219.7	708.3	1220.8	512.5	2.380	2.445	82.3	15.1	148.5	2.7	17.7	84.9	33.8	39.8	0.849			
6.5-3	6.5	2.556	1222.0	710.0	1223.0	513.0	2.382	2.445	82.3	15.1	148.6	2.6	17.7	85.4	33.7	39.8	0.847			
AVG												2.8	17.8	84.4	33.9	39.8	0.851			
0.0-1	0.0	0.0	0.0	0.0	0.0	0.0	0.000	2.706	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513			
0.0-2	0.0	0.0	0.0	0.0	0.0	0.0	0.000	2.706	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513			
0.0-3	0.0	0.0	0.0	0.0	0.0	0.0	0.000	2.706	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513			
AVG												100.0	100.0	0.0	100.0	39.8	2.513			
0.0-1	0.0	0.0	0.0	0.0	0.0	0.0	0.000	2.706	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513			
0.0-2	0.0	0.0	0.0	0.0	0.0	0.0	0.000	2.706	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513			
0.0-3	0.0	0.0	0.0	0.0	0.0	0.0	0.000	2.706	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513			
AVG												100.0	100.0	0.0	100.0	39.8	2.513			

Computed By: G. FLOWERS

Checked By: T. LYNN

SSD = Saturated Surface Dry

gm = gram

pcf = pounds per cubic foot

Gmb = Bulk Specific Gravity of Compacted Mix

Gsb = Bulk Specific Gravity of Aggregate

Sp. Gr. = Specific Gravity

cc = cubic centimeter

in = inches

Gmm = Theoretical Maximum Specific Gravity of Mix

Gse = Effective Specific Gravity of Aggregate

TMD = Theoretical Maximum Density

AC = Asphalt Cement

Gsa = Apparent Specific Gravity of Aggregate

Gb = Specific Gravity of Asphalt Cement

Table F6.2: Various Test Results for Mortars Compacted With the Marshall Hammer

National Center for Asphalt Technology

SMA Mix Design Summary

Mortar Mix "F"

Marshall Stability			Marshall Flow		
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
Average			Average		

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
Average		

Permeability						
Blows	Specimen A		Specimen B		average	
	VTM	k (in/min)	VTM	k (in/min)	VTM	k (in/min)
10	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A
50	N/A	N/A	N/A	N/A	N/A	N/A

Moisture Susceptibility									
without Lime					with 1% Lime				
Conditioned					Conditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)				
Unconditioned					Unconditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
		N/A					N/A		
		N/A					N/A		
		N/A					N/A		
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)				
Tensile Strength Ratio (%)					Tensile Strength Ratio (%)				

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number		
	25			Average
	4			
	40			

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number		
	3600			Average
	4500			

Draindown (%)	Test Temp (deg C)	Sample Number		
	140	A	B	Average
	155	0.000	0.033	0.017
	170	0.000	0.082	0.041
		0.000	0.000	0.000

Table F6.3: Results from Mortar Work
National Center for Asphalt Technology
SMA Mix Design Summary
Mortar Mix "F"

OPTIMUM GRADATION - - 20% Passing 4.75 mm Sieve

SHRP 100 REV

PROJECT: NCHRP 9-8			MATERIAL: Labstock Granite/8% Wimpey/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:							80	DATE:
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _s Effective Sp. Gr. of Agg. (G _{se})		Bulk Sp. Gr. of Agg. (G _{sb})				Percent Coarse Aggregate:							2,688	January 31, 1996
			2.745		2.740				Bulk Specific Gravity of CA (G _{ca}):							100.93	
									Unit wt. of CA in DRC (pcf):							1616.7	
									Unit wt. of CA in DRC (kg/m ³):								
Specimen Number	Asphalt Content (%)	Average Thickness (mm)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITY		VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)			
						(F-E)	(G _b)		(G _b)	(G _b)				O			
5.0-1	5.0	105.0	4201.9	2461.8	4237.3	1775.5	2.367	2.528	83.1	11.5	147.7	6.4	16.9	62.1	33.1	39.8	0.831
5.0-2	5.0	105.0	4195.1	2461.1	4228.2	1767.1	2.374	2.528	83.4	11.6	148.1	6.1	16.6	63.3	32.9	39.8	0.826
5.0-3	5.0	105.0	4204.3	2472.4	4236.3	1763.9	2.384	2.528	83.7	11.6	148.7	5.7	16.3	64.8	32.6	39.8	0.819
AVG												6.1	16.6	63.4	21.8	39.8	0.826
5.5-1	5.5	104.1	4220.1	2469.2	4235.6	1766.4	2.389	2.509	83.5	12.8	149.1	4.8	16.5	71.1	32.8	39.8	0.824
5.5-2	5.5	104.0	4217.6	2475.0	4234.4	1759.4	2.397	2.509	83.7	12.9	149.6	4.5	16.3	72.6	32.6	39.8	0.819
5.5-3	5.5	103.5	4236.1	2484.7	4246.9	1762.2	2.404	2.509	84.0	12.9	150.0	4.2	16.0	73.8	32.4	39.8	0.814
AVG												4.5	16.3	72.5	32.6	39.8	0.819
6.0-1	6.0	104.2	4252.4	2491.2	4262.8	1771.6	2.400	2.490	83.4	14.1	149.8	3.6	16.6	78.3	32.8	39.8	0.825
6.0-2	6.0	104.1	4241.6	2482.8	4249.6	1766.8	2.401	2.490	83.4	14.1	149.8	3.6	16.6	78.4	32.8	39.8	0.825
6.0-3	6.0	103.2	4231.1	2479.2	4238.5	1759.3	2.405	2.490	83.6	14.1	150.1	3.4	16.4	79.2	32.7	39.8	0.822
AVG												3.5	16.5	78.6	32.8	39.8	0.824
7.0-1	7.0					0.0	0.000	2.453	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513
7.0-2	7.0					0.0	0.000	2.453	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513
7.0-3	7.0					0.0	0.000	2.453	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513
AVG												100.0	100.0	0.0	100.0	39.8	2.513
7.5-1	7.5					0.0	0.000	2.434	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513
7.5-2	7.5					0.0	0.000	2.434	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513
7.5-3	7.5					0.0	0.000	2.434	0.0	0.0	0.0	100.0	100.0	0.0	100.0	39.8	2.513
AVG												100.0	100.0	0.0	100.0	39.8	2.513

Computed By: G. FLOWERS

Checked By: T. LYNN

SSD = Saturated Surface Dry

gm = gram

pcf = pounds per cubic foot

Gmb = Bulk Specific Gravity of Compacted Mix

Gsb = Bulk Specific Gravity of Aggregate

Sp. Gr. = Specific Gravity

cc = cubic centimeter

in = inches

Gmm = Theoretical Maximum Specific Gravity of Mix

Gse = Effective Specific Gravity of Aggregate

TMD = Theoretical Maximum Density

AC = Asphalt Cement

Gsa = Apparent Specific Gravity of Aggregate

Gb = Specific Gravity of Asphalt Cement

Table F6.4: Various Test Results for Mortars Compacted With the SGC
National Center for Asphalt Technology
SMA Mix Design Summary
Mortar Mix "F"

Marshall Stability			Marshall Flow		
Specimen Number	Uncorrected Value (N)	Correction Factor	Corrected Value (N)	Specimen Number	Flow 0.25mm
Average			Average		

Indirect Tensile Strength		
Specimen Number	Ultimate Load (N)	Tensile Strength (kPa)
Average		

Permeability						
Blows	Specimen A		Specimen B		average	
	VTM	k (in/min)	VTM	k(in/min)	VTM	k(in/min)
10	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A
40	N/A	N/A	N/A	N/A	N/A	N/A
50	N/A	N/A	N/A	N/A	N/A	N/A

Moisture Susceptability									
without Lime					with 1% Lime				
Conditioned					Conditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)				
Unconditioned					Unconditioned				
Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)	Specimen Number	VTM (%)	Deg. Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
		N/A					N/A		
		N/A					N/A		
		N/A					N/A		
Average Tensile Strength (kPa)					Average Tensile Strength (kPa)				
Tensile Strength Ratio (%)					Tensile Strength Ratio (%)				

Resilient Modulus (kPa)	Test Temp (deg C)	Specimen Number		
				Average
	25			
4				
40				

Creep Stiffness (MPa)	Test Time (sec)	Specimen Number		
				Average
	3600			
4500				

Draindown (%)	Test Temp (deg C)	Sample Number		
		A	B	Average
	140	0.000	0.033	0.017
155	0.000	0.082	0.041	
170	0.000	0.000	0.000	

**Appendix G -
Flat or Elongated SMA Mixture Design and Results**

Table G1. Flat and Elongated SMA Mixture Design Results
National Center for Asphalt Technology
SMA Trial Gradation Summary

