Designing Stone Matrix Asphalt Mixtures Volume II(a) – Research Results for Part 1 of Phase I

Final Report

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CHAPTER 1 - INTRODUCTION

1.1 BACKGROUND

Stone Matrix Asphalt (SMA) has been used in Europe for over 20 years to resist studded tires and to provide better rutting resistance. Because of its success in Europe, five states through the cooperation of the Federal Highway Administration (FHWA) constructed SMA mixes in the United States in 1991. Since that time the use of SMA in the U.S. has increased significantly. To date, SMA mixtures constructed in the U.S. have been designed using a compactive effort of fifty blows on each side of the sample with a conventional Marshall hammer. Some people have selected optimum asphalt content yielding air voids as low as three percent and some yielding air voids as high as four percent. More specific guidance for developing SMA mix designs is needed so that optimum performance can be obtained. The purpose of this study is to develop this specific guidance.

The emphasis of this study is to develop a simple straightforward design procedure for SMA that is repeatable and that can be used by any agency or laboratory that is equipped to do Hot Mix Asphalt (HMA) testing. The mix design method must select a high quality SMA mixture as the end product. This design procedure is envisioned as one method with two separate compaction options. The design can be done using either a flat-faced, static base Marshall hammer, or a Superpave gyratory compactor. Whichever compaction method is chosen, it is anticipated that the design procedure will contain five steps.

1. Select and test materials to ensure they meet the required specifications. This includes aggregate testing, asphalt binder testing using the Superpave binder equipment, and testing of the stabilizing additive.
2. Select an optimum aggregate gradation for the mixture that will provide stone-on-stone contact.
3. Test the mortar to determine if it meets specifications designed to ensure mixture durability and resistance to thermal cracking.
4. Test the final mixture for moisture susceptibility and draindown performance.
5. Test the final mixture to determine its ability to resist rutting.

Of course each of these basic steps requires some more detail, but in their general form, they serve as the end product vision being used to guide this research project.

1.2 PROJECT OBJECTIVES

The objectives of this research project are as follows:

1) define materials and mixture properties required to maximize the durability and rut resistance of SMA, and
2) develop an SMA mixture design method including a procedure to determine moisture sensitivity.

1.3 SCOPE

A mixture design method for SMA was developed based on work performed in the laboratory. This laboratory testing involved two inter-related tasks. The first was to identify critical SMA material and mixture properties. However, to accomplish this, the second task of selecting appropriate laboratory tests was completed simultaneously. Since SMA is a two component mixture, (an aggregate skeleton partially filled with an asphalt cement rich mortar), the search for critical material and mixture properties and the appropriate test to measure them focused on these two components as well as the complete SMA mixture.

CHAPTER 2 - LITERATURE REVIEW

The complete literature review is provided in Volume I of this report. Due to the large amount of material, it was deemed appropriate to provide the complete review as a separate volume. A summary of the information included in Volume I is provided below.

2.1 INTRODUCTION

Known by several names, such as Splittmastixasphalt in Europe where the material was first utilized and Stone Matrix Asphalt when it was adopted in the U.S., this durable, deformation-resisting mix has become generically known by its initials SMA. Stone Matrix Asphalt is, in fact, not a particularly good translation of the German word as it fails to convey the sense of crushed stone, which is an essential feature of the mix.

The bibliography on SMA is extensive with much of the early publications being in German. SMA was devised to resist the wearing and abrasion of studded tires. It was a natural growth from spreading chips on Gussasphalt. Use of SMA declined when studded tires were banned in most countries but began to increase when asphalt technologists found that SMA was a good mix to resist rutting and that cellulose fibers could be substituted in the mix for asbestos fibers, which fell out of favor because of health fears (1).

SMA is a simple idea; find a hard, durable, quality stone, fracture it into roughly cubical shape and of a size consistent with the proposed layer thickness, and then glue the stones together with a durable, moisture-resistant mortar of just the right quantity to give stone-on-stone contact among the coarse aggregate particles. For the asphalt technologist, the trick is getting the various parameters right. This is where the recipes come in. Most European specifications are reflections of mix ingredients and proportions that seem to work quite well. Many specifications are based on Germany’s (10) early work. In 1993, SMA was first placed in Bulgaria (66); Britain is ready to embark in 1994 (70); and Japan has been using SMA for several years (86). However, as Bellin (41) points out, in Germany, contractors are responsible for design of the mixes. So, it is not surprising that there is an element of unknown about their design process, with producers having their own ways of arriving at satisfactory mixes. The European specifications then, will provide the mix designer with some guidelines of what has worked when using European materials. However, specifications from other countries will not necessarily tell the designer what tests to apply or how to do a mix design. Good results are not necessarily guaranteed when different materials are used in the U.S. and when some of the European criteria are sacrificed for economics or for different test procedures. Still, there are remarkably few failures of SMA in the U.S. reported in the literature, most of the problems apparently being fat spots in the newly laid mat (11) and one case (4) that seems to have been a production/construction control problem.

It was not until about 1990 that interest in SMA was sparked in North America, following a study tour (26) of five European countries by a group of pavement specialists from the U.S. The favorable reaction of the team to SMA soon caught the attention of the trade press and a flurry of articles on SMA followed, especially after SMA projects were constructed first in Canada in late 1990 (24) and then in several U.S. states in 1991. Technical reports and published papers of substance relating to North American experience began to appear in late

1991. In this same year, the Federal Highway Administration and the National Asphalt Pavement Association jointly initiated a Technical Working Group made up of those persons who had experience with SMA in the United States. Their goal was to develop guidelines to assist in the adoption of SMA in this country.

The use of SMA in North America is less than five years old at the time this report was prepared. Work in the U.S. is deviating more and more from the European recipe-type mixes, sometimes for economic reasons and, as always, in a desire for improved HMA performance. The basic features of SMA in the U.S. (gap-grading, high stone content, lots of filler, and high binder contents) are typical of European SMAs, and attempting to meet these criteria has served as the framework for mix designs. However, some early specifications in the U.S. have required minimum Marshall stabilities and voids in the mineral aggregate (VMA) values. In contrast, these parameters are not part of European SMA specifications. The German specification (10), for example, does not even mention VMA.

In the late 1980s, the American Association of State Highway and Transportation Officials assembled a joint task force to report on rutting in asphalt pavements. The group produced a report (3), which was published in February 1989. SMA is not mentioned in the report because there was no experience among the highway agencies with SMA at the time. However, shortly thereafter, news about SMA began to circulate through exchanges of technical information between local technologists and Europeans (particularly Bellin (41), who had been loaned to the Strategic Highway Research Program (SHRP) from Lower Saxony). During the European study tour (26), U.S. pavement specialists had the opportunity to see SMA in action and hear about it through presentations such as the one by Liljedhal (8). Based on European experience (1, 2, 4, 5, 6, 7, 9, 10, 11, 12), decision-makers in the U.S. deemed SMA worthy of trials. The first project was in Wisconsin and was reported in the trade press by Scherocman (14).

2.2 AGGREGATE QUALITY AND GRADATION

Crushed limestone was used in the Wisconsin project although the practice in Europe generally is not to use limestone, sandstone or similar stone for coarse aggregates (20, 35, 41). In an attempt to replicate European practice, the Michigan SMA project used very high quality mineral aggregate that was transported some 480 km (300 miles) to the project site (40).

The importance of aggregate quality is acknowledged in a number of specifications. Flakiness, abrasion, polishing, and resistance to impact are only a few of the aggregate tests mentioned by various European authors (2, 11, 70). In the U.S. context, the SMA Technical Working Group model guideline on materials (81) addresses the issue of aggregate quality. The specification for aggregate quality from this guideline is provided in Table 2.1.

Information about aggregate gradations appear extensively throughout the papers reviewed. For comparison, many of the gradations used by authors gave been repeated in the individual reviews in Volume I of this report. In the first project in the U.S., Scherocman (14) noted that the gradation followed the “30-20-10 rule,” which is a useful guideline for specifiers and designers of SMA who are lacking model procedures. The rule of thumb indicates that the aggregate gradation should have 30 percent passing the 4.75-mm (#4) sieve, 20 percent passing the 2.36-mm (#8) sieve, and 10 percent passing the 0.075-mm (#200) sieve.

The gradation nomenclature used in Europe indicates the top size stone. For example, 0/11 indicates that 11-mm (7/16 inches) is the top size stone.

Table 2.1: Coarse Aggregate Specifications for SMA Mixtures (Guidelines 1994)

TEST	METHOD	SPEC. MAXIMUM	SPEC. MINIMUM
Los Angeles Abrasion, % Loss	AASHTO T 96	30	-
Flat & Elongated, % 3 to 1 5 to 1	ASTM D 4791	 20 5	 - -
Absorption, %	AASHTO T 85	2	-
Soundness (5 Cycles), % Sodium Sulfate Magnesium Sulfate	AASHTO T 104	 15 20	 - -
Crushed Content, %* One Face Two Faces		 - -	 100 90
Durability Index	AASHTO T 210	-	40

*Most State DOT's have their own method for calculating crushed content. If no method currently exists for the agency, Pennsylvania DOT Test Method No. 621 can be used.

2.3 MIX DESIGN

Other projects in Michigan, Georgia and Missouri followed the one in Wisconsin and were also reported in the trade press before more detailed reports were published by research bodies or state highway departments (21, 22, 23, 25, 27, 28, and 29). To help potential users of SMA, Bukowski (20) produced the FHWA's work plan, which contained a summary of the first five SMAs that had been built in the U.S. in 1991. Bukowski said that these projects had generally followed the German 12.5-mm (½-inch) gradation band, which he provided in his report along with other mix design guidelines such as using 50-blow Marshall compaction and air voids between 3 and 4 percent. Bukowski also warned users not to be driven by Marshall stability results, noting that a failing measurement should not be the only reason for rejecting an SMA mix design. This advice is common among Europeans; the German Asphalt Pavement Association (36), Bellin (41), and Milster (53) are three examples.

So, what were U.S. designers to do? Blindly accept the European specifications, which called for aggregate of such high quality that it might have to be trucked hundreds of kilometers? Pryor (21) reported that for the Michigan SMA demonstration project in 1991, aggregate was hauled over 480 km (300 miles) to the mixing plant. Assuming that the right aggregate could be obtained, were designers to then accept a recipe-type approach in lieu of some laboratory tests which designers could rely on to indicate expected performance? What tests are related to performance? Had anyone correlated familiar tests such as creep properties or resilient modulus with SMA performance? Stuart (35) noted that little in the way of structural tests had been done in Europe. This is true. With a few exceptions, the European literature on

SMA mixtures does not discuss these matters. Stuart's opinion in 1992 (35) was that it had yet to be determined if diametral and tensile strength tests were applicable to SMAs. Even Stuart's most comprehensive report on European practices did not provide the reader with a clear mix design and testing protocol. Bellin (41) explained why; there is no specific design method in Germany. More recently in Europe, Richter (19) has indicated the use of some tests which are not common for technologists in North America. So, could the European SMA technology somehow be adapted to U.S. climates and local materials? Could some testing techniques be devised to assure mix designers and construction engineers that satisfactory mixture quality is being obtained?