GRADATION A--20% Passing 4.75 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP9-8			MATERIALS: 100 % Flat or Elongated/Dolcito/Ergon AC-20/Cellulose				COARSE AGGREGATE INFORMATION:				Percent Coarse Aggregate:				DATE:		
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa) = 2.676		Effective Sp. Gr. of Agg. (Gse) = 2.658		Bulk Sp. Gr. of Agg. (Gsb) = 2.644				Bulk Specific Gravity of CA (Gca): 2.615				OCTOBER 31, 1995		
											Unit wt. of CA in DRC (pcf): 93.90						
											Unit wt. of CA in DRC (kg/m ³): 1504.1						
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D (F-E)	J	(100-B) x I (Gsb)	B x I (Gb)	(1 x 62.4)	100(1-I/J)	(100-K)	100(O-N)			
100A-A1	6.3	2.662	1214.4	687.1	1216.1	529.0	2.296	2.416	81.4	14.1	143.3	5.0	18.6	73.2	34.2	42.4	0.806
100A-A2	6.3	2.655	1218.3	691.6	1219.9	528.3	2.306	2.416	81.7	14.2	143.9	4.6	18.3	74.8	33.9	42.4	0.799
100A-A3	6.3	2.708	1216.2	687.6	1219.3	531.7	2.287	2.416	81.0	14.1	142.7	5.3	19.0	72.0	34.4	42.4	0.812
												5.0	18.6	73.3	34.2	42.4	0.806

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gse = Effective Specific Gravity of Aggregate
 Gsb = Bulk Specific Gravity of Aggregate Gc = Specific Gravity of Asphalt Cement

GRADATION B--24% Passing 4.75 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP9-8			MATERIALS: 100 % Flat or Elongated/Dolcito/Ergon AC-20/Cellulose				COARSE AGGREGATE INFORMATION:				Percent Coarse Aggregate:				DATE:		
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa) = 2.675		Effective Sp. Gr. of Agg. (Gse) = 2.654		Bulk Sp. Gr. of Agg. (Gsb) = 2.643				Bulk Specific Gravity of CA (Gca): 2.615				OCTOBER 31, 1995		
											Unit wt. of CA in DRC (pcf): 93.90						
											Unit wt. of CA in DRC (kg/m ³): 1504.1						
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D (F-E)	J	(100-B) x I (Gsb)	B x I (Gb)	(1 x 62.4)	100(1-I/J)	(100-K)	100(O-N)			
100A-B1	6.3	2.602	1216.4	694.1	1217.7	523.6	2.323	2.413	82.3	14.3	145.0	3.7	17.7	79.1	33.4	42.4	0.788
100A-B2	6.3	2.607	1222.6	702.0	1223.8	521.8	2.343	2.413	83.0	14.4	146.2	2.9	17.0	82.9	32.8	42.4	0.774
100A-B3	6.3	2.606	1218.1	698.6	1219.4	520.8	2.339	2.413	82.9	14.4	146.0	3.1	17.1	81.9	33.0	42.4	0.777
												3.2	17.3	81.3	33.1	42.4	0.779

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gse = Effective Specific Gravity of Aggregate
 Gsb = Bulk Specific Gravity of Aggregate Gc = Specific Gravity of Asphalt Cement

GRADATION C--28% Passing 4.75 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP9-8			MATERIALS: 100 % Flat or Elongated/Dolcito/Ergon AC-20/Cellulose				COARSE AGGREGATE INFORMATION:				Percent Coarse Aggregate:				DATE:		
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa) = 2.674		Effective Sp. Gr. of Agg. (Gse) = 2.655		Bulk Sp. Gr. of Agg. (Gsb) = 2.642				Bulk Specific Gravity of CA (Gca): 2.615				OCTOBER 31, 1995		
											Unit wt. of CA in DRC (pcf): 93.90						
											Unit wt. of CA in DRC (kg/m ³): 1504.1						
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D (F-E)	J	(100-B) x I (Gsb)	B x I (Gb)	(1 x 62.4)	100(1-I/J)	(100-K)	100(O-N)			
100A-C1	6.3	2.535	1216.9	703.9	1217.6	513.7	2.369	2.414	84.0	14.6	147.8	1.9	16.0	88.4	32.1	42.4	0.757
100A-C2	6.3	2.527	1214.7	703.5	1215.4	511.9	2.373	2.414	84.1	14.6	148.1	1.7	15.9	89.3	32.0	42.4	0.754
100A-C3	6.3	2.541	1225.0	710.8	1225.6	514.8	2.380	2.414	84.3	14.6	148.5	1.4	15.7	90.9	31.8	42.4	0.749
												1.7	15.9	89.5	32.0	42.4	0.753

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gse = Effective Specific Gravity of Aggregate
 Gsb = Bulk Specific Gravity of Aggregate Gc = Specific Gravity of Asphalt Cement

Table G2: Flat and Elongated SMA Mixture Design Results
National Center for Asphalt Technology
SMA Mix Design Summary

OPTIMUM GRADATION - - 21% Passing 4.75 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP9-8			MATERIAL: 100 % Flat or Elongated/Dolcito/ AC-20/Cellulose						COARSE AGGREGATE INFORMATION:										
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa) = 2.676		Effective Sp. Gr. of Agg. (Gse) = 2.669		Bulk Sp. Gr. of Agg. (Gsb) = 2.644		Percent Coarse Aggregate: 79			Bulk Specific Gravity of CA (Gca): 2.615		Unit wt. of CA in DRC (pcf): 93.90		Unit wt. of CA in DRC (kg/m3): 1504.1		DATE: NOVEMBER 13 1995	
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS							
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc		
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S		
						(F-E)	D		(100-B) x I	B x I	(1 x 62.4)	100(1-I/J)	(100-K)	100(O-N)					
							(F-E)		(Gsb)	(Gb)				O					
6.0-1	6.0	2.683	1215.6	686.3	1218.6	532.3	2.284	2.435	81.2	13.4	142.5	6.2	18.8	67.0	35.1	42.4	0.829		
6.0-2	6.0	2.678	1210.8	682.8	1213.2	530.4	2.283	2.435	81.2	13.4	142.4	6.3	18.8	66.8	35.2	42.4	0.829		
6.0-3	6.0	2.718	1214.0	686.6	1217.7	531.1	2.286	2.435	81.3	13.4	142.6	6.1	18.7	67.3	35.1	42.4	0.827		
AVG												6.2	18.8	67.0	35.1	42.4	0.828		
6.5-1	6.5	2.706	1209.9	679.4	1212.0	532.6	2.272	2.417	80.3	14.4	141.8	6.0	19.7	69.4	35.8	42.4	0.845		
6.5-2	6.5	2.716	1224.3	691.8	1227.4	535.6	2.286	2.417	80.8	14.5	142.6	5.4	19.2	71.7	35.4	42.4	0.835		
6.5-3	6.5	2.686	1212.8	684.0	1214.8	530.8	2.285	2.417	80.8	14.5	142.6	5.5	19.2	71.5	35.5	42.4	0.836		
AVG												5.6	19.3	70.9	35.6	42.4	0.839		
7.0-1	7.0	2.675	1211.1	683.1	1212.5	529.4	2.288	2.400	80.5	15.6	142.8	4.7	19.5	76.0	35.7	42.4	0.842		
7.0-2	7.0	2.660	1218.8	690.3	1219.7	529.4	2.302	2.400	81.0	15.7	143.7	4.1	19.0	78.6	35.3	42.4	0.833		
7.0-3	7.0	2.686	1216.5	689.2	1218.1	528.9	2.300	2.400	80.9	15.7	143.5	4.2	19.1	78.2	35.4	42.4	0.834		
AVG												4.3	19.2	77.6	35.5	42.4	0.836		
7.5-1	7.5	2.632	1230.8	700.9	1231.7	530.8	2.319	2.383	81.1	17.0	144.7	2.7	18.9	85.8	35.2	42.4	0.830		
7.5-2	7.5	2.663	1222.8	693.1	1224.6	531.5	2.301	2.383	80.5	16.8	143.6	3.4	19.5	82.4	35.7	42.4	0.842		
7.5-3	7.5	2.649	1224.4	695.6	1225.6	530.0	2.310	2.383	80.8	16.9	144.2	3.0	19.2	84.1	35.4	42.4	0.835		
AVG												3.1	19.2	84.1	35.5	42.4	0.836		

Computed By: G. FLOWERS

Checked By: T. LYNN

SSD = Saturated Surface Dry
 Sp. Gr. = Specific Gravity
 TMD = Theoretical Maximum Density

gm = gram
 cc = cubic centimeter
 AC = Asphalt Cement
 pcf = pounds per cubic foot
 in = inches

Gmb = Bulk Specific Gravity of Compacted Mix
 Gmm = Theoretical Maximum Specific Gravity of Mix
 Gsa = Apparent Specific Gravity of Aggregate

Gsb = Bulk Specific Gravity of Aggregate
 Gse = Effective Specific Gravity of Aggregate
 Gb = Specific Gravity of Asphalt Cement

Table G3: Flat and Elongated SMA Mixture Design and Results
National Center for Asphalt Technology
SMA Optimum Mix Summary

OPTIMUM GRADATION - - 21% Passing 4.75 mm Sieve/OPTIMUM ASPHALT CONTENT - - 7.2%

MARSHALL 50 BLOWS

PROJECT: NCHRP9-8			MATERIAL: 100 % Flat or Elongated/Dolcico/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:													
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa) = 2.676		Effective Sp. Gr. of Agg. (Gse) = 2.669		Bulk Sp. Gr. of Agg. (Gsb) = 2.644		Percent Coarse Aggregate: 79			Bulk Specific Gravity of CA (Gca): 2.615			Unit wt. of CA in DRC (pcf): 93.90			Unit wt. of CA in DRC (kg/m3): 1504.1			DATE: December 5, 1995	
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS										
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc					
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S					
						(F-E)	D (F-E)		$\frac{(100-B) \times I}{(Gsb)}$	$\frac{B \times I}{(Gb)}$	(1 x 62.4)	100(1-I/J)	(100-K)	$\frac{100(O-N)}{O}$								
7.2-1	7.2	2.666	1212.3	688.4	1214.0	525.6	2.307	2.393	81.0	16.2	143.9	3.6	19.0	81.0	35.3	42.4	0.833					
7.2-2	7.2	2.650	1220.4	693.2	1222.0	528.8	2.308	2.393	81.0	16.2	144.0	3.6	19.0	81.3	35.3	42.4	0.832					
7.2-3	7.2	2.653	1215.1	689.4	1216.7	527.3	2.304	2.393	80.9	16.2	143.8	3.7	19.1	80.6	35.4	42.4	0.834					
7.2-4	7.2	2.664	1208.6	684.3	1211.2	526.9	2.294	2.393	80.5	16.1	143.1	4.1	19.5	78.7	35.7	42.4	0.841					
AVG												3.8	19.2	80.4	35.4	42.4	0.835					
Computed By: G. FLOWERS			Checked By: T. LYNN																			
SSD = Saturated Surface Dry			gm = gram			pcf = pounds per cubic foot			Gmb = Bulk Specific Gravity of Compacted Mix			Gsb = Bulk Specific Gravity of Aggregate										
Sp. Gr. = Specific Gravity			cc = cubic centimeter			in = inches			Gmm = Theoretical Maximum Specific Gravity of Mix			Gse = Effective Specific Gravity of Aggregate										
TMD = Theoretical Maximum Density			AC = Asphalt Cement			Gsa = Apparent Specific Gravity of Aggregate			Gb = Specific Gravity of Asphalt Cement													

**TABLE G4. - Flat and Elongated SMA Mixture Design Results
NCHRP 9-8
Task 10 Evaluation of Flat or Elongated Particles
Mix Aggregate: 100% Flat and Elongated**

Moisture Susceptibility				
Conditioned				
Specimen Number	Air Voids (%)	Deg. of Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
20 blows	5.9	79.2	4671	417
1	6.2	66.0	4782	423
2	5.9	68.9	4448	396
Average Tensile Strength (kPa)				412
Unconditioned				
Specimen Number	Air Voids (%)	Deg. of Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
3	6.4	N/A	9008	800
4	6.1	N/A	9119	806
25 Blows	5.7	N/A	9786	880
Average Tensile Strength (kPa)				829
Tensile Strength Ratio (%)				49.7

Aggregate Breakdown Sieve Analysis					
Sieve (mm)	Optimum Gradation	Marshall 50 Blows			
		1	2	3	Average
19.00	100.0	100.0	100.0	100.0	100.0
12.50	90.1	92.6	93.6	92.1	92.8
9.50	52.6	64.0	64.1	62.6	63.6
4.75	21.0	30.7	30.6	29.8	30.4
2.36	17.9	22.2	22.1	21.8	22.0
1.18	15.8	18.0	18.0	18.2	18.1
0.60	13.4	15.0	15.0	14.9	15.0
0.30	12.4	13.4	13.4	13.3	13.4
0.15	11.1	11.9	11.9	11.9	11.9
0.75	10.0	10.0	10.0	9.9	10.0

Table G5: Flat and Elongated SMA Mixture Design and Results
National Center for Asphalt Technology
SMA Trial Gradation Summary

GRADATION A--20% Passing 4.75 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP9-8			MATERIALS: 100% Cubical/Dolcito/AC-20/Cellulose				COARSE AGGREGATE INFORMATION:						Percent Coarse Aggregate:			DATE:		
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa}) = 2.665		Effective Sp. Gr. of Agg. (G _{se}) = 2.659		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.626			Bulk Specific Gravity of CA (G _{ca}): 2.593			Unit wt. of CA in DRC (pcf): 97.20		Unit wt. of CA in DRC (kg/m ³): 1557.0		October 26, 1995	
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS						
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D	J	(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)				
						(F-E)	D	J	(Gsb)	(Gb)		O						
100B-A1	6.3	2.640	1204.7	684.4	1208.5	524.1	2.299	2.416	82.0	14.1	143.4	4.9	18.0	73.0	33.6	39.9	0.841	
100B-A2	6.3	2.699	1217.4	689.8	1219.9	530.1	2.297	2.416	81.9	14.1	143.3	4.9	18.1	72.6	33.6	39.9	0.842	
100B-A3	6.3	2.731	1204.7	684.4	1210.5	526.1	2.290	2.416	81.7	14.1	142.9	5.2	18.3	71.5	33.8	39.9	0.847	
												5.0	18.1	72.4	33.7	39.9	0.844	

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gse = Effective Specific Gravity of Aggregate
 Gb = Bulk Specific Gravity of Aggregate Gc = Specific Gravity of Asphalt Cement

GRADATION B--24% Passing 4.75 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP9-8			MATERIALS: 100% Cubical/Dolcito/Ergon AC-20/Cellulose				COARSE AGGREGATE INFORMATION:						Percent Coarse Aggregate:			DATE:		
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa}) = 2.665		Effective Sp. Gr. of Agg. (G _{se}) = 2.658		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.626			Bulk Specific Gravity of CA (G _{ca}): 2.593			Unit wt. of CA in DRC (pcf): 97.20		Unit wt. of CA in DRC (kg/m ³): 1557.0		October 26, 1995	
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS						
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D	J	(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)				
						(F-E)	D	J	(Gsb)	(Gb)		O						
100B-B1	6.3	2.635	1219.3	699.0	1220.8	521.8	2.337	2.415	83.4	14.4	145.8	3.2	16.6	80.5	32.4	39.9	0.813	
100B-B2	6.3	2.603	1209.7	695.0	1211.8	516.8	2.341	2.415	83.5	14.4	146.1	3.1	16.5	81.3	32.3	39.9	0.810	
100B-B3	6.3	2.616	1221.3	702.7	1222.7	520.0	2.349	2.415	83.8	14.4	146.6	2.7	16.2	83.0	32.1	39.9	0.805	
												3.0	16.4	81.6	32.3	39.9	0.810	

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gse = Effective Specific Gravity of Aggregate
 Gb = Bulk Specific Gravity of Aggregate Gc = Specific Gravity of Asphalt Cement

GRADATION C--28% Passing 4.75 mm Sieve

MARSHALL 50 BLOW

PROJECT: NCHRP9-8			MATERIALS: 100% Cubical/Dolcito/Ergon AC-20/Cellulose				COARSE AGGREGATE INFORMATION:						Percent Coarse Aggregate:			DATE:		
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa}) = 2.664		Effective Sp. Gr. of Agg. (G _{se}) = 2.659		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.626			Bulk Specific Gravity of CA (G _{ca}): 2.593			Unit wt. of CA in DRC (pcf): 97.20		Unit wt. of CA in DRC (kg/m ³): 1557.0		October 26, 1995	
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS						
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D	J	(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)				
						(F-E)	D	J	(Gsb)	(Gb)		O						
100B-C1	6.3	2.612	1215.1	689.5	1216.8	527.3	2.304	2.416	82.2	14.2	143.8	4.6	17.8	74.0	33.4	39.9	0.837	
100B-C2	6.3	2.587	1215.6	700.9	1216.9	516.0	2.356	2.416	84.1	14.5	147.0	2.5	15.9	84.4	31.9	39.9	0.800	
100B-C3	6.3	2.590	1223.8	706.6	1224.7	518.1	2.362	2.416	84.3	14.5	147.4	2.2	15.7	85.8	31.7	39.9	0.795	
												3.1	16.5	81.4	32.3	39.9	0.810	

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gse = Effective Specific Gravity of Aggregate
 Gb = Bulk Specific Gravity of Aggregate Gc = Specific Gravity of Asphalt Cement

Table G6: Flat and Elongated SMA Mixture Design and Results
National Center for Asphalt Technology
SMA Mix Design Summary