One of the earliest investigations in the U.S. was conducted by Little, Dutt, and Syed, who produced an interim report (15) in 1991. However, a primary objective was to evaluate the influence of a low density polyethylene modifier (LDPE), not to evaluate the applicability of familiar tests on an unfamiliar HMA. The authors used several methods of compaction in the laboratory, including 50-blow Marshall, which is commonly used in Europe. Little, et al used several non standard tests and a Texas standard TEX-226-F for indirect tensile testing. The authors also used the Schellenberg drainage test, which Stuart (35) describes in detail. A drainage test is deemed necessary to ensure that the binder-rich mortar in an SMA will not drain by gravity during storage or in transit to the paving site. One of the conclusions by Little, et al was that a suitably stiff mortar would probably require polymer modification. In a dramatic photograph, Milster (53) shows impressive mortar stiffness with cellulose fibers, which indicates that polymer modification is not always necessary.

Several reports in the U.S. in 1991 and 1992 dealt with the U.S. SMA projects. Little (16), Brown (40), and Stuart (35) all performed comparative mix designs for Georgia DOT, which also produced a report (31) and supplemental specifications (32). Missouri's experience was reported by McDaniel (34). Scherocman (46, 50) and Brown (40, 48) reported on others, apart from numerous items in the trade press. The practical problem of producing an SMA with cellulose fibers in a drum mixer without losing fibers in the exhaust gas dust collection system was addressed by Karnemaat, Vreibel, and Van Deusen (54) early in 1993 but this was based on experience with the earlier Michigan projects. Up to this point, it appeared that SMA mix design in the U.S. had generally followed the European guidelines although there were some variations. However, even in 1991 researchers were looking beyond the "30-20-10 rule" and European-derived guidelines. The design principle for the mortar in the Indiana SMA in October 1991 was reported by Haddock, Liljedhal, and Kriech early in 1993 (61). Briefly, their approach was based on calculating the voids in the coarse aggregate skeleton and then varying the mortar content until the correct air voids range was satisfied. Designing the mortar has stretched the imagination of several authors (8, 44, 61, 64, 65, 77, 84). Recently, Carpenter (77), and Brown and Mallick (84) have addressed mixture volumetric properties and achievement of the stone-on-stone contact that SMA is supposed to provide in service. Brown and Mallick (84) suggest a design procedure that is intended to answer this problem. In Belgium, Francken and Vanelstraete (65) have developed a computer-aided design program.

2.4 FILLER

A fundamental question in the design of the mortar is the role of the filler. Filler means different things to different authors. In the German specification, it appears to be the material finer than

0.090-mm (10, 36, 42, 53). McDaniel (34) in 1992, reporting on Missouri's entry into SMA in 1991, recommended a gradation for mineral filler with 70-100 percent passing the 0.075-mm sieve and not more than 5 percent passing the 0.020-mm sieve. However, he did not explain the basis for the recommendation. Shelton's report (80) on Missouri's experimental SMA overlay appears to allow the regular mineral filler given in the Missouri Standard Specifications for Highway Construction except that portland cement is not allowed. This standard allows for 70-100 percent passing the 0.075-mm sieve and does not say anything about smaller particle size distribution. In contrast to Missouri, a proposed specification in the United Kingdom by Walsh (70) allows the use of portland cement.

In the literature reviewed, no studies appear to have been performed on mortars with more than 5 percent passing the 0.020-mm sieve. Scherocman and Schütz (49) expressed concern over the fineness of the filler used in Wisconsin in 1991 (39 percent of the filler was smaller than 0.02-mm in size), although it does not seem to have adversely affected early performance (62). Lack of published research on this aspect of SMA has not stopped authors from recommending a limitation on material passing the 0.02-mm size. Bukowski (20), and recent FHWA guidelines (81) have included the criterion limiting the amount of material finer than 0.02-mm size.

According to Bellin (41), type of filler is not named in specifications or requests for proposals in Germany. He indicates that ground limestone is used and that baghouse fines are not used much. Scherocman (46) notes that baghouse fines are not normally returned into the SMA production line in Europe. There are no clear reasons for not using baghouse fines. It may be that German producers, being responsible for the mix design, and accountable for the mix, merely wish to eliminate a potential variable. They also require that clean aggregate be used thus reducing the amount of material collected in the baghouse.

2.5 DRAINDOWN AND STABILIZING ADDITIVES

One of the questions facing mix designers is how to deal with the design of the mortar. Milster (53), in a photograph, illustrates the difference in stiffening effects between the mortar fractions of an SMA and a dense-graded mix. SMAs have higher asphalt cement contents and lower aggregate surface areas than regular dense-graded mixes, which renders them vulnerable to draindown of the binder during storage or while the material is being hauled to the paving site. Bellin (41) reported that the Schellenberg draindown test is used in Germany to ensure that the mix does not lose its cementing mortar. Details of the test are reported by Stuart (35). In the United Kingdom, Walsh (70) references another test, while Brown and Mallick (84) proposed a test method, which has been accepted in the FHWA's Model Material and Construction Guidelines (81).

Stabilizing additives are used to prevent draindown. Many years ago, asbestos fibers were used but were discontinued because of health fears. In Sweden, this brought about a rapid reduction in the use of SMA (2) until the early 1980s when cellulose fibers became popular. Mineral fibers, cellulose fibers, and polymers are used to prevent draindown or to improve the binder properties. Marek and Dukatz (71) claim that acceptable SMA mixtures can be made without fibers and that asphalt draindown can be minimized by using fines from the crushing of aggregate. They provided no data to support their contentions.

Harders (67) used the Ring and Ball softening point test in evaluating the effect of stabilizers. Richter (19) also used this test among others that are less familiar. Serfass and Samanos (33), and Schröder and Kluge (51) have also used the softening point test. According to Schröder and Kluge, mortar compositions with softening points between 85 and 100°C (185-212º F) provide the right viscosity and impact strength. Sometimes fibers and polymers are combined, as noted by Reinke (59) and Fujita (86); and a multigrade asphalt has also been used as reported in the trade press (56) and by Kriech (57) and Haddock et al (61).

2.6 RUTTING RESISTANCE PERFORMANCE

A review of the literature indicates that there are no clearly defined approaches to SMA mix design, nor are there performance-related mix tests that designers and practitioners can embrace with confidence. Despite these apparent drawbacks, SMAs in the U.S. appear to be living up to their reputation as a rut-resisting mix. In Georgia, a fine SMA without fibers performed very well in a loaded wheel rutting test as did a conventional mix (60). Brown and Manglorkar (69) found static creep values for SMA and dense-graded mixes were about the same, but under dynamic creep testing, SMAs had slightly higher permanent strain values. Stuart and Malquist (76) used various rutting tests and concluded that stabilizing additives had no significant effect on rutting susceptibility even though optimum binder contents varied over a wide range. Mogawer and Stuart (78) used the French rut tester, the Georgia Loaded Wheel, and the Gyratory Testing Machine and found no significant differences among the mixes tested. However, they did find that both Marshall and Gyratory compaction fractured the aggregate which altered the gradation of the mixture. Walsh (70) proposes to use a wheel tracking test at 45°C (113º F). Fujita (86) indicates that in a dynamic wheel tracking test used in Japan, SMA is far superior to regular dense-graded HMA.

2.7 OTHER USES OF SMA

Rinckes (6) and Polcak (75) deal with some less obvious applications of SMA. The former discusses the use of SMA in the Netherlands for military purposes, container terminal roads, and thin surfacings for factory floors; Polcak reports on apparent acoustical benefits derived from the use of SMA. Hoppe (18) mentions the use of SMA to achieve noise reduction near residences and its application on bridge decks. Fujita (86) also reports bridge deck applications and a thin SMA using 5-mm (3/16-inch) maximum size aggregate for resurfacing a pavement in a tunnel in Japan. Very thin surfacings of SMA have also been used in France (33). In contrast to thin surfacing applications, Ohlsson and Sandin (7) report that they are considering 22-mm (7/8-inch) maximum size stone in SMA.

CHAPTER 3 - TEST PLAN

3.1 INTRODUCTION

This chapter contains the Test Plan as proposed at the initiation of the research project. As the testing progressed, changes were necessary to some of the test procedures to accomplish the stated objectives. The objectives of Phase I were to determine the material and mixture properties necessary to obtain a durable, rut resistance SMA mixture. In addition, tests to distinguish these properties were to be determined and a tentative mix design procedure developed. To accomplish these goals, laboratory testing focused on three major areas, the coarse aggregate skeleton, the mortar, and the complete mixture.

3.2 TENTATIVE MIXTURE DESIGN METHOD

A tentative mix design procedure based on existing information was provided to TRB in early June 1994. This early submission of a tentative mix design procedure allowed for use and evaluation of the method during the 1994 construction season. The knowledge gained from Phase I testing and from user experience was used to revise the procedure. This revised mix design procedure is submitted as Volume III of this report.

3.3 TASK 1 - STATE OF THE ART

The RFP for this project outlined Task 1 as follows: “Review and analyze current laboratory design procedures, specifications, and construction practices for SMA. This review will include and expand on the activities of the FHWA’s SMA Technical Working Group.”

Current mix design procedures, specifications, and construction procedures were obtained from all available sources; in particular, available published literature. These sources of information included the SMA Technical Working Group (SMA TWG) jointly sponsored by the Federal Highway Administration (FHWA) and the National Asphalt Pavement Association (NAPA), State Departments of Transportation that had funded SMA projects, the FHWA, and contractors that had constructed SMA projects in the U.S. Information relating to SMA mix design was also obtained from several individuals in countries in Europe as well as other countries that had been active in SMA work. The National Center for Asphalt Technology (NCAT) has also conducted a large amount of tests on SMA and this data was closely reviewed for the project.

The state-of-the-art review is provided in Volume I of this report.

3.4 TASK 2 - CRITICAL MATERIAL AND MIXTURE PROPERTIES

The RFP described Task 2 as: “Based on the above information (state-of-the-art review) and the experience of the researchers, identify and evaluate material and mixture properties critical to the performance of SMA. The researchers are expected to identify how changes in aggregate type, shape, and grading; fraction passing the 0.075-mm (# 200) sieve; stabilizers; and asphalt cement affect mixture volumetrics, durability, and performance of SMA." To accomplish these goals, the two SMA mixture components, aggregate skeleton and mortar, were studied to determine their influence on mixture volumetric properties, durability and performance. Testing therefore focused on the aggregate, mortar, and mixture properties.

3.4.1 Aggregate Properties

For the purpose of the aggregate testing performed in this project, the coarse aggregate is considered to be that portion retained on the 4.75-mm (#4) sieve. The fine aggregate portion is all the aggregate material passing the 4.75-mm (#4) sieve excluding the material finer than the 0.075-mm (#200) sieve. This finer material is referred to as mineral filler.

The important aggregate properties and their specifications were initially guided by current information from the SMA TWG. In Phase II of this study, information from the NCHRP 4-19 project, "Aggregate Tests Related to Asphalt Concrete Performance in Pavements" and the SHRP program will also be closely evaluated. These three sources along with the work performed in this contract should ultimately provide adequate information concerning the desired aggregate properties for SMA mixtures.

In addition to aggregate properties, the effects of aggregate type, shape, and gradation on SMA mixture properties were also investigated. The influence of aggregate type and shape were determined by using five different aggregates. These aggregate types were identified as a limestone, gravel, granite, Florida limestone, and traprock. Each of these aggregates has unique properties to contribute to an SMA mixture. Differences in aggregate shape run from cubical for the granite, to slightly flat and elongated for the limestone, to slightly rounded for the gravel. Each of the aggregates was blended into nine separate gradations and tested. The nine gradations are listed in Table 3.1. For gradations 1-5, gradation of the coarse aggregate fraction (larger than 4.75-mm (#4) sieve) is equivalent to that shown for gradation 6. Thus for gradations 1-6 the proportions of coarse and fine aggregate were varied while the gradings of the coarse and fine aggregate were held constant. In gradations 7, 8, and 9, the amount and grading of the fine aggregate and the amount of coarse aggregate were held constant while the coarse aggregate grading was varied.