OPTIMUM GRADATION - - 21% Passing 4.75 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP9-8			MATERIAL: 100% Cubical/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:										Percent Coarse Aggregate: 79	DATE: NOVEMBER 13,
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa) = 2.665		Effective Sp. Gr. of Agg. (Gse) = 2.664		Bulk Sp. Gr. of Agg. (Gsb) = 2.626		Bulk Specific Gravity of CA (Gca): 2.593			Unit wt. of CA in DRC (pcf): 97.20			Unit wt. of CA in DRC (kg/m3): 1557.0					
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS							
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc			
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S			
						(F-E)	$\frac{D}{(F-E)}$		$\frac{(100-B) \times I}{(Gsb)}$	$\frac{B \times I}{(Gb)}$	(I x 62.4)	100(I-I/J)	(100-K)	$\frac{100(O-N)}{O}$						
6.0-1	6.0	2.683	1209.4	683.0	1212.0	529.0	2.286	2.436	81.8	13.4	142.7	6.1	18.2	66.1	34.5	39.9	0.865			
6.0-2	6.0	2.681	1206.4	684.5	1210.3	525.8	2.294	2.436	82.1	13.4	143.2	5.8	17.9	67.5	34.3	39.9	0.860			
6.0-3	6.0	2.699	1211.6	683.7	1214.4	530.7	2.283	2.436	81.7	13.4	142.5	6.3	18.3	65.6	34.6	39.9	0.868			
AVG												6.1	18.1	66.4	34.5	39.9	0.864			
6.5-1	6.5	2.668	1215.4	691.0	1218.4	527.4	2.305	2.418	82.1	14.6	143.8	4.7	17.9	73.8	34.4	39.9	0.861			
6.5-2	6.5	2.667	1213.7	686.4	1216.3	529.9	2.290	2.418	81.6	14.5	142.9	5.3	18.4	71.4	34.8	39.9	0.871			
6.5-3	6.5	2.706	1211.7	682.7	1214.2	531.5	2.280	2.418	81.2	14.5	142.3	5.7	18.8	69.6	35.1	39.9	0.879			
AVG												5.2	18.4	71.6	34.7	39.9	0.870			
7.0-1	7.0	2.668	1236.4	704.9	1237.1	532.2	2.323	2.401	82.3	15.9	145.0	3.2	17.7	81.7	34.2	39.9	0.857			
7.0-2	7.0	2.662	1220.3	693.2	1221.1	527.9	2.312	2.401	81.9	15.8	144.2	3.7	18.1	79.5	34.5	39.9	0.865			
7.0-3	7.0	2.672	1230.3	700.3	1231.0	530.7	2.318	2.401	82.1	15.8	144.7	3.4	17.9	80.7	34.3	39.9	0.860			
AVG												3.5	17.9	80.6	34.3	39.9	0.861			

Computed By: G. FLOWERS
 SSD = Saturated Surface Dry
 Sp. Gr. = Specific Gravity
 TMD = Theoretical Maximum Density

gm = gram
 cc = cubic centimeter
 AC = Asphalt Cement

Checked By: T. LYNN
 pcf = pounds per cubic foot
 in = inches

Gmb = Bulk Specific Gravity of Compacted Mix
 Gmm = Theoretical Maximum Specific Gravity of Mix
 Gsa = Apparent Specific Gravity of Aggregate

Gsb = Bulk Specific Gravity of Aggregate
 Gse = Effective Specific Gravity of Aggregate
 Gb = Specific Gravity of Asphalt Cement

Table G7: Flat and Elongated SMA Mixture Design and Results
National Center for Asphalt Technology
SMA Optimum Mix Summary

OPTIMUM GRADATION - - 21% Passing 4.75 mm Sieve/OPTIMUM ASPHALT CONTENT - - 6.9%

MARSHALL 50 BLOWS

PROJECT: NCHRP9-8			MATERIAL: 100% Cubical/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:										
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (G; Effective Sp. Gr. of Agg. (Gse) = 2.665			Bulk Sp. Gr. of Agg. (Gsb) = 2.626			Percent Coarse Aggregate: 79			Bulk Specific Gravity of CA (Gca): 2.593				Unit wt. of CA in DRC (pcf): 97.20			DATE: December 5, 1
									Unit wt. of CA in DRC (kg/m3): 1557.0										
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS						
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc		
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S		
						(F-E)	D (F-E)		(100-B) x I (Gsb)	B x I (Gb)	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N) O					
6.9-1	6.9	2.676	1212.9	688.9	1215.1	526.2	2.305	2.399	81.7	15.5	143.8	3.9	18.3	78.6	34.6	39.9	0.868		
6.9-2	6.9	2.695	1211.6	685.1	1213.7	528.6	2.292	2.399	81.3	15.4	143.0	4.5	18.7	76.2	35.0	39.9	0.877		
6.9-3	6.9	2.714	1212.0	687.3	1214.7	527.4	2.298	2.399	81.5	15.5	143.4	4.2	18.5	77.3	34.8	39.9	0.873		
6.9-4	6.9	2.670	1214.8	691.8	1216.8	525.0	2.314	2.399	82.0	15.6	144.4	3.5	18.0	80.3	34.4	39.9	0.861		
AVG												4.0	18.4	* 78.1 *	34.7	39.9	0.870		
Computed By: G. FLOWERS			Checked By: T. LYNN																
SSD = Saturated Surface Dry			gm = gram			pcf = pounds per cubic foot			Gmb = Bulk Specific Gravity of Compacted Mix			Gsb = Bulk Specific Gravity of Aggregate							
Sp. Gr. = Specific Gravity			cc = cubic centimeter			in = inches			Gmm = Theoretical Maximum Specific Gravity of Mix			Gse = Effective Specific Gravity of Aggregate							
TMD = Theoretical Maximum Density			AC = Asphalt Cement						Gsa = Apparent Specific Gravity of Aggregate			Gb = Specific Gravity of Asphalt Cement							

**TABLE G8. - Flat and Elongated SMA Mixture Design and Results
NCHRP 9-8
Task 10 Evaluation of Flat or Elongated Particles
Mix Aggregate: 100% Cubical**

Moisture Susceptibility				
Conditioned				
Specimen Number	Air Voids (%)	Deg. of Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
2	5.6	61.4	5338	474
4	6.7	63.8	4615	410
6	6.6	63.4	4726	417
Average Tensile Strength (kPa)				434
Unconditioned				
Specimen Number	Air Voids (%)	Deg. of Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
1	6.1	N/A	9730	876
5	6.6	N/A	8452	741
7	6	N/A	8896	796
Average Tensile Strength (kPa)				804
Tensile Strength Ratio (%)				53.9

Aggregate Breakdown Sieve Analysis					
Sieve (mm)	Optimum Gradation	Marshall 50 Blows			
		1	2	3	Average
19.00	100.0	100.0	100.0	100.0	100.0
12.50	90.1	92.9	91.8	92.0	92.2
9.50	52.6	61.8	59.9	62.4	61.4
4.75	21.0	26.0	25.1	26.8	26.0
2.36	17.9	19.8	19.4	20.5	19.9
1.18	15.8	16.7	16.6	17.4	16.9
0.60	13.4	14.0	13.9	14.3	14.1
0.30	12.4	12.7	12.6	12.9	12.7
0.15	11.1	11.4	11.3	11.6	11.4
0.75	10.0	9.5	9.4	9.6	9.5

Table G9: Flat and Elongated SMA Mixture Design and Results
National Center for Asphalt Technology
SMA Trial Gradation Summary

GRADATION A--20% Passing 4.75 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP9-8			MATERIALS: 75% F and E/ 25% Cubical/Dolcito/AC-20/Cellulose						COARSE AGGREGATE INFORMATION:				Percent Coarse Aggregate:			DATE:	
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa}) = 2.673		Effective Sp. Gr. of Agg. (G _{se}) = 2.659		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.639						Bulk Specific Gravity of CA (G _{ca}): 2.609			October 26, 1995	
													Unit wt. of CA in DRC (pcf): 95.40				
													Unit wt. of CA in DRC (kg/m ³): 1528.2				
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (G _{mb})	TMD (G _{mm})	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D		(100-B) x I	B x I	(1 x 62.4)	100(I-I/J)	(100-K)	100(O-N)			
75A-A1	6.3	2.704	1213.9	685.1	1217.8	532.7	2.279	2.416	80.9	14.0	142.2	5.7	19.1	70.2	34.5	41.4	0.835
75A-A2	6.3	2.722	1221.5	690.5	1223.6	533.1	2.291	2.416	81.4	14.1	143.0	5.2	18.6	72.3	34.2	41.4	0.826
75A-A3	6.3	2.700	1193.3	669.8	1197.9	528.1	2.260	2.416	80.2	13.9	141.0	6.5	19.8	67.3	35.1	41.4	0.848
												5.8	19.2	69.9	34.6	41.4	0.836

Computed By: G. FLOWERS Checked By: T. LYNN
SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

GRADATION B--24% Passing 4.75 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP9-8			MATERIALS: 75% F and E/ 25% Cubical/Dolcito/AC-20/Cellulose						COARSE AGGREGATE INFORMATION:				Percent Coarse Aggregate:			DATE:	
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa}) = 2.672		Effective Sp. Gr. of Agg. (G _{se}) = 2.655		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.639						Bulk Specific Gravity of CA (G _{ca}): 2.609			October 26, 1995	
													Unit wt. of CA in DRC (pcf): 95.40				
													Unit wt. of CA in DRC (kg/m ³): 1528.2				
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (G _{mb})	TMD (G _{mm})	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D		(100-B) x I	B x I	(1 x 62.4)	100(I-I/J)	(100-K)	100(O-N)			
75A-B1	6.3	2.684	1216.4	691.3	1218.2	526.9	2.309	2.413	82.0	14.2	144.1	4.3	18.0	76.0	33.7	41.4	0.814
75A-B2	6.3	2.661	1230.7	705.8	1231.9	526.1	2.339	2.413	83.1	14.4	146.0	3.1	16.9	82.0	32.8	41.4	0.793
75A-B3	6.3	2.646	1207.8	686.7	1209.4	522.7	2.311	2.413	82.0	14.2	144.2	4.2	18.0	76.4	33.6	41.4	0.812
												3.9	17.6	78.1	33.4	41.4	0.806