A schematic of the tests used to determine the effects of the aggregate on the SMA mixture is shown in Figure 3.1. The left branch of this figure shows that a mix design was completed for each of the five aggregates using the tentative mixture design method. Gradations 1, 2, and 3 from Table 3.1 were the trial gradations evaluated in developing the mix designs. The volumetrics of these mixtures were determined and evaluated to show the effects of aggregate type, shape, and grading. Moisture susceptibility and draindown data were also collected for these mixtures. This data provides an indication of how aggregate type, shape, and grading affect the durability and performance of the SMA mixture.

For determining the influence of aggregate on the SMA aggregate skeleton, each of the coarse aggregate blends from the mixture designs were tested by five different methods designed to determine when stone-on-stone contact has been achieved. The five methods evaluated include dry-rodded unit weight, vibrating table, Kango hammer, Marshall hammer, and SHRP gyratory compactor. Two percent asphalt cement was added to the coarse aggregate when compacted with the Marshall and Kango hammers, and the SHRP gyratory compactor. This testing provided data

Table 3.1: Gradations Used to Evaluate Stone-On-Stone Contact

	PERCENT PASSING								
Sieve Size (mm)	Grad 1	Grad 2	Grad 3	Grad 4	Grad 5	Grad 6	Grad 7	Grad 8	Grad 9
19.0	100	100	100	100	100	100	100	100	100
12.5	92	91	90	90	88	87	85	88	92
9.5	64	58	55	52	46	40	35	45	65
4.75	40	30	25	20	10	0	25	25	25
2.36	30	25	20	17	10	0	20	20	20
1.16	24	20	17	15	10	0	17	17	17
0.60	18	16	14	13	10	0	14	14	14
0.30	16	14	13	12	10	0	13	13	13
0.15	12	12	11	11	10	0	11	11	11
0.075	10	10	10	10	10	0	10	10	10

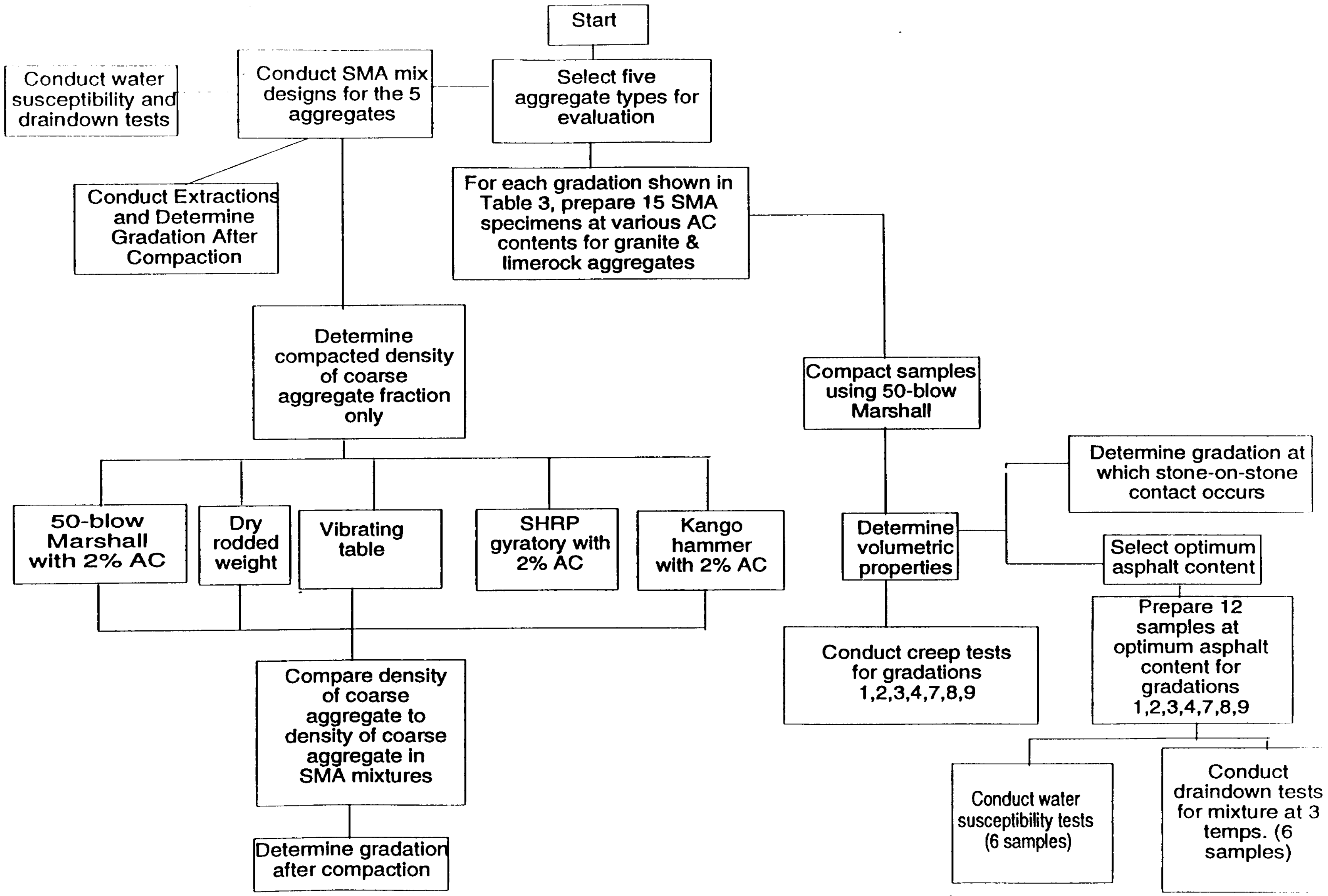

Figure 3.1 Test matrix for aggregate skeleton and SMA mixture testing.

to indicate how aggregate type, shape, and grading affected the coarse aggregate skeleton.

The right branch of Figure 3.1 shows that the granite and Florida limestone aggregates were used to produce SMA mixtures at various asphalt cement contents. For each gradation in Table 3.1, three replicates at each of five different asphalt cement contents were produced for both the granite and Florida limestone. Fifty blows of a conventional, mechanical Marshall hammer were used to compact the specimens. For gradations 1, 2, 3, 4, 7, 8, and 9, creep testing was performed on each of the specimens. This data shows the influence of both asphalt cement content and gradation on the SMA mixtures.

In addition to creep testing, the volumetric properties of each specimen were also determined. This data was used to select an optimum asphalt cement content for each of the gradations. Moisture susceptibility and draindown sensitivity data were collected for gradations 1, 2, 3, 4, 7, 8, and 9 at the optimum asphalt cement contents.

3.4.2 Mortar Properties

It is widely believed that the mortar provides the SMA mixture with durability. To achieve durability, the mortar must contain adequate amounts of asphalt cement, fine aggregate, filler, and stabilizing additive. The total SMA mortar consists of the aggregate fraction passing the 2.36-mm (#8) sieve, asphalt cement, mineral filler, and a stabilizing additive (usually fibers).

Since the coarse aggregate fraction was designed as the aggregate material retained on the 4.75mm (#4) sieve and the fine aggregate in the mortar is the fraction passing the 2.36-mm (#8) sieve, an obvious gap has occurred. The aggregate fraction smaller than the 4.75-mm (#4) sieve but larger than the 2.36-mm (#8) sieve has not been included in either the coarse or mortar aggregate fractions. This fraction was not included in the coarse aggregate fraction because aggregate producers in the United States typically use the 4.75-mm (#4) not the 2.36-mm (#8) sieve as the break point for coarse/fine aggregate separation. The 4.75-mm to 2.36-mm (#4-#8) aggregate material was not included in the mortar aggregate fraction because it was too large. Its inclusion in the mortar would have made the mortar infinitely more difficult to test. The exclusion of this one aggregate fraction from either the coarse or mortar aggregate fractions introduces very little error. In a typical SMA mixture, only about four percent of the total aggregate falls into this fraction. The exclusion of this small amount therefore is justified.

For testing purposes, the mortar was further divided into the fine mortar fraction consisting of asphalt cement, aggregate passing the 0.075-mm (#200) sieve, and stabilizing additive. Analysis of the mortar included tests on both the total mortar fraction and the fine mortar fraction. The fine mortar fraction was considered to be a binder and was tested in the SHRP binder equipment before and after aging. The total mortar fraction which was considered to be more like a mixture was tested at low, intermediate, and high temperatures using the bending beam rheometer, resilient modulus, indirect tensile test, and Brookfield viscometer. The complete test plans for the fine and total mortar fractions are shown in Tables 3.2 and 3.3 respectively. The testing protocols for these tests were developed in conjunction with Task 3.

The effects of asphalt cement properties were investigated by using four different asphalt cements. These were an AC-20 and three different polymer modified AC-20's. Each of these was initially tested to categorize them within the SHRP binder specifications; they were then tested in various configurations in both the fine and total mortar fractions to determine their effect on the mortar.

Table 3.2: Test Plan for Preliminary Evaluation of Fine Mortar Fraction*

Material	Original		RTFO	After PAV		
	DSR	BV	DSR	DSR	DT	BBR
AC-20, F1, LD	X	X	X	X	X	X
AC-20, F1, FA	X	X	X	X	X	X
AC-20, LD	X	X	X	X	X	X
AC-20, FA	X	X	X	X	X	X
AC-20, F2, LD	X	X	X			
AC-20, F2, FA	X	X	X			
AC-20M1, F1, LD	X	X	X			
AC-20M1, F1, FA	X	X	X			
AC-20M1, LD	X	X	X	X	X	X
AC-20M1, FA	X	X	X	X	X	X
AC-20M2, FA	X	X	X			
AC-20M3, FA	X	X	X			
AC-20M1, F2, LD	X	X	X	X	X	X
AC-20M1, F2, FA	X	X	X	X	X	X
AC-20	X	X	X	X	X	X
AC-20M1	X	X	X	X	X	X
AC-20, FA, F2	X	X	X			
AC-20, FA, F3	X	X	X			

F1 = Cellulose fiber
F3 = Rock Wool Fiber
BBR = Bending Beam Rheometer
DSR = Dynamic Shear Rheometer
RTFO= RollngThin Film Film Oven
LD = Limestone dust
F2 = Slag Wool Fiber
M1 - SBS
M2 - SBR
M3 - Polyolefin
DT = Direct Tension
FA = Fine graded baghouse fines
AC-20M = Modified AC-20
BV = Brookfield Viscosity
PAV = Pressure Aging Vessel

*Test temperatures were based on SHRP guidance for Auburn, Alabama.

The effect of various stabilizing additives was investigated by using AC-20 in conjunction with three separate fibers as well as testing the three modified AC-20’s. One cellulose and two mineral fibers were selected for use. Asphalt modifiers were selected to be SBS, SBR, and polyolefin. These stabilizing additives were tested in various combinations in both the fine and total mortar fractions.

The manner in which mineral filler affects the mortar was investigated using two different mineral filler materials. A processed, crushed limestone dust, and baghouse fines produced from a limestone/natural sand mixture were used. These two fillers were tested in various combinations in both the fine and total mortar fractions.

Table 3.3: Test Plan For Preliminary Evaluation of Total Mortar Fraction*

Temperature(°C)	-12	5			175
Material/Test	BBR	RM	ITS	ITSF	BV
AC-20, LD	X	X	X	X	X
AC-20, FA	X	X	X	X	X
AC-20, F1, LD	X	X	X	X	X
AC-20, F1, FA	X	X	X	X	X
AC-20, F2, LD	X	X	X	X	X
AC-20M, LD	X	X	X	X	X
AC-20M, FA	X	X	X	X	X
AC-20M, F1, LD	X	X	X	X	X
AC-20M, F1, FA	X	X	X	X	X
AC-20M, F2, LD	X	X	X	X	X

F1 = Cellulose fiber
F2 = Slag Wool Fiber
ITS = Indirect Tensile Strength
ITSF = Indirect Tensile Strain At Failure
LD = Limestone dust
FA = Fine graded baghouse fines
BV = Brookfield Viscosity
RM = Resilient Modulus
BBR = Bending Beam Rheometer
AC-20M = Modified AC-20 w/SBS

* Low and high temperature were determined by SHRP suggested for Auburn, Alabama.

3.4.3 Mixture Properties

Figure 3.1 shows that complete SMA mixtures were tested to determine volumetric properties, moisture susceptibility, creep properties and draindown characteristics. As shown in the figure, two of the five aggregates were chosen for testing seven of the nine gradations listed in Table 3.1. Specimens were produced at various asphalt cement contents and their volumetric properties were determined to show the influence that asphalt cement content, and aggregate type, shape, and grading have on SMA mixture properties. Moisture susceptibility and draindown testing were performed on the mixtures at optimum asphalt cement content to determine how asphalt cement content, and aggregate type, shape and grading affected mixture durability and performance. Creep testing was performed to determine how air void level and aggregate structure affected the mixture performance.

3.5 TASK 3 - SELECTION OF LABORATORY TESTS

Eventually the laboratory tests for SMA may be much more sophisticated than those presently available. However, the initial design procedures should use simple tests that are readily available and that can be conducted in both design and field laboratories. The SHRP procedures for design of dense graded mixtures have not been completed for levels II and III. When these procedures are completed, they should be considered for SMA mixtures as well, but until SHRP levels II and III have been finalized, the Marshall approach and/or SHRP level I should be used for designing SMA mixtures. Work will be performed in Phase II of this project to adopt SHRP level I as a mix design procedure for SMA. Volume III of this report presents a tentative mix design procedure using the Marshall hammer.

A number of tests have been conducted at NCAT on SMA mixtures to evaluate the material and mixture properties and to compare those results to dense graded mixtures. These tests have included Marshall stability and flow, indirect tensile strength, resilient modulus, creep, permanent deformation tests, and gyratory shear. These tests include most of those that have been used in the past to evaluate dense graded mixtures. The results have generally shown that SMA laboratory properties do not appear to be as good as laboratory properties of dense graded mixtures. The Marshall stability is typically lower for SMA, the flow higher, the resilient modulus lower, the indirect tensile strength lower, and the gyratory shear and permanent deformation tests are about the same as with dense graded mixtures. This does not mean that dense graded mixes perform better in the field than SMA mixes. It does mean that some of these tests may not be applicable for evaluating the quality of SMA mixtures. Of the tests listed above, the ones that have shown the most promise in evaluating the quality of SMA mixtures are the gyratory shear and permanent deformation tests. Based on comments from the TRB selected panel, the gyratory shear was not included in this part of the study.

Most of the mixture performance testing on SMA mixtures will be done in Phase II. The testing in Phase II will include SHRP Simple Shear, laboratory wheel tracking, and any tests showing promise from the NCHRP 9-7 project entitled, “Field Procedures and Equipment to Implement SHRP Asphalt Specifications.” Some of these tests may be difficult to perform in a field laboratory so other tests may need to be used as surrogate tests or the test procedures may need to be simplified if possible.

3.5.1 Aggregate Skeleton Testing

The method for identifying when stone-on-stone contact is achieved involved using five different techniques to densify the coarse aggregate fraction (material retained on the 4.75-mm (#4) sieve) of each aggregate type. The voids in the coarse aggregate (VCA) of the coarse aggregate only fractions were then compared to the VCA within the entire SMA mixture. When the VCA of the coarse aggregate in the SMA mixture was less than or equal to the VCA in the coarse aggregate only fraction, stone-on-stone contact was assumed to exist within the mixture. This testing is represented in Figure 3.1 where it shows the five different methods used to densify the coarse aggregate only fraction. Analysis of these test results should produce a viable test method for determining when stone-on-stone contact exists.

3.5.2 Mortar Testing

Analysis of the mortar included tests on both the total mortar fraction and the fine mortar fraction. This test plan for the mortar is shown in Tables 3.2 and 3.3. The tests listed have not previously been used to evaluate mortar properties. The primary purpose of the mortar work was to determine the potential of these tests to measure desirable properties of the SMA mortar.

The fine mortar fraction was tested using the SHRP binder tests. These tests were conducted on unaged samples, samples aged in the Rolling Thin Film Oven (RTFO), and on samples aged with the Pressure Aging Vessel (PAV). The tests included several combinations of materials as shown in Table 3.2. Analysis of these tests should provide some indication if the SHRP binder tests can be used to effectively measure the properties of the SMA fine mortar.

The total mortar fraction was tested to determine its properties at low, intermediate, and high temperatures. The actual tests performed varied depending on the temperature as shown in Table 3.3. Since little published work on the desired properties of the SMA total mortar exists the intent of these tests was to determine their potential for evaluating the quality of the total SMA mortar. The mortar should be stiff enough to help resist deformation at high temperatures and flexible enough to resist fatigue and cracking at low temperatures.

3.5.3 Mixture Testing

In addition to the testing discussed above, draindown characteristics were determined for SMA mixtures. A test method developed at NCAT was used for this purpose. Analysis of these results should be helpful in developing methods to minimize draindown of asphalt cement in SMA mixtures.

For moisture susceptibility it is recommended that the modified Lottman method be used (AASHTO T 283). For comparison purposes, a wheel tracking device will also be used to determine rutting potential and moisture susceptibility as part of Phase II. This equipment performs tests on the mixture underwater and has been shown to indicate when moisture damage occurs as well as quantifying rutting potential of the mix.

3.6 TASK 4 - INTERIM REPORT

The requirement of Task 4 was to submit an interim report summarizing the work in Tasks 1-3, and including a tentative mix design procedure and a detailed work plan for Phase II. As a minimum, the following items should be included in the interim report:

1. A procedure to determine when stone-on-stone contact exists in the aggregate skeleton,
2. properties of SMA with and without stone-on-stone contact,
3. procedure to determine SMA mortar properties,
4. effect of aggregate type, shape, and gradation on SMA properties,
5. evaluation of creep, volumetric properties, and moisture susceptibility in SMA mixtures,
6. detailed test plan for Phase II, and
7. revised tentative SMA mixture design procedure.

CHAPTER 4 - TEST RESULTS

As discussed in Chapter 3, tests were conducted on aggregates, mortar, and SMA mixtures to determine critical material and mixture properties, and to investigate laboratory tests to measure these properties. The information was developed to provide the knowledge necessary for preparation of a mix design procedure. The test plan in Chapter 3 was carried out as closely as was practical. However, during the testing some modifications to the original plan were made since some of the tests could not be conducted as described in the test plan.

4.1 AGGREGATE TEST RESULTS

Five aggregate types were selected for use in this study: traprock, granite, limestone, Florida limestone, and silicious gravel. These aggregates were selected because they provided a range of qualities from excellent to marginal. Traprock and silicious gravel are very hard materials while Florida limestone is very soft. Limestone and granite are somewhere between these two extremes. The surface textures, absorption characteristics, and shapes are also very different for each of the aggregates.

All five aggregates were tested in both coarse and fine fractions to evaluate their basic properties. The measured properties for the coarse aggregates are provided in Table 4.1. The fine aggregate properties are presented in Table 4.2. The coarse and fine gravel aggregates were

Table 4.1: Properties of the Coarse Aggregates

		AGGREGATE TYPE				
Property	Test Method	Granite	FL Limestone	Gravel	Limestone	Traprock
Bulk Specific Gravity	AASHTO T85	2.664	2.373	2.565	2.725	2.932
Apparent Specific Gravity	AASHTO T85	2.713	2.602	2.643	2.755	3.024
Absorption, %	AASHTO T85	0.7	3.7	1.2	0.4	1.0
Los Angeles Abrasion, % Loss	AASHTO T96	37.0	36.0	17.0	24.0	17.0
Flat & Elongated	ASTM D4791					
3 to 1		0.6	0.3	1.8	5.9	1.6
5 to 1		0	0	0	1.0	0
Soundness (5 Cycles), % Loss Sodium Sulfate	AASHTO T104	0.3	12	3.3	0.2	1.1
Crushed Content, %						
One Face		-	-	100	-	-
Two Faces		-	-	67	-	-

Table 4.2: Properties of the Fine Aggregates

		AGGREGATE TYPE				
Property	Test Method	Granite	FL Limestone	Gravel	Limestone	Traprock
Bulk Specific Gravity	AASHTO T84	2.695	2.358	2.436	2.684	2.903
Apparent Specific Gravity	AASHTO T84	2.711	2.662	2.628	2.770	3.003
Absorption, %	AASHTO T84	0.2	4.8	3.0	1.2	1.2
Soundness (5 Cycles), % Loss Sodium Sulfate	AASHTO T104	0.3	12	3.3	0.2	1.1
Liquid Limit, %	AASHTO T89	*	*	*	*	*
Plasticity Index, %	AASHTO T90	NP	NP	NP	NP	NP

NP: Non-Plastic
* - Liquid limit could not be determined.

obtained from two different sources. This explains the difference in the absorption values for these two materials.

4.1.1 Coarse Aggregate Test Results

The data in Table 4.1 shows that the coarse aggregates were non-absorptive except for Florida limestone which had a water absorption value of 3.7 percent. The absorption values of the other coarse aggregates were 1.2% or less.

The L.A. abrasion values for all the aggregates were below 40 percent which is relatively low. The Florida limestone is known to be a soft material but has a reasonably low L.A. abrasion value of 36 percent. However, it did abraid easily during compaction of mixtures. This raises questions as to the practical meaning of the L.A. abrasion loss value. The traprock and gravel are known to be very hard aggregates and the measured L.A. abrasion values below 20 percent for these two aggregates support this. The L.A. abrasion tests seem to predict trends in aggregate quality, but it is not an accurate measure of the breakdown potential for these aggregates.

The Florida limestone also had a high loss (12 percent) in the sodium sulfate soundness test while the other aggregates did not. This test may discriminate between good and marginal aggregates better than the L.A. abrasion test.

All aggregates used in this study were 100 percent crushed except for the gravel. The crushed content for the coarse gravel was 100 percent with one or more fractured faces, and 67 percent with two or more fractured faces.

4.1.2 Fine Aggregate Test Results

The fine aggregate properties shown in Table 4.2 have a trend similar to those of the coarse aggregate fractions. The crushed content for the fine gravel aggregate was probably 100 percent but could not be measured for the finer particles due to the small size. The larger fine aggregate, 4.75-mm to 0.60-mm (# 4 - #30) did contain 100 percent particles with one or more fractured faces.