Computed By: G. FLOWERS Checked By: T. LYNN
SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

GRADATION C--28% Passing 4.75 mm Sieve

MARSHALL 50 BLOW

PROJECT: NCHRP9-8			MATERIALS: 75% F and E/ 25% Cubical/Dolcito/AC-20/Cellulose						COARSE AGGREGATE INFORMATION:				Percent Coarse Aggregate:			DATE:	
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa}) = 2.671		Effective Sp. Gr. of Agg. (G _{se}) = 2.649		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.638						Bulk Specific Gravity of CA (G _{ca}): 2.593			October 26, 1995	
													Unit wt. of CA in DRC (pcf): 97.20				
													Unit wt. of CA in DRC (kg/m ³): 1557.0				
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (G _{mb})	TMD (G _{mm})	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D		(100-B) x I	B x I	(1 x 62.4)	100(I-I/J)	(100-K)	100(O-N)			
75A-C1	6.3	2.536	1212.0	701.8	1212.6	510.8	2.373	2.408	84.3	14.6	148.1	1.5	15.7	90.7	31.8	41.4	0.769
75A-C2	6.3	2.549	1223.9	708.6	1224.4	515.8	2.373	2.408	84.3	14.6	148.1	1.5	15.7	90.7	31.8	41.4	0.769
75A-C3	6.3	2.544	1209.5	697.7	1210.6	512.9	2.358	2.408	83.8	14.5	147.1	2.1	16.2	87.3	32.2	41.4	0.780
												1.7	15.9	89.5	32.0	41.4	0.773

Computed By: G. FLOWERS Checked By: T. LYNN
SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

Table G10: Flat and Elongated SMA Mixture Design and Results
National Center for Asphalt Technology
SMA Mix Design Summary

OPTIMUM GRADATION - - 21% Passing 4.75 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP9-8			MATERIAL: 75% F and E/ 25% Cubical/Dolceto/AC-20/Cellulose						COARSE AGGREGATE INFORMATION:										Percent Coarse Aggregate: 79		DATE: 79		
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa) = 2.673		Effective Sp. Gr. of Agg. (Gse) = 2.670		Bulk Sp. Gr. of Agg. (Gsb) = 2.639													Bulk Specific Gravity of CA (Gca): 2.609		NOVEMBER 13,	
			WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS											
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA d						
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S						
						(F-E)	$\frac{D}{(F-E)}$		$\frac{(100-B) \times I}{(Gsb)}$	$\frac{B \times I}{(Gb)}$	(I x 62.4)	100(I-I/J)	(100-K)	$\frac{100(O-N)}{O}$									
6.5-1	6.5	2.655	1207.9	683.4	1209.5	526.1	2.296	2.417	81.3	14.6	143.3	5.0	18.7	73.2	35.0	41.4	0.846						
6.5-2	6.5	2.682	1222.6	694.3	1224.7	530.4	2.305	2.417	81.7	14.6	143.8	4.6	18.3	74.7	34.7	41.4	0.840						
6.5-3	6.5	2.673	1214.5	687.2	1215.9	528.7	2.297	2.417	81.4	14.6	143.3	5.0	18.6	73.4	35.0	41.4	0.845						
AVG												4.9	18.5	73.7	34.9	41.4	0.844						
7.0-1	7.0	2.668	1222.6	692.3	1223.8	531.5	2.300	2.400	81.1	15.7	143.5	4.2	18.9	78.1	35.2	41.4	0.851						
7.0-2	7.0	2.652	1223.4	696.0	1224.7	528.7	2.314	2.400	81.5	15.8	144.4	3.6	18.5	80.6	34.8	41.4	0.842						
7.0-3	7.0	2.631	1224.5	697.1	1225.3	528.2	2.318	2.400	81.7	15.8	144.7	3.4	18.3	81.4	34.7	41.4	0.839						
AVG												3.7	18.6	80.0	34.9	41.4	0.844						
7.5-1	7.5	2.645	1228.1	699.7	1229.0	529.3	2.320	2.383	81.3	17.0	144.8	2.6	18.7	85.9	35.0	41.4	0.846						
7.5-2	7.5	2.650	1222.9	693.6	1224.0	530.4	2.306	2.383	80.8	16.9	143.9	3.2	19.2	83.1	35.4	41.4	0.856						
7.5-3	7.5	2.647	1224.0	697.4	1226.8	529.4	2.312	2.383	81.0	16.9	144.3	3.0	19.0	84.3	35.2	41.4	0.852						
AVG												3.0	18.9	84.4	35.2	41.4	0.852						

Computed By: G. FLOWERS

Checked By: T. LYNN

SSD = Saturated Surface Dry
 Sp. Gr. = Specific Gravity
 TMD = Theoretical Maximum Density

gm = gram
 cc = cubic centimeter
 AC = Asphalt Cement

pcf = pounds per cubic foot
 in = inches

Gmb = Bulk Specific Gravity of Compacted Mix
 Gmm = Theoretical Maximum Specific Gravity of Mix
 Gsa = Apparent Specific Gravity of Aggregate

Gsb = Bulk Specific Gravity of Aggregate
 Gse = Effective Specific Gravity of Aggregate
 Gb = Specific Gravity of Asphalt Cement

Table G11: Flat and Elongated SMA Mixture Design and Results
National Center for Asphalt Technology
SMA Optimum Mix Summary

OPTIMUM GRADATION - - 21% Passing 4.75 mm Sieve/OPTIMUM ASPHALT CONTENT - - 67.0%

MARSHALL 50 BLOWS

PROJECT: NCHRP9-8			MATERIAL: 75% F and E/ 25% Cubical/Dolcito/AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate: 79		DATE: December 5,	
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gs Effective Sp. Gr. of Agg. (Gse) Bulk Sp. Gr. of Agg. (Gsb) = 2.673 2.661 2.639											Bulk Specific Gravity of CA (Gca): 2.609			
			WEIGHTS			MIX VOLUM	SPECIFIC GRAVITIES		VOLUMES			VOIDS					
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA d
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)	$\frac{D}{(F-E)}$		$\frac{(100-B) \times I}{(Gsb)}$	$\frac{B \times I}{(Gb)}$	(I x 62.4)	100(1-I/J)	(100-K)	$\frac{100(O-N)}{O}$			
7.0-1	7.0	2.688	1222.6	692.3	1223.8	531.5	2.300	2.396	81.1	15.7	143.5	4.0	18.9	78.9	35.2	41.4	0.851
7.0-2	7.0	2.652	1223.4	696.0	1224.7	528.7	2.314	2.396	81.5	15.8	144.4	3.4	18.5	81.4	34.8	41.4	0.842
7.0-3	7.0	2.631	1224.5	697.1	1225.3	528.2	2.318	2.396	81.7	15.8	144.7	3.2	18.3	82.3	34.7	41.4	0.839
7.0-4	7.0	2.659	1220.1	692.2	1221.9	529.7	2.303	2.396	81.2	15.7	143.7	3.9	18.8	79.5	35.1	41.4	0.849
7.0-5	7.0	2.700	1216.4	687.1	1219.2	532.1	2.286	2.396	80.6	15.6	142.6	4.6	19.4	76.4	35.6	41.4	0.861
7.0-6	7.0	2.687	1209.9	683.3	1213.1	529.8	2.284	2.396	80.5	15.6	142.5	4.7	19.5	76.0	35.7	41.4	0.863
7.0-7	7.0	2.682	1206.7	683.4	1209.5	526.1	2.294	2.396	80.8	15.7	143.1	4.3	19.2	77.7	35.4	41.4	0.856
7.0-8	7.0	2.680	1217.3	692.3	1219.3	527.0	2.310	2.396	81.4	15.8	144.1	3.6	18.6	80.7	35.0	41.4	0.845
AVG												4.0	18.9	79.1	35.2	41.4	0.851

Computed By: G. FLOWERS

Checked By: T. LYNN

SSD = Saturated Surface Dry

gm = gram

pcf = pounds per cubic foot

Gmb = Bulk Specific Gravity of Compacted Mix

Gsb = Bulk Specific Gravity of Aggregate

Sp. Gr. = Specific Gravity

cc = cubic centimeter

in = inches

Gmm = Theoretical Maximum Specific Gravity of Mix

Gse = Effective Specific Gravity of Aggregate

TMD = Theoretical Maximum Density

AC = Asphalt Cement

Gsa = Apparent Specific Gravity of Aggregate

Gb = Specific Gravity of Asphalt Cement

**TABLE G12. - Flat and Elongated SMA Mixture Design and Results
NCHRP 9-8
Task 10 Evaluation of Flat or Elongated Particles
Mix Aggregate: 75% Flat and Elongated**