4.1.3 Mineral Filler Test Results

Two mineral fillers were selected for use in the study. The first material was a commercially available limestone dust and the second was a sample of baghouse fines from a local HMA plant. The properties of the two fillers are shown in Table 4.3. The limestone dust was significantly finer than the baghouse fines as shown in the gradations in Tables 4.4(a) and 4.4(b) respectively. The sizes of the mineral fillers were measured three ways and the results are shown for comparison. The results for the three methods compare reasonably well but not as good as desired. There is a significant difference between the sizes measured with the hydrometer and particle-size analyzer for the limestone dust. Both of these fillers are very fine with more than 40

Table 4.3: Properties of the Mineral Fillers

		MINERAL FILLER TYPE	
Property	Test Method	Limestone Dust	Baghouse Fines
Apparent Specific Gravity	AASHTO T100	2.900	2.711
Plasticity Index, %	AASHTO T90	NP	NP
Passing 0.02 mm sieve, %	--	63	41

NP: Non-Plastic
* - Test results from particle size analyzer.

Table 4.4(a): Limestone Dust Gradation

	PERCENT PASSING		
Sieve (mm)	Wet Sieve	Hydrometer	Particle-Size Analyzer
2.36	100.0	-	100.0
1.18	99.7	-	100.0
0.60	98.8	-	100.0
0.30	96.3	-	100.0
0.15	90.5	-	95.8
0.075	80.4	-	86.0
0.045	-	56.9	76.9
0.020	-	46.6	62.7

Table 4.4(b): Baghouse Fines Gradation

	PERCENT PASSING		
Sieve (mm)	Wet Sieve	Hydrometer	Particle-Size Analyzer
2.36	100.0	-	100.0
1.18	99.9	-	100.0
0.60	99.8	-	99.7
0.30	99.0	-	97.2
0.15	96.3	-	92.3
0.075	89.2	-	80.3
0.045	-	65.6	66.4
0.020	-	49.5	40.7

percent smaller than the 0.020-mm size. The particle-size analyzer used for this study was a Coulter Model LS-200. Ultrasonic agitation was used in the particle size analyzer to facilitate particle separation.

4.1.4 Aggregate Skeleton Test Results

Work was performed to evaluate the ability of five different methods to determine when stone-on-stone contact exists in the coarse aggregate fraction. Since one objective in the design of SMA mixtures is to produce a mixture with stone-on-stone contact, it is essential that a method be available to define this condition. A method presently being used at NCAT is to dry-rod the coarse aggregate and to determine the voids in the coarse aggregate (VCA_{DRC}) in this dry-rodded condition. If the VCA of the coarse aggregate in the mixture is equal to or less than the VCA_{DRC}, then it is assumed that stone-on-stone contact exists. Methods other than the dry-rodded technique were evaluated to determine if they were equal to or better than the dry-rodded method for determining stone-on-stone contact. The other methods tried were a conventional, mechanical Marshall hammer, SHRP gyratory compactor, vibrating table, and Kango (vibrating) hammer. There are two concerns with all five methods: The amount of aggregate breakdown, and its impact on the resulting VCA of the coarse aggregate. Aggregate breakdown during this test results in a decrease in VCA. Ideally the aggregate breakdown during the test should be approximately equal to that observed during the mixing, placing and compacting operations in the field. The amount of breakdown during these construction operations has been assumed to be relatively low, but no formal study has been performed to measure this. Certainly the use of softer aggregates will result in more breakdown, but the typical requirement that the L.A. abrasion value be 30 percent or less should result in minimal breakdown during construction.

For each of the methods used, three specimens were batched such that their gradations matched gradation 6 in Table 3.1. The three specimens were compacted according to the given method and the VCA of the compacted specimens determined. The gradations of the extracted aggregate from the Marshall, SHRP, and Kango methods along with the gradations of the compacted aggregate from the two remaining methods were then determined according to AASHTO T 11 and T 27.

The Marshall hammer method employed 50-blows per face of a conventional, mechanical Marshall hammer. The three specimens had 2 percent by total weight of AC-20 asphalt cement added to aid compaction. When they had cooled sufficiently, they were extracted from the molds and their bulk specific gravities determined according to AASHTO T 269, section 3.2. The VCA for each specimen was obtained using equation 4.1.

$$VCA = 100 - \left(\frac{G_{mb}}{G_{sb}} \times P_{CA} \right) \qquad (4.1)$$

where,

G_{sb} - bulk specific gravity of the total aggregate
G_{mb} - bulk specific gravity of the compacted specimen
P_{CA} - percent of coarse aggregate in the mixture (100 percent in this case).

After determining the VCA the asphalt cement from each of the specimens was extracted according to AASHTO T 164, method A, with the fines being recovered by the centrifuge method.

The dry-rodded method was done according to AASHTO T 19, Unit Weight and Voids in Aggregate. Three replicates were again produced. A 3 litre (0.1 ft^3) capacity metal container was used. The VCA in the dry-rodded condition (VCA_{DRC}) can be calculated using equation 4.2.

$$VCA_{DRC} = \frac{G_{sb}\gamma_w - \gamma_s}{G_{sb}\gamma_w} \times 100 \qquad (4.2)$$

where,

G_{sb} - bulk specific gravity of the total aggregate
γ_w - unit weight of water (999 kg/m^3)
γ_s - unit weight of the aggregate in the dry-rodded condition (kg/m^3).

Using the vibrating table, the aggregate specimens were compacted in the same metal container used for the dry-rodded method. The container was fixed to a vibrating table capable of vibrating at 50 Hz and charged with approximately one-third of the aggregate sample. The sample was vibrated for one minute and then stopped and more of the aggregate sample was added until the container was approximately two-thirds full. It was then vibrated for an additional minute and stopped. Finally, the container was filled to overflowing with the remainder of the sample and mounded on top. The sample was again vibrated for one minute. At the end, the container was removed, the excess aggregate struck off, and the VCA of the aggregate determined according to the method of AASHTO T 19. No rodding was used at any time. The VCA of the aggregate for this method was calculated using equation 4.2.

The SHRP gyratory method employed 100 revolutions of the SHRP gyratory compactor. The three specimens had 2 percent by total mix weight of AC-20 asphalt cement added to aid compaction. The specimens were produced in 100-mm (4 inch) diameter molds. When they had cooled sufficiently, they were extracted from the molds and their bulk specific gravities determined according to AASHTO T 269, section 3.2. The VCA for each specimen was obtained using equation 4.1.

The vibrating hammer method used the British Kango hammer to compact specimens and followed the protocol outlined by the Asphalt Institute for the design of Open Graded Friction Courses (Mix Design Method 1978). The molds were 150-mm (6 inches) in diameter and the hammer was attached to a compaction frame. Two percent AC-20 asphalt cement by weight of total mix was added to each aggregate sample and the mix placed in the mold. The mold and hammer were then placed in position and two 4.54-kg (10 lbs.) weights were attached to the hammer. The hammer was vibrated on the sample for 15 seconds and then removed. A dial gauge was used to determine the height of the sample after compaction. Using this height, the bulk specific gravities were determined according to AASHTO T 269, section 3.2. The VCA for each specimen was obtained using equation 4.1.

After determining the VCA the asphalt cement from each of the specimens was extracted according to AASHTO T 164, method A, and the fines were recovered by the centrifuge method.

The results of the tests are shown in Table 4.5. The test results show very little variability between VCA replicates or between the different methods. They show that for each aggregate the Marshall hammer and the SHRP gyratory compactor provided the lowest VCAs. The vibrating table and dry- rodded method provided approximately equal VCA for all aggregates. The Kango hammer always provided the highest VCA and therefore the lowest coarse aggregate density. In the case of the vibrating table and dry rodded methods, the VCA for all aggregates was within the range of 37 to 42 percent. This seems to indicate that different types of coarse aggregates having the same gradation will provide similar VCA values.

As previously mentioned, one concern is the breakdown of coarse aggregate in the compaction process. A test method is needed to force the aggregate particles together without excessively breaking them. To investigate aggregate breakdown, after compaction of the coarse aggregate, a gradation analysis was conducted on each sample to evaluate the amount of breakdown. The test results are presented in Tables 4.6-4.10 for the granite, Florida limestone, gravel, limestone, and traprock, respectively. Breakdown is defined as the change in the amount of material passing the 4.75-mm (#4) sieve from the original gradation to the “after compaction” gradation.

Table 4.6 shows that there is significant breakdown with the 50 blow Marshall hammer and with the SHRP gyratory compactor for the granite aggregate. The percent passing the 4.75-mm (#4) sieve increased by 8-11 percent for these two methods. The other three compaction methods show very little breakdown. Florida limestone (Table 4.7) had more breakdown than the granite aggregate. The percent passing the 4.75-mm (#4) sieve increased by 13-20 percent for the Marshall and SHRP compactors. The other three methods produced very little breakdown. The gravel (Table 4.8) shows much less breakdown with the SHRP gyratory compactor than with the Marshall hammer (11 percent for Marshall and 3 percent for SHRP gyratory). The other three methods show very little breakdown of the gravel. Limestone shows a very high breakdown when compacted with the Marshall hammer (26 percent) as well as a significant amount of breakdown (10 percent) with the SHRP gyratory compactor (Table 4.9). There is very little breakdown of the limestone with the other three methods. The compaction of traprock shows the same general trend as that for gravel (Table 4.10). The Marshall hammer produced the most

Table 4.5: Voids in the Coarse Aggregate Test Results for the Coarse Aggregate Only Fraction

		VOIDS IN THE COARSE AGGREGATE, %				
Method	No.	Granite	FL Limestone	Gravel	Limestone	Traprock
Marshall Hammer	1 2 3	32.7 31.6 32.1	26.9 27.4 26.4	33.3 33.8 33.2	30.3 29.4 29.9	35.0 36.2 -
	Avg	32.1	26.9	33.4	29.9	35.6
	SD	0.55	0.50	0.82	0.45	0.85
SHRP Gyratory Compactor	1 2 3	36.0 33.4 34.7	29.8 29.9 31.3	37.6 36.8 37.2	36.4 36.9 36.6	39.5 38.7 39.3
	Avg	34.7	30.3	37.2	36.6	39.2
	SD	1.30	0.84	0.40	0.25	0.42
Dry-Rodded	1 2 3	39.1 39.3 39.1	39.8 38.8 38.0	37.3 37.6 37.3	42.5 42.8 42.2	40.9 40.7 40.8
	Avg.	39.2	38.9	37.4	42.5	40.8
	SD	0.12	0.90	0.17	0.30	0.10
Vibrating Table	1 2 3	40.2 39.8 40.1	40.6 39.9 39.0	37.8 37.9 37.6	41.6 41.6 41.7	40.7 41.0 40.6
	Avg	40.0	39.8	37.8	41.6	40.8
	SD	0.21	0.80	0.15	0.06	0.21
Kango Hammer	1 2 3	48.2 47.2 47.1	43.7 44.1 44.4	45.5 45.0 45.8	47.2 47.6 47.7	48.5 48.0 49.2
	Avg	47.5	44.1	45.4	47.5	48.6
	SD	0.61	0.35	0.40	0.26	0.60

SD=Standard Deviation

Table 4.6: Gradations Before and After VCA Determination For Granite

	PERCENT PASSING					
Sieve Size (Mm)	Original Gradation	50 Blow Marshall	Dry Rodded Test	Vibratory Table	100 Gyr. Shrp	Kango Hammer
19.0	100.0	100.0	100.0	100.0	100.0	100.0
12.5	87.0	89.8	87.2	88.6	87.9	88.1
9.5	40.0	56.3	44.7	42.9	52.4	41.5
4.75	0.0	14.2	2.5	1.4	11.2	2.5
2.36	0.0	7.0	0.7	0.4	5.1	1.0
1.18	0.0	5.0	0.6	0.4	3.4	0.9
0.60	0.0	3.8	0.5	0.4	2.4	0.8
0.30	0.0	2.7	0.5	0.3	1.6	0.8
0.15	0.0	1.8	0.4	0.3	0.9	0.7
0.075	0.0	1.2	0.3	0.2	0.4	0.6

Table 4.7: Gradations Before and After VCA Determination for Florida Limestone

	PERCENT PASSING					
Sieve Size (Mm)	Original Gradation	50 Blow Marshall	Dry Rodded Test	Vibratory Table	100 Gyr. Shrp	Kango Hammer
19.0	100.0	100.0	100.0	100.0	100.0	100.0
12.5	87.0	91.3	86.2	88.8	88.9	90.0
9.5	40.0	57.4	39.3	42.3	48.4	46.1
4.75	0.0	21.9	2.5	2.4	14.8	1.3
2.36	0.0	10.0	0.8	1.0	6.6	0.8
1.18	0.0	6.6	0.7	0.9	4.6	0.7
0.60	0.0	4.7	0.7	0.9	3.5	0.7
0.30	0.0	3.7	0.7	0.9	2.8	0.6
0.15	0.0	2.9	0.6	0.8	2.3	0.5
0.075	0.0	2.4	0.4	0.6	2.0	0.4

Table 4.8: Gradations Before and After VCA Determination for Gravel

	PERCENT PASSING					
Sieve Size (Mm)	Original Gradation	50 Blow Marshall	Dry Rodded Test	Vibratory Table	100 Gyr. Shrp	Kango Hammer
19.0	100.0	100.0	100.0	100.0	100.0	100.0
12.5	87.0	90.8	88.5	89.0	89.2	88.4
9.5	40.0	58.3	45.0	43.1	49.2	42.8
4.75	0.0	13.4	2.7	2.3	5.4	2.4
2.36	0.0	5.3	0.4	0.5	1.8	0.4
1.18	0.0	3.1	0.4	0.4	1.1	0.4
0.60	0.0	1.9	0.4	0.4	0.7	0.3
0.30	0.0	1.1	0.4	0.4	0.5	0.2
0.15	0.0	0.6	0.5	0.4	0.3	0.2
0.075	0.0	0.2	0.3	0.3	0.1	0.1

Table 4.9: Gradations Before and After VCA Determination for Limestone

	PERCENT PASSING					
Sieve Size (Mm)	Original Gradation	50 Blow Marshall	Dry Rodded Test	Vibratory Table	100 Gyr. Shrp	Kango Hammer
19.0	100.0	100.0	100.0	100.0	100.0	100.0
12.5	87.0	91.7	88.9	85.9	88.6	86.7
9.5	40.0	66.8	44.2	41.6	52.8	43.7
4.75	0.0	24.5	1.5	1.4	10.8	1.6
2.36	0.0	12.4	0.5	0.4	5.7	0.7
1.18	0.0	7.0	0.4	0.3	3.5	0.5
0.60	0.0	4.2	0.3	0.3	2.2	0.4
0.30	0.0	2.8	0.3	0.3	1.5	0.4
0.15	0.0	1.9	0.3	0.2	1.1	0.3
0.075	0.0	1.5	0.3	0.2	0.9	0.3

Table 4.10: Gradations Before and After VCA Determination for Traprock

	PERCENT PASSING					
Sieve Size (Mm)	Original Gradation	50 Blow Marshall	Dry Rodded Test	Vibratory Table	100 Gyr. Shrp	Kango Hammer
19.0	100.0	100.0	100.0	100.0	100.0	100.0
12.5	87.0	88.6	87.5	86.6	86.8	86.6
9.5	40.0	51.1	43.4	42.2	47.6	40.6
4.75	0.0	12.9	1.6	1.5	6.0	3.6
2.36	0.0	4.5	0.3	0.4	2.1	0.4
1.18	0.0	2.6	0.3	0.4	1.3	0.4
0.60	0.0	1.8	0.3	0.4	1.0	0.3
0.30	0.0	1.3	0.2	0.4	0.8	0.3
0.15	0.0	0.9	0.2	0.3	0.6	0.3
0.075	0.0	0.7	0.2	0.3	0.5	0.2

breakdown (12 percent) , the SHRP gyratory compactor was second (5 percent), and the other three methods produced very little breakdown. In general, the Marshall hammer produced about twice as much breakdown as the SHRP gyratory while the remaining three methods produced no significant breakdown.

After looking at the change in the 4.75-mm (#4) sieve data for the various aggregates and compactor methods, it appeared that the reason for the lower VCA with the Marshall hammer and SHRP gyratory compactor was breakdown of aggregate. If this breakdown is representative of that which takes place during construction, then it is acceptable. However, if this breakdown is significantly more or less than that which actually occurs during production placement and compaction, then it is not acceptable and will produce some error in the measure of stone-on-stone contact. An analysis of the data shows that the difference in VCA produced by the various methods is a direct result of aggregate breakdown (Figure 4.1). The method ultimately selected to measure stone-on-stone contact should result in breakdown similar to that which occurs during construction. Using the dry-rodded and vibrating table compaction methods as indicators, the minimum VCA for the aggregates investigated and for most other aggregates is expected to be about 37 percent and the maximum breakdown about 3 percent. Samples of SMA mixtures compacted in the laboratory with the Marshall hammer were extracted to evaluate the amount of breakdown in these mixtures. The extracted gradation results are provided in Table 4.11. The breakdown of the aggregates in the compacted SMA mixture was very similar to the breakdown of the coarse aggregate only (Tables 4.6-4.10) when compacted with the SHRP gyratory but less than the Marshall and more than the other methods. The breakdown of the Florida limestone was considerably different due to the modified percent passing the 9.5-mm (3/8-inch) sieve.

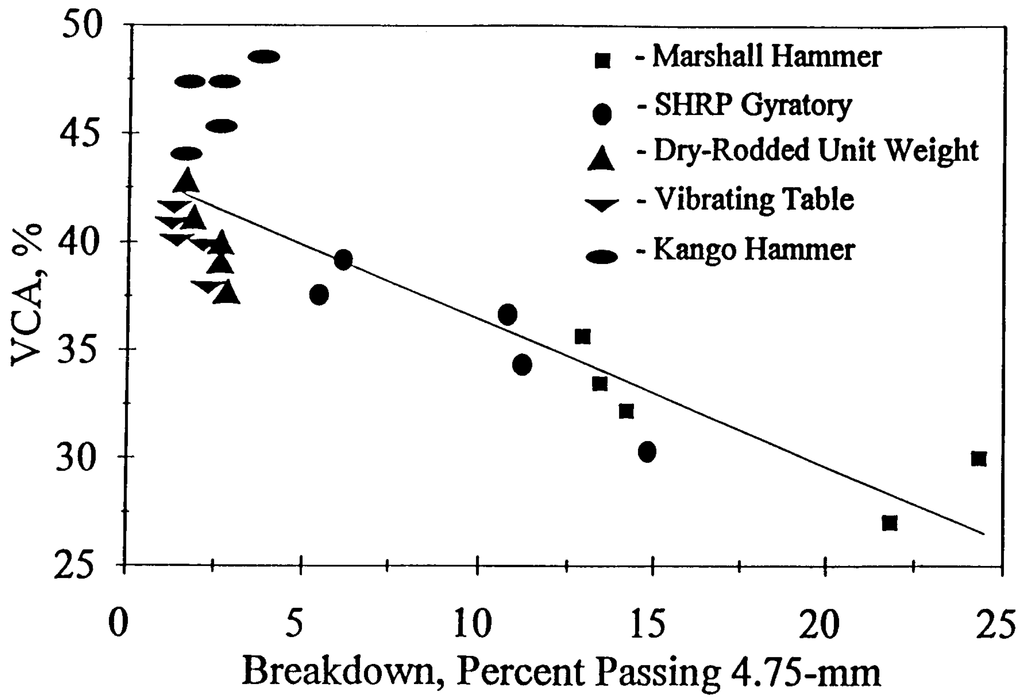

Figure 4.1: Effect of Aggregate Breakdown on VCA

Table 4.11: Gradation Results for the Extracted Granite, Florida Limestone, Gravel, Limestone, and Traprock SMA Mixtures After Compaction With the Marshall Hammer

Percent Passing						
Sieve Size (mm)	Original Gradation	Extracted Aggregate Gradations				
		Granite	FL Limestone	Gravel	Limestone	Traprock
19.0	100	100.0	100.0	100.0	100.0	100.0
12.5	90	92.8	92.2	91.3	93.5	90.8
9.5	55*	66.2	60.0	67.0	69.7	63.7
4.75	25	40.8	36.2	31.0	35.1	32.4
2.36	20	27.2	27.9	22.9	25.8	23.9
1.18	17	22.4	23.1	19.0	19.8	19.7
0.60	14	18.8	19.7	15.7	16.0	16.6
0.30	13	16.0	17.7	14.1	14.0	14.6
0.15	11	13.3	15.6	12.5	12.1	12.7
0.075	10	11.3	13.6	11.0	10.5	11.1

* The original gradation for Florida limestone had only 40 percent passing the 9.5-mm sieve.

4.2 MORTAR TEST RESULTS

Very little work has been performed in the past to characterize the quality of the mortar. It needs to be stiff enough to resist rutting, to prevent draindown, and to hold the aggregate skeleton in place, but flexible enough to resist fatigue and thermal cracking.

The mortar in SMA is typically defined as that portion of the aggregate passing the 2.36-mm (#8) sieve, mineral filler, stabilizing additive, and asphalt cement. It is a near voidless mixture that will flow at room temperature. To test the mortar, it was decided to make use of the Strategic Highway Research Program (SHRP) binder testing equipment and accompanying protocol. The reasons for attempting to use the SHRP binder tests were to answer two questions. 1) Are these SHRP tests applicable to the mortar?, and 2) can these SHRP binder tests measure properties that can be used to differentiate between various mortar qualities?

To attempt to fully understand the mortar characteristics, the mortar was tested in two fractions. The fine mortar fraction contained that portion of the aggregate passing the 0.075-mm (#200) sieve, (typically referred to as filler), stabilizing additive, and asphalt cement. The total mortar fraction as previously defined was also tested. The percentages of the various components of the mortar are shown in Table 4.12(a) and 4.12(b) for the fine and total mortar, respectively. These percentages are within the range that would be expected for SMA mixtures produced using current Federal Highway Administration (FHWA) guidelines.

Mortar testing involved the use of one neat asphalt cement, three modified asphalt cements, two mineral fillers (described in Sec. 4.1.3), and three fiber types (used as stabilizing additives). In SMA construction, the modifiers in modified asphalt cements are sometimes considered as stabilizing additives and other stabilizing additives such as fiber may not be required. For this study, combinations containing modified asphalt cements only and modified asphalt cements with fibers were both tested.