Moisture Susceptibility				
Conditioned				
Specimen Number	Air Voids (%)	Deg. of Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
2	5.4	63.1	4671	416
5	5.4	74.2	4337	384
7	6.3	62.1	4559	399
Average Tensile Strength (kPa)				400
Unconditioned				
Specimen Number	Air Voids (%)	Deg. of Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
3	5.7	N/A	9675	859
4	5.6	N/A	8174	721
6	5.7	N/A	7784	690
Average Tensile Strength (kPa)				757
Tensile Strength Ratio (%)				52.8

Aggregate Breakdown Sieve Analysis					
Sieve (mm)	Optimum Gradation	Marshall 50 Blows			
		1	2	3	Average
19.00	100.0	100.0	100.0	100.0	100.0
12.50	90.1	93.0	93.0	91.5	92.5
9.50	52.6	64.8	35.3	64.3	54.8
4.75	21.0	29.7	30.0	28.2	29.3
2.36	17.9	22.1	22.0	21.2	21.8
1.18	15.8	18.4	18.1	17.7	18.1
0.60	13.4	15.0	14.9	14.6	14.8
0.30	12.4	13.5	13.3	13.0	13.3
0.15	11.1	12.0	11.8	11.6	11.8
0.75	10.0	10.0	9.8	9.7	9.8

TABLE G13. - Flat and Elongated SMA Mixture Design and Results
National Center for Asphalt Technology
SMA Trial Gradation Summary

GRADATION A--20% Passing 4.75 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP9-8			MATERIALS: 50% F or E /50% Cubical/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:						Percent Coarse Aggregate:		DATE:
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa})		Effective Sp. Gr. of Agg. (G _{se})		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.635		Bulk Specific Gravity of CA (G _{ca}): 2.604		Unit wt. of CA in DRC (pcf): 95.80		Unit wt. of CA in DRC (kg/m ³): 1534.6		80		October 27, 1995
			2.670		2.656												
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (G _{mb})	TMD (G _{mm})	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	D	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D	J	(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)			
50A-A1	6.3	2.683	1220.4	692.7	1222.8	530.1	2.302	2.414	81.9	14.2	143.7	4.6	18.1	74.5	33.7	41.0	0.822
50A-A2	6.3	2.690	1216.2	685.6	1218.3	532.7	2.283	2.414	81.2	14.0	142.5	5.4	18.8	71.2	34.3	41.0	0.836
50A-A3	6.3	2.701	1223.1	688.6	1225.2	536.6	2.279	2.414	81.1	14.0	142.2	5.6	18.9	70.6	34.4	41.0	0.838
												5.2	18.6	72.1	34.1	41.0	0.832

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot G_{mb} = Bulk Specific Gravity of Compacted Mix G_{sb} = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches G_{mm} = Theoretical Maximum Specific Gravity of Mix G_{se} = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement G_{sa} = Apparent Specific Gravity of Aggregate G_b = Specific Gravity of Asphalt Cement

GRADATION B--24% Passing 4.75 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP9-8			MATERIALS: 50% F or E /50% Cubical/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:						Percent Coarse Aggregate:		DATE:
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa})		Effective Sp. Gr. of Agg. (G _{se})		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.634		Bulk Specific Gravity of CA (G _{ca}): 2.604		Unit wt. of CA in DRC (pcf): 95.80		Unit wt. of CA in DRC (kg/m ³): 1534.6		76		October 27, 1995
			2.670		2.657												
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (G _{mb})	TMD (G _{mm})	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	D	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D <td>J <td>(100-B) x I</td> <td>B x I</td> <td>(I x 62.4)</td> <td>100(1-I/J)</td> <td>(100-K)</td> <td>100(O-N)</td> <td></td> <td></td> <td></td> </td>	J <td>(100-B) x I</td> <td>B x I</td> <td>(I x 62.4)</td> <td>100(1-I/J)</td> <td>(100-K)</td> <td>100(O-N)</td> <td></td> <td></td> <td></td>	(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)			
50A-B1	6.3	2.599	1217.3	697.9	1218.9	521.0	2.336	2.415	83.1	14.4	145.8	3.3	16.9	80.7	32.7	41.0	0.798
50A-B2	6.3	2.597	1217.8	699.2	1219.0	519.8	2.343	2.415	83.3	14.4	146.2	3.0	16.7	82.1	32.6	41.0	0.794
50A-B3	6.3	2.611	1218.3	698.3	1220.1	521.8	2.335	2.415	83.1	14.4	145.7	3.3	16.9	80.4	32.8	41.0	0.800
												3.2	16.8	81.1	32.7	41.0	0.797

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot G_{mb} = Bulk Specific Gravity of Compacted Mix G_{sb} = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches G_{mm} = Theoretical Maximum Specific Gravity of Mix G_{se} = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement G_{sa} = Apparent Specific Gravity of Aggregate G_b = Specific Gravity of Asphalt Cement

GRADATION C--28% Passing 4.75 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP9-8			MATERIALS: 50% F or E /50% Cubical/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:						Percent Coarse Aggregate:		DATE:
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa})		Effective Sp. Gr. of Agg. (G _{se})		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.634		Bulk Specific Gravity of CA (G _{ca}): 2.604		Unit wt. of CA in DRC (pcf): 95.80		Unit wt. of CA in DRC (kg/m ³): 1534.6		72		October 27, 1995
			2.669		2.652												
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES		VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (G _{mb})	TMD (G _{mm})	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc
A	B	C	D	E	F	G	D	J	K	L	M	N	O	P	Q	R	S
						(F-E)	D <td>J <td>(100-B) x I</td> <td>B x I</td> <td>(I x 62.4)</td> <td>100(1-I/J)</td> <td>(100-K)</td> <td>100(O-N)</td> <td></td> <td></td> <td></td> </td>	J <td>(100-B) x I</td> <td>B x I</td> <td>(I x 62.4)</td> <td>100(1-I/J)</td> <td>(100-K)</td> <td>100(O-N)</td> <td></td> <td></td> <td></td>	(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)			
50A-C1	6.3	2.543	1218.0	702.4	1219.0	516.6	2.358	2.411	83.9	14.5	147.1	2.2	16.1	86.3	32.1	41.0	0.783
50A-C2	6.3	2.546	1215.6	703.0	1216.4	513.4	2.368	2.411	84.2	14.6	147.7	1.8	15.8	88.6	31.8	41.0	0.776
50A-C3	6.3	2.544	1215.5	701.7	1216.7	515.0	2.360	2.411	84.0	14.5	147.3	2.1	16.0	86.9	32.1	41.0	0.782
												2.0	16.0	87.3	32.0	41.0	0.781

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot G_{mb} = Bulk Specific Gravity of Compacted Mix G_{sb} = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches G_{mm} = Theoretical Maximum Specific Gravity of Mix G_{se} = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement G_{sa} = Apparent Specific Gravity of Aggregate G_b = Specific Gravity of Asphalt Cement

TABLE G14. - Flat and Elongated SMA Mixture Design and Results
National Center for Asphalt Technology
SMA Mix Design Summary

OPTIMUM GRADATION - - 21% Passing 4.75 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP9-8			MATERIAL: 50% F or E /50% Cubical/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:												
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa) = 2.670		Effective Sp. Gr. of Agg. (Gse) = 2.660		Bulk Sp. Gr. of Agg. (Gsb) = 2.635		Percent Coarse Aggregate: 79			Bulk Specific Gravity of CA (Gca): 2.604			Unit wt. of CA in DRC (pcf): 95.80			Unit wt. of CA in DRC (kg/m3): 1534.6			DATE: November 16,
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS								
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc				
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S				
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)							
							(F-E)		(Gsb)	(Gb)				O							
6.5-1	6.5	2.630	1219.6	696.3	1220.8	524.5	2.325	2.410	82.5	14.7	145.1	3.5	17.5	79.9	34.0	41.0	0.830				
6.5-2	6.5	2.652	1203.7	679.7	1204.8	525.1	2.292	2.410	81.3	14.5	143.0	4.9	18.7	73.8	35.0	41.0	0.853				
6.5-3	6.5	2.676	1219.0	691.2	1220.4	529.2	2.303	2.410	81.7	14.6	143.7	4.4	18.3	75.8	34.7	41.0	0.845				
AVG												4.3	18.1	76.5	34.6	41.0	0.843				
7.0-1	7.0	2.664	1223.9	695.4	1225.1	529.7	2.311	2.393	81.5	15.8	144.2	3.4	18.5	81.3	34.8	41.0	0.849				
7.0-2	7.0	2.665	1222.2	694.4	1223.6	529.2	2.310	2.393	81.5	15.8	144.1	3.5	18.5	81.1	34.8	41.0	0.850				
7.0-3	7.0	2.687	1222.6	694.7	1224.2	529.5	2.309	2.393	81.5	15.8	144.1	3.5	18.5	81.0	34.9	41.0	0.850				
AVG												3.5	18.5	81.2	34.8	41.0	0.849				
7.5-1	7.5	2.692	1222.7	695.3	1224.1	528.8	2.312	2.376	81.2	16.9	144.3	2.7	18.8	85.7	35.1	41.0	0.856				
7.5-2	7.5	2.674	1228.3	698.0	1229.3	531.3	2.312	2.376	81.2	16.9	144.3	2.7	18.8	85.7	35.1	41.0	0.856				
7.5-3	7.5	2.656	1229.3	699.9	1230.0	530.1	2.319	2.376	81.4	17.0	144.7	2.4	18.6	87.1	34.9	41.0	0.852				
AVG												2.6	18.8	86.2	35.1	41.0	0.855				