4.2.1 Asphalt Cements

Before mortar testing began, the neat asphalt cement (AC-20) and the three modified asphalt cements were tested and classified under the SHRP binder grading system. Table 4.13 lists the asphalt cement types evaluated and the subsequent SHRP classifications. Modifiers were added as percent by weight of asphalt cement. Due to preference with one modifier supplier, the AC-20 modified with 4 percent SBS was from a different crude source and refining procedure than was the neat AC-20 used in all other testing. However, the AC-20 used with 4 percent SBS was a PG 64-22 before modification just as the neat AC-20 used in this study. The SBS modified asphalt cement was modified by the producer and shipped to the laboratory for further evaluation. The SBR and Polyolefin modified asphalt cements were produced using the same base AC-20 shown in Table 4.13. The SBR was incorporated into the AC-20 by the SBR producer and then delivered to the laboratory. The Polyolefin was added to the AC-20 in the laboratory.

4.2.2 Fiber

The fibers selected for inclusion in the testing matrix were cellulose, rock wool, and slag wool. Both cellulose and rock wool have had extensive use in SMA. The slag wool has been tried during full-scale production and placement on an experimental basis and has proven very

Table 4.12(a): Fine Mortar Composition

Material	Percent of Fine Mortar Weight		
	Filler	Asphalt Cement	Modifier
AC-20, F1, LD	60.4	37.7	1.9
AC-20, F1, FA	60.4	37.7	1.9
AC-20, LD	61.5	38.5	-
AC-20, FA	61.5	38.5	-
AC-20, F2, LD	60.0	37.5	2.5
AC-20, F2, FA	60.0	37.5	2.5
AC-20M1, F1, LD	60.4	37.7	1.9
AC-20M1, F1, FA	60.4	37.7	1.9
AC-20M1, LD	61.5	38.5	-
AC-20M1, FA	61.5	38.5	-
AC-20M2, FA	59.7	37.3	-
AC-20M3, FA	60.0	37.5	3.0
AC-20M1, F2, LD	60.0	37.5	2.5
AC-20M1, F2, FA	-	100.0	2.5
AC-20	-	100.0	-
AC-20M1	-	100.0	-
AC-20, FA, F2	60.0	37.7	2.5
AC-20, FA, F3	60.0	37.5	2.5

Table 4.12(b): Total Mortar Composition

Material	Percent of Total Mortar Weight			
	Fine Agg.	Filler	Asphalt Cement	Fiber
AC-20 LD	30.0	45.0	25.0	-
AC-20 FA	33.0	42.0	25.0	-
AC-20, F1, LD	29.9	44.8	25.0	0.3
AC-20, F1, FA	32.8	41.9	25.0	0.3
AC-20, F2, LD	29.9	44.8	24.9	0.4
AC-20M, LD	30.0	45.0	25.0	-
AC-20M, FA	33.0	42.0	25.0	-
AC-20M, F1, LD	29.9	44.8	25.0	0.3
AC-20M, F1, FA	32.8	41.9	25.0	0.3
AC-20M, F2, LD	29.9	44.8	24.9	0.4

Table 4.13: Asphalt Cement Data

Asphalt Cement Designation	Modifier	Percent Modifier by Binder Weight	PG Grade
AC-20	None	0	64-22
AC-20 M1	SBS	4	70-28
AC-20 M2	SBR	3	64-22
AC-20 M3	Polyolefin	8	70-22

Table 4.14: Fiber Properties

PROPERTY	CELLULOSE	ROCK WOOL	SLAG WOOL
Bulk Density (kg/m^3)	28	-	160
Ave. Fiber Length (mm)	1.1	6.4	-
Ave. Fiber Thickness (mm)	0.045	0.005	0.005

effective to date. Typical properties of the three fibers are shown in Table 4.14.

4.2.3 Fine Mortar Test Results

The fine mortar testing matrix is shown in Table 3.2. Each of the material combinations listed in the lefthand column were tested under SHRP protocol as if they were PG 64-22 binders. The material combinations were first tested as unaged materials in the Brookfield viscometer (BV) and the Dynamic Shear Rheometer(DSR). They were then aged in the Thin Film Oven (RTFO) and the residue tested again in the DSR. Finally, some of the combinations' RTFO residues were aged in the Pressure Aging Vessel (PAV) and that residue tested in the DSR, Bending Beam Rheometer (BBR), and Direct Tension (DT) device. The test results are provided in Tables 4.15-4.17.

There are a number of observations that can be made from the fine mortar tests. It appears that the Brookfield viscometer is not a satisfactory test for the SMA mortars. All of the mortars were too stiff to test at the SHRP designated temperature of 135º C (275º F). For this reason, 175º C (347º F) was used. This is widely believed to be the upper limit obtainable before damage to the asphalt cement occurs. However, most of the mortars were too stiff to test even at the elevated temperature of 175º C (347º F). This test therefore should be dropped from any further
evaluations. The dynamic shear rheometer, bending beam, and direct tension appear to be satisfactory tests for the fine mortar. These tests were relatively easy to conduct.

Another observation made from Tables 4.15 and 4.16 is the effect of binder type on the phase angle (δ). The δ for the AC-20M1 binder was always in the 60s, even with the various fillers added. However, all mortars with other binders had δ values approximately 80 or above. It appears that δ is a discriminating measure of the elastic component of the asphalt cement properties even when other additives such as fiber and filler are included.

Table 4.15: Results of Unaged Fine Mortar Testing

Fine Mortar Combination	Brookfield Viscosity[a] (@ 175°C) (cP)	Dynamic Shear (@ 64°C)		
		G^* (kPa)	δ (°)	$G^*/\sin\delta$ (kPa)
AC-20,LD	882	5.459	87.2	5.466
AC-20,FA	9507[b]	6.741	86.9	6.751
AC-20,F1,LD	***	8.789	80.6	8.909
AC-20,F1,FA	***	12.670	82.5	12.779
AC-20M1,LD	4050	11.200	65.4	12.318
AC-20M1,FA	***	12.990	66.0	14.219
AC-20M1,F2,LD	***	11.380	66.0	12.457
AC-20M1,F2,FA	***	15.540	64.8	17.175
AC-20,F2,LD	6507[b]	5.982	86.5	5.993
AC-20,F2,FA	***	8.865	85.7	8.890
AC-20M1,F1,LD	***	17.030	62.4	19.217
AC-20M1,F1,FA	***	23.200	62.3	26.203
AC-20M2,FA	13273[c]	9.821	83.7	9.881
AC-20M3,FA	15053[d]	12.320	81.4	12.460
AC-20,F3,FA	***	8.013	86.0	8.033
AC-20	75	1.033	86.9	1.035
AC-20M1	287	2.408	67.2	2.220
AC-20M2	133	1.284	84.4	1.290
AC-20M3	150	2.362	83.4	2.378

[a]Test conducted using a no. 3 spindle in the mixing vessel at a speed of 20 rpm.
[b]Test conducted at 10 rpm (material too stiff to measure at 20 rpm).
[c]Test conducted at 5 rpm (material too stiff to measure at 20 rpm). A value of 7779 cP was obtained for a test performed with a no. 27 spindle at 20 rpm.
[d]Test conducted at 5 rpm (material too stiff to measure at 20 rpm). A value of 6108 cP was obtained for a test performed with a no. 27 spindle at 20 rpm.
***Material stiffness such that viscosity measurements could not be obtained.

LD - Limestone Dust
FA - Baghouse Fines
F1 - Cellulose Fiber
F2 - Slag wool
F3 - Rock wool
AC-20M1 - SBS
AC-20M2 - SBR
AC-20M3 - Polyolefin

Table 4.16: Fine Mortar Properties After Aging in the Thin Film Oven Test (TFOT)

Fine Mortar Combination	Dynamic Shear (@ 64°C)		
	G^* (kPa)	δ (°)	$G^*/\sin\delta$ (kPa)
AC-20,LD	9.505	85.1	9.540
AC-20,FA	12.190	84.1	12.255
AC-20,F1,LD	13.680	80.3	13.878
AC-20,F1,FA	23.670	79.6	24.065
AC-20M1,LD	17.120	62.9	19.231
AC-20M1,FA	23.690	62.8	26.635
AC-20M1,F2,LD	13.840	63.2	15.506
AC-20M1,F2,FA	30.640	61.4	34.898
AC-20,F2,LD	10.780	84.5	10.830
AC-20,F2,FA	16.710	83.5	16.818
AC-20M1,F1,LD	26.450	60.0	30.542
AC-20M1,F1,FA	35.150	59.6	40.753
AC-20M2,FA	16.830	81.2	17.031
AC-20M3,FA	25.340	78.9	25.823
AC-20,F3,FA	16.880	84.0	16.973
AC-20*	2.290	85.4	2.297
AC-20M1*	4.655	64.1	5.175
AC-20M2*	2.476	82.4	2.498
AC-20M3*	5.142	78.1	5.255

*RTFOT used as per SHRP specifications.
**The Rolling Thin Film Oven Test as specified by the SHRP specifications was attempted for the mortars; however, the test could not be performed since the materials “walked-out” of the RTFO bottles. Therefore, only the AC-20, AC-20M1, AC-20M2 and AC-20M3 were conditioned in the RTFOT. All other combinations were aged in the thin film oven.
***Test at this temperature was not required for SHRP classification.

Table 4.17: Fine Mortar Properties After Aging in the Pressure Aging Vessel (PAV)

Fine Mortar Combination	Dynamic Shear (@ 25ºC)			BBR[a] (@ -12ºC)		DTT[b] (@ -12ºC)	
	G* (MPa)	δ(º)	G*sinδ (MPa)	Stiffness (MPa)	m (Slope)	Stress (MPa)	Strain (%)
AC-20,LD	14.300	55.8	11.827	828	0.323	6.3	0.5
AC-20,FA	15.480	55.9	12.818	1152	0.335	5.6	0.4
AC-20,F1,LD	12.230	57.9	10.360	763	0.349	4.8	0.3
AC-20,F1,FA	16.930	55.8	14.003	1023	0.291	1.4	0.02[c]
AC-20M1,LD	10.310	51.9	8.113	496	0.345	5.8	3.1
AC-20M1,FA	8.791	54.2	7.130	632	0.325	5.7	1.0[d]
AC-20M1,F2,LD	11.740	50.5	9.059	614	0.311	2.5	0.2[e]
AC-20M1,F2,FA	12.100	52.9	9.651	604	0.302	2.2	0.2[e]
AC-20	3.416	54.1	2.767	204	0.355	1.8	0.7
AC-20M1	2.705	48.7	2.032	100	0.356	2.5	2.6
AC-20M2	2.800	54.7	2.285	158	0.381	1.5	0.5
AC-20M3	5.205	47.3	3.825	215	0.323	1.7	0.7

[a]Bending Beam Rheometer
[b]Direct Tension Test
[c]Results low in part due to end failures of all four specimens.
[d]Average of four observations as per test standard; however, this includes two samples which experienced end failures.
[e]All four specimens experienced end failures.

The baghouse fines always stiffened the mortar more than limestone dust. It was anticipated that the limestone dust would stiffen the mortar more because it was finer. Cellulose fiber always stiffened the binder more than slag wool fiber . Rock wool fiber appeared to stiffen the binder about the same as slag wool. The SBS polyolefin modifiers provided about the same increase in stiffness while the SBR modifier provided little increase in stiffness at 64ºC (147ºF.) when mixed with the neat asphalt cement (Tables 4.15 and 4.16).