Computed By: G. FLOWERS

Checked By: T. LYNN

SSD = Saturated Surface Dry

gm = gram

pcf = pounds per cubic foot

Gmb = Bulk Specific Gravity of Compacted Mix

Gsb = Bulk Specific Gravity of Aggregate

Sp. Gr. = Specific Gravity

cc = cubic centimeter

in = inches

Gmm = Theoretical Maximum Specific Gravity of Mix

Gse = Effective Specific Gravity of Aggregate

TMD = Theoretical Maximum Density

AC = Asphalt Cement

Gsa = Apparent Specific Gravity of Aggregate

Gb = Specific Gravity of Asphalt Cement

TABLE G15. - Flat and Elongated SMA Mixture Design and Results
National Center for Asphalt Technology
SMA Optimum Mix Summary

OPTIMUM GRADATION - - 21% Passing 4.75 mm Sieve/OPTIMUM ASPHALT CONTENT - - 6.8%

MARSHALL 50 BLOWS

PROJECT: NCHRP9-8			MATERIAL: 50% F or E /50% Cubical/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate: 79		DATE: December 5,		
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gs Effective Sp. Gr. of Agg. (Gse) = 2.670			Bulk Sp. Gr. of Agg. (Gsb) = 2.635								Bulk Specific Gravity of CA (Gca): 2.604				
														Unit wt. of CA in DRC (pcf): 95.80				
														Unit wt. of CA in DRC (kg/m3): 1534.6				
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUM	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA d	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D		(100-B) x I	B x I	(I x 62.4)	100(1-I/J)	(100-K)	100(O-N)				
						(F-E)	(F-E)		(Gsb)	(Gb)				O				
6.8-1	6.8	2.663	1226.7	698.6	1228.0	529.4	2.317	2.399	82.0	15.4	144.6	3.4	18.0	81.1	34.5	41.0	0.841	
6.8-2	6.8	2.658	1224.7	699.7	1226.3	526.6	2.326	2.399	82.3	15.4	145.1	3.1	17.7	82.8	34.2	41.0	0.835	
6.8-3	6.8	2.647	1216.4	692.7	1217.5	524.8	2.318	2.399	82.0	15.4	144.6	3.4	18.0	81.2	34.5	41.0	0.840	
6.8-4	6.8	2.661	1226.5	697.6	1227.4	529.8	2.315	2.399	81.9	15.4	144.5	3.5	18.1	80.7	34.5	41.0	0.842	
AVG												3.3	18.0	81.4	34.4	41.0	0.840	
Computed By: G. FLOWERS			Checked By: T. LYNN															
SSD = Saturated Surface Dry			gm = gram			pcf = pounds per cubic foot			Gmb = Bulk Specific Gravity of Compacted Mix					Gsb = Bulk Specific Gravity of Aggregate				
Sp. Gr. = Specific Gravity			cc = cubic centimeter			in = inches			Gmm = Theoretical Maximum Specific Gravity of Mix					Gse = Effective Specific Gravity of Aggregate				
TMD = Theoretical Maximum Density			AC = Asphalt Cement						Gsa = Apparent Specific Gravity of Aggregate					Gb = Specific Gravity of Asphalt Cement				

**TABLE G16. - Flat and Elongated SMA Mixture Design and Results
NCHRP 9-8
Task 10 Evaluation of Flat or Elongated Particles
Mix Aggregate: 50% Flat and Elongated**

Moisture Susceptibility				
Conditioned				
Specimen Number	Air Voids (%)	Deg. of Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
1	5.5	60.3	4003	353
6	5.3	59.3	3837	339
7	6.6	58.4	3892	338
Average Tensile Strength (kPa)				343
Unconditioned				
Specimen Number	Air Voids (%)	Deg. of Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
3	6.1	N/A	7896	693
4	6	N/A	8563	754
5	5.4	N/A	9008	797
Average Tensile Strength (kPa)				748
Tensile Strength Ratio (%)				45.9

Aggregate Breakdown Sieve Analysis					
Sieve (mm)	Optimum Gradation	Marshall 50 Blows			
		1	2	3	Average
19.00	100.0	100.0	100.0	100.0	100.0
12.50	90.1	92.7	91.5	91.9	92.0
9.50	52.6	64.2	63.2	64.4	63.9
4.75	21.0	28.9	28.4	28.8	28.7
2.36	17.9	21.7	21.5	21.7	21.6
1.18	15.8	18.0	17.9	18.1	18.0
0.60	13.4	15.0	14.8	15.0	14.9
0.30	12.4	13.5	13.3	13.4	13.4
0.15	11.1	12.0	11.8	12.0	11.9
0.75	10.0	9.9	9.8	9.9	9.9

TABLE G17. - Flat and Elongated SMA Mixture Design and Results
National Center for Asphalt Technology
SMA Trial Gradation Summary

GRADATION A--20% Passing 4.75 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP9-8			MATERIALS: 25% F or E/75% Cubical/Dolcito/AC-20/Cellulose						COARSE AGGREGATE INFORMATION:				Percent Coarse Aggregate:			DATE:		
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa}) = 2.668		Effective Sp. Gr. of Agg. (G _{se}) = 2.664		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.630						Bulk Specific Gravity of CA (G _{ca}): 80			October 31, 1995		
									Unit wt. of CA in DRC (pcf): 96.50				Unit wt. of CA in DRC (kg/m ³): 1545.8					
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D	J	(100-B) x 1	B x 1	(1 x 62.4)	100(I-J)	(100-K)	100(O-N)				
						(F-E)	D	J	(Gsb)	(G _b)				O				
25A-A1	6.3	2.680	1217.2	691.3	1220.2	528.9	2.301	2.420	82.0	14.1	143.6	4.9	18.0	72.8	33.6	40.4	0.831	
25A-A2	6.3	2.693	1216.5	687.1	1219.1	532.0	2.287	2.420	81.5	14.1	142.7	5.5	18.5	70.3	34.0	40.4	0.841	
25A-A3	6.3	2.724	1212.0	680.3	1214.5	534.2	2.269	2.420	80.8	13.9	141.6	6.2	19.2	67.4	34.5	40.4	0.854	
												5.6	18.6	70.2	34.1	40.4	0.842	

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gse = Effective Specific Gravity of Aggregate
 Gb = Bulk Specific Gravity of Aggregate Gc = Specific Gravity of Asphalt Cement

GRADATION B--24% Passing 4.75 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP9-8			MATERIALS: 25% F or E/75% Cubical/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:				Percent Coarse Aggregate:			DATE:		
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa}) = 2.667		Effective Sp. Gr. of Agg. (G _{se}) = 2.650		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.630						Bulk Specific Gravity of CA (G _{ca}): 76			October 31, 1995		
									Unit wt. of CA in DRC (pcf): 96.50				Unit wt. of CA in DRC (kg/m ³): 1545.8					
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D	J	(100-B) x 1	B x 1	(1 x 62.4)	100(I-J)	(100-K)	100(O-N)				
						(F-E)	D	J	(Gsb)	(G _b)				O				
25A-B1	6.3	2.589	1211.3	695.1	1212.4	517.3	2.342	2.409	83.4	14.4	146.1	2.8	16.6	83.1	32.4	40.4	0.802	
25A-B2	6.3	2.593	1212.4	695.5	1213.6	518.1	2.340	2.409	83.4	14.4	146.0	2.9	16.6	82.8	32.5	40.4	0.803	
25A-B3	6.3	2.599	1216.1	698.2	1218.3	520.1	2.338	2.409	83.3	14.4	145.9	2.9	16.7	82.4	32.5	40.4	0.805	
												2.9	16.6	82.8	32.5	40.4	0.803	

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gse = Effective Specific Gravity of Aggregate
 Gb = Bulk Specific Gravity of Aggregate Gc = Specific Gravity of Asphalt Cement

GRADATION C--28% Passing 4.75 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP9-8			MATERIALS: 25% F or E/75% Cubical/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:				Percent Coarse Aggregate:			DATE:		
AC Sp. Gr. (G _b) = 1.025			Apparent Sp. Gr. of Agg. (G _{sa}) = 2.667		Effective Sp. Gr. of Agg. (G _{se}) = 2.653		Bulk Sp. Gr. of Agg. (G _{sb}) = 2.630						Bulk Specific Gravity of CA (G _{ca}): 72			October 31, 1995		
									Unit wt. of CA in DRC (pcf): 96.50				Unit wt. of CA in DRC (kg/m ³): 1545.8					
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	D	J	(100-B) x 1	B x 1	(1 x 62.4)	100(I-J)	(100-K)	100(O-N)				
						(F-E)	D	J	(Gsb)	(G _b)				O				
25A-C1	6.3	2.515	1213.6	703.8	1214.1	510.3	2.378	2.412	84.7	14.6	148.4	1.4	15.3	90.8	31.4	40.4	0.776	
25A-C2	6.3	2.538	1215.6	703.7	1216.8	513.1	2.369	2.412	84.4	14.6	147.8	1.8	15.6	88.6	31.6	40.4	0.782	
25A-C3	6.3	2.533	1210.7	700.7	1211.5	510.8	2.370	2.412	84.4	14.6	147.9	1.7	15.6	88.9	31.6	40.4	0.782	
												1.6	15.5	89.4	31.5	40.4	0.780	

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gse = Effective Specific Gravity of Aggregate
 Gb = Bulk Specific Gravity of Aggregate Gc = Specific Gravity of Asphalt Cement

TABLE G18. - Flat and Elongated SMA Mixture Design and Results
National Center for Asphalt Technology
SMA Mix Design Summary

OPTIMUM GRADATION - - 21% Passing 4.75 mm Sieve

MARSHALL 50 BLOWS

PROJECT: NCHRP9-8			MATERIAL: 25% F or E/75% Cubical/Dolcico/ AC-20/Cellulose						COARSE AGGREGATE INFORMATION:					Percent Coarse Aggregate: 79		DATE: November 16		
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gsa) = 2.668		Effective Sp. Gr. of Agg. (Gse) = 2.663		Bulk Sp. Gr. of Agg. (Gsb) = 2.630			Bulk Specific Gravity of CA (Gca): 2.598					Unit wt. of CA in DRC (pcf): 96.50		Unit wt. of CA in DRC (kg/m3): 1545.8	
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUME	SPECIFIC GRAVITIES			VOLUMES			VOIDS					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc	
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	
						(F-E)	$\frac{D}{(F-E)}$		$\frac{(100-B) \times I}{(Gsb)}$	$\frac{B \times I}{(Gb)}$	(I x 62.4)	100(1-I/J)	(100-K)	$\frac{100(O-N)}{O}$				
6.5-1	6.5	2.688	1216.9	690.9	1218.7	527.8	2.306	2.412	82.0	14.6	143.9	4.4	18.0	75.5	34.4	40.4	0.852	
6.5-2	6.5	2.680	1225.3	696.2	1226.9	530.7	2.309	2.412	82.1	14.6	144.1	4.3	17.9	76.1	34.4	40.4	0.850	
6.5-3	6.5	2.666	1218.5	692.4	1220.2	527.8	2.309	2.412	82.1	14.6	144.1	4.3	17.9	76.1	34.4	40.4	0.850	
AVG												4.3	18.0	75.9	34.4	40.4	0.850	
7.0-1	7.0	2.647	1224.7	698.0	1226.0	528.0	2.320	2.395	82.0	15.8	144.7	3.2	18.0	82.5	34.4	40.4	0.851	
7.0-2	7.0	2.658	1228.5	701.1	1229.8	528.7	2.324	2.395	82.2	15.9	145.0	3.0	17.8	83.3	34.3	40.4	0.848	
7.0-3	7.0	2.666	1219.7	694.8	1224.5	529.7	2.303	2.395	81.4	15.7	143.7	3.9	18.6	79.2	34.9	40.4	0.863	
AVG												3.3	18.1	81.7	34.5	40.4	0.854	
7.5-1	7.5	2.663	1220.5	692.9	1221.6	528.7	2.308	2.378	81.2	16.9	144.0	2.9	18.8	84.5	35.1	40.4	0.867	
7.5-2	7.5	2.677	1220.4	690.9	1221.6	530.7	2.300	2.378	80.9	16.8	143.5	3.3	19.1	82.8	35.3	40.4	0.873	
7.5-3	7.5	2.671	1215.3	688.2	1217.1	528.9	2.298	2.378	80.8	16.8	143.4	3.4	19.2	82.4	35.4	40.4	0.875	
AVG												3.2	19.0	83.2	35.3	40.4	0.872	

Computed By: G. FLOWERS Checked By: T. LYNN

SSD = Saturated Surface Dry gm = gram pcf = pounds per cubic foot Gmb = Bulk Specific Gravity of Compacted Mix Gsb = Bulk Specific Gravity of Aggregate
 Sp. Gr. = Specific Gravity cc = cubic centimeter in = inches Gmm = Theoretical Maximum Specific Gravity of Mix Gse = Effective Specific Gravity of Aggregate
 TMD = Theoretical Maximum Density AC = Asphalt Cement Gsa = Apparent Specific Gravity of Aggregate Gb = Specific Gravity of Asphalt Cement

TABLE G19. - Flat and Elongated SMA Mixture Design and Results
National Center for Asphalt Technology
SMA Optimum Mix Summary

OPTIMUM GRADATION - - 21% Passing 4.75 mm Sieve/OPTIMUM ASPHALT CONTENT - - 6.8%

MARSHALL 50 BLOWS

PROJECT: NCHRP9-8			MATERIAL: 25% F or E/75% Cubical/Dolcito/Ergon AC-20/Cellulose						COARSE AGGREGATE INFORMATION:											
AC Sp. Gr. (Gb) = 1.025			Apparent Sp. Gr. of Agg. (Gs Effective Sp. Gr. of Agg. (Gse) = 2.668			Bulk Sp. Gr. of Agg. (Gsb) = 2.630			Percent Coarse Aggregate: 79			Bulk Specific Gravity of CA (Gca): 2.598				Unit wt. of CA in DRC (pcf): 96.50			DATE: December 5, 2011	
									Unit wt. of CA in DRC (kg/m3): 1545.8											
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOLUM	SPECIFIC GRAVITIES			VOLUMES			VOIDS							
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	VCA (%)	VCA drc (%)	VCA / VCA drc			
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S			
						(F-E)	D (F-E)		$\frac{(100-B) \times I}{(Gsb)}$	$\frac{B \times I}{(Gb)}$	(I x 62.4)	100(1-I/J)	(100-K)	$\frac{100(O-N)}{O}$						
6.8-1	6.8	2.639	1225.6	698.3	1227.5	529.2	2.316	2.397	82.1	15.4	144.5	3.4	17.9	81.1	34.4	40.4	0.850			
6.8-2	6.8	2.644	1222.9	696.5	1224.7	528.2	2.315	2.397	82.0	15.4	144.5	3.4	18.0	81.0	34.4	40.4	0.850			
6.8-3	6.8	2.649	1224.5	698.1	1226.6	528.5	2.317	2.397	82.1	15.4	144.6	3.3	17.9	81.3	34.3	40.4	0.849			
6.8-4	6.8	2.658	1220.3	696.3	1222.5	526.2	2.319	2.397	82.2	15.4	144.7	3.3	17.8	81.8	34.3	40.4	0.848			
AVG												3.3	17.9	81.3	34.3	40.4	0.849			
Computed By: G. FLOWERS			Checked By: T. LYNN																	
SSD = Saturated Surface Dry			gm = gram			pcf = pounds per cubic foot			Gmb = Bulk Specific Gravity of Compacted Mix			Gsb = Bulk Specific Gravity of Aggregate								
Sp. Gr. = Specific Gravity			cc = cubic centimeter			in = inches			Gmm = Theoretical Maximum Specific Gravity of Mix			Gse = Effective Specific Gravity of Aggregate								
TMD = Theoretical Maximum Density			AC = Asphalt Cement						Gsa = Apparent Specific Gravity of Aggregate			Gb = Specific Gravity of Asphalt Cement								

**TABLE G20. - Flat and Elongated SMA Mixture Design and Results
NCHRP 9-8 Phase II
Task 10 Evaluation of Flat or Elongated Particles
Mix Aggregate: 25% Flat and Elongated**

Moisture Susceptibility				
Conditioned				
Specimen Number	Air Voids (%)	Deg. of Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
1	5.6	58.9	4115	370
2	5.9	70.1	4115	372
5	6.1	66.7	4059	363
Average Tensile Strength (kPa)				368
Unconditioned				
Specimen Number	Air Voids (%)	Deg. of Sat. (%)	Ultimate Load (N)	Tensile Strength (kPa)
4	5.5	N/A	8007	719
6	6.7	N/A	8730	785
7	5.8	N/A	9341	833
Average Tensile Strength (kPa)				779
Tensile Strength Ratio (%)				47.3

Aggregate Breakdown Sieve Analysis					
Sieve (mm)	Optimum Gradation	Marshall 50 Blows			
		1	2	3	Average
19.00	100.0	100.0	100.0	100.0	100.0
12.50	90.1	93.1	92.6	92.0	92.6
9.50	52.6	64.1	62.9	65.2	64.1
4.75	21.0	28.0	29.6	27.6	28.4
2.36	17.9	21.2	21.7	21.1	21.3
1.18	15.8	17.6	18.2	17.5	17.8
0.60	13.4	14.7	15.0	14.6	14.8
0.30	12.4	13.2	13.5	13.1	13.3
0.15	11.1	11.8	12.1	11.6	11.8
0.75	10.0	9.8	10.1	9.7	9.9