Observations after the PAV (Table 4.17) show that the mortars containing fillers had significantly greater G* values and BBR stiffness values than mortars not containing fillers. The data also shows that the strain of the mortars containing M1 on the average are greater than the strain value for the other binders.

4.2.3.1 Mixing/Blending Procedures

Before any testing could be conducted, methods of blending the constituent materials had to be investigated in order to establish a standard protocol. It was decided that the mortars would be treated as if they were HMA Mixtures. As a result, mixing guidelines outlines in the Marshall Mix Design Method were followed. However, these procedures had to be refined to produce a mixing protocol tailored for SMA mortars. After experimentation with a few methods, a mixing procedure was developed that was adequate (i.e. its use produced a homogeneous mixture). A summary of the procedural development follows.

First, batches of mineral filler (lime dust) passing the 0.075-mm (No. 200) sieve were prepared and heated 20°C higher than the mixing temperature in order to facilitate mixing. The appropriate amount of asphalt was then added to produce a fines to asphalt ratio of 1.6 (typical for SMA mixtures). The mixture was then stirred by hand with a metal spatula over a hot plate. It was determined that this method would not work based predominantly on the fact that the hot plate was unable to provide uniform heating. In order to prevent overheating and possible damage to the asphalt cement, it was decided to use a heating mantle and mechanical mixing. Also, upon pouring the sample, it was noticed that uncoated dust particles were present at the bottom of the mixing vessel.

As a second attempt, batches of minus 0.075-mm (No. 200) lime dust were prepared and heated to the proper temperature (20°C above mixing temperature). The asphalt cement was added and the mix placed into a heating mantle at the mixing temperature. The mixture was then stirred using a low shear mixing paddle (approximately 300 rpm) with some hand stir agitation to mix the mineral filler adhering to the wall of the vessel. It was readily determined that the ability of the mantle to maintain a constant mixing temperature was a function of the fluid level inside the mantle. This resulted in increasing the sample size of twice that of its original size. While this resolved the temperature problem for the most part (temperature gradients were experienced due to uncoated dust pockets in the vessel; however, large temperature fluctuations were eliminated) the mixture was impossible to mix thoroughly due to the size of the sample. In addition, the size of the sample and the fact that a single batch was used aggravated the uncoated particles problem experienced earlier. At this point it was recognized that the blends could not be treated as a liquid solution.

Instead of adding asphalt to individual batches of mineral filler, for the third experiment, one hundred gram batches of dust were prepared with the intent of adding them one at a time to the appropriate amount of asphalt cement. Specifically, 562.5 grams of asphalt was placed in a 1200 gram stainless steel beaker which was then placed into the heating mantle. A mixing paddle was lowered into the asphalt and powered to the mixing speed of 300 rpm. The mineral filler was then added and mixed 100 grams at a time until the fines to asphalt ratio requirement was satisfied. This produced a mixture of 900 grams of mineral filler and 562.5 grams of asphalt. This method seemed to work well in that the mixing temperature was properly maintained and thorough mixing was achieved. Thus, it was decided to adopt this method as standard.

One interesting revelation resulting from this experimentation was that it was noticed that the addition of the eighth one hundred gram batch of mineral filler produced a significant increase in the viscosity of the material. This was especially true with the baghouse fines. When the seventh batch of filler was added, the dust to asphalt ratio was 1.244. Hence the stiffness appeared to increase greatly when the dust to asphalt ratio exceeded this number. Subjectively, this seems to support the dust to asphalt ratio of 1.2 often recommended for dense graded mixtures.

4.2.3.2 Brookfield Viscometer

Several problems associated with the Brookfield Viscometer were discovered. First it was recognized that the prescribed sample size of 10.5 grams was inappropriate. Due to the specific gravity of the mortar (approximately 1.6), the sample weight had to be adjusted so that the sample volume in the Brookfield cup was the same as it is for an asphalt binder. Secondly, the dust tended to separate from the asphalt resulting in viscosity values that were not precise. This was expected since the mixtures were tow phase systems. Thirdly, the addition of fiber resulted in blends having stiffnesses such that they could not be measured by the equipment. This was especially true of the baghouse fines mixtures. In an attempt to combat some of these problems as effort was made to determine the Brookfield viscosity in the heating mantle (as opposed to the sample cup). This also failed resulting in either inconsistent values or no values at all. The values that were obtained in this manner are also erroneous due to the fact that the test temperatures could not be maintained as precisely as prescribed by SHRP.

4.2.3.3 Dynamic Shear Rheometer
The DSR appeared to be an acceptable test to conduct on the fine mortars. The stiffness of most of the mortars was such that specimen molding was difficult. However, it was generally true that if a specimen could be molded then it could be tested. The only problem was magnified as the viscosity of the mortar increased. At higher test temperatures these problems are significantly reduced.

4.2.3.4 Rolling Thin Film and Thin Film Oven Tests
An attempt was made to use the Rolling Thin Film Oven Test (RTFOT) since it is the preferred method prescribed by SHRP. However, the mortar stiffness was such that the material exhibited Weissenberg properties (flowed uphill) and “climbed” out of the bottles. Thus the Thin Film Oven Test (TFOT) was used as an alternative. In either case, the standard sample weights were adjusted so that the appropriate volume was present in the bottles and pans. This was necessary in order to insure that the proper test film thickness developed. A problem associated with the TFOT was the separation of the constituent materials over the five hour testing time. As a result, a layer of crust formed on the bottom of the TFOT pans which had to be scraped out, reheated and remixed before any testing could proceed.

4.2.3.5 Pressure Aging Vessel
A problem with the PAV conditioning was noticed upon removal of some of the stiffer mortars. It was discovered that the 100°C (212°F) temperature was not high enough to produce the film thickness required by SHRP. In fact, some of the mortars did not even flow to the edge of the PAV pans as they were heated. This invariably produced inconsistencies in the aging of the materials which in turn most likely affected all results obtained from testing of the PAV residue.

4.2.3.6 Bending Beam Rheometer
Specimen molding was the major problem associated with the BBR. Several different steps were either tried or taken in an attempt to prevent or at least limit the amount of air voids in the specimens. These steps included heating the molds and packing or “rodding” some of the stiffer mortars into the molds. These techniques seemed to work and produced beams with limited or no air voids. These voids represented a loss of cross-sectional area and consequently produced lower stiffness values than probably would have been observed.

4.2.3.7 Direct Tension Testing

As with the BBR, the problem encountered with the DTT was roted in the molding of the test specimens. However, unlike the BBR molds, the flexible silicone dTT molds could not be “packed” or “rodded” effectively enough to produce acceptable specimens. In addition, the molded specimens contained air voids which resulted in the loss of cross-sectional area as observed with the BBR. Of the samples tested, a considerable number experiences failure at the interface between the asphalt and the end piece. It is uncertain as to the cause of this problem and whether or not its related to the material being tested or the test procedure\equipment.

4.2.3.8 Testing Considerations

Based on observations from the fine mortar testing it appears that some of the SHRP binder tests are applicable to SMA fine mortars. Specifically, the dynamic shear and bending beam rheometers can be used to test fine mortars provided certain modifications are made to the testing procedures. The direct tension test does not seem applicable to SMA fine mortars.

The major concern of using SHRP binder tests on SMA fine mortars is the question of both intermediate and long-term aging. The research conducted thus far suggests that the RTFO, TFO, and PAV conditioning tests are difficult at best when applied to fine SMA mortars. Consequently, the test results obtained after the aging processes are questionable. However, if the aging can be accomplished in a satisfactory manner, the DSR and BBR tests can be used to distinguish between SMA mortars.

To overcome aging difficulties it is proposed that the binders be ages according to SHRP procedures prior to being mixed to form the fine mortar. This should provide for proper binder aging while allowing the fine mortars to be tested in the DSR and BBR. While it is true that certain mineral fillers might affect the aging characteristics of some binders, these fillers are very few.

In an attempt to ensure that the fine mortars could be mixed using the ages binders, a polumer modified AC-20 was aged in both the RTFO and PAV according to SHRP protocol. SMA fine mortars were then mixed from each of the RTFO and PAV residues. The mixing and molding of these fine mortars were then mixed from each of the RTFO and PAV residues. The mixing and molding of these fine mortars were completed successfully. This method of aging and producing fine mortars if there fore recommended for all future SMA fine mortar testing.

4.2.4 Total Mortar Testing

Several types of tests were conducted on the total mortar to evaluate their potential for measuring the quality of the total binder. These tests included the bending beam rheometer at -12ºC (10ºF), the resilient modulus, indirect tensile strength, and indirect tensile strength at failure were measured at 5ºC (41ºF.) and the Brookfield viscometer again at 175ºC (347ºF). The test results for the total mortar are shown in Table 4.18. As observed with the fine mortar, the Brookfield viscometer does not appear to be satisfactory for measuring the quality of the total mortar as most of the mortars were too stiff to be tested in this device.

Several observations are made concerning the data in Table 4.18. The baghouse fines generally stiffened the mixture more than limestone dust. The AC-20M1 (SBS modified) mixtures were almost always less stiff than the AC-20 mixtures. The AC020M1 should be less stiff at lower temperatures due to the SHRP grade shown in Table 4.13. Sometimes the cellulose

Table 4.18: Results From the Total Mortar Testing

Temperature	Low (-12ºC)		Intermediate (5ºC)			High (175ºC)
Total Mortar Combination	Bending Beam Rheometer		Resilient Modulus (MPa)	Indirect Tensile Strength (kPa)	Indirect Tensile Strain at Failure (mm/mm)	Brookfield Viscosity (cP)*
	S (MPa)	m (slope)				
AC-20,LD	914	0.385	704	838	0.0312	4642
AC-20,FA	1396	0.285	1318	1057	0.0288	**
AC-20, F1,LD	795	0.365	711	818	0.0259	4766
AC-20, F1,FA	1164	0.330	1035	1005	0.0282	**
AC-20, F2,LD	808	0.405	897	861	0.0282	3791
AC-20M1, LD	519	0.410	593	632	0.0267	8646
AC-20M1, FA	748	0.340	662	883	0.0265	**
AC-20M1, F1,LD	502	0.380	649	660	0.0281	12037
AC-20M1, F1,FA	915	0.340	759	703	0.0230	**
AC-20M1, F2,LD	482	0.390	455	529	0.0270	11604

*Measurements taken at time = 5 minutes in order to minimize phase separation effects. However, separation of the asphalt and aggregate still occurred resulting in viscosity values that are questionable.
**Material stiffness such that viscosity measurements could not be obtained.

(Fiber 1) stiffened the mixture more than the slag wool (Fiber 2) and sometimes the reverse was true. The data for the total mortar and fine mortar indicate a close relationship between total mortar properties and fine mortar properties even when two different temperatures were used (Figures 4.2-4.4). It appears that measuring the properties of either the fine or total mortars would allow the properties of the other to be determined. The stiffness values for the total mortar as measured by the bending beam rheometer have approximately the same magnitude as that for the fine mortar (Figure 4.2). For example, the best fit line indicates that a fine mortar stiffness of 700 MPa would have a total mortar stiffness of approximately 700 MPa. A fine mortar stiffness of 1100 MPa would have a total mortar stiffness of approximately 1250 MPa. The magnitude of the resilient modulus at 5ºC (41ºF) is very similar to the magnitude of the fine mortar stiffness at -12ºC (10ºF) (Figure 4.3). The fine mortar BBR stiffness at -12ºC was also very similar to the total mortar indirect tensile strength at 5ºC (Figure 4.4).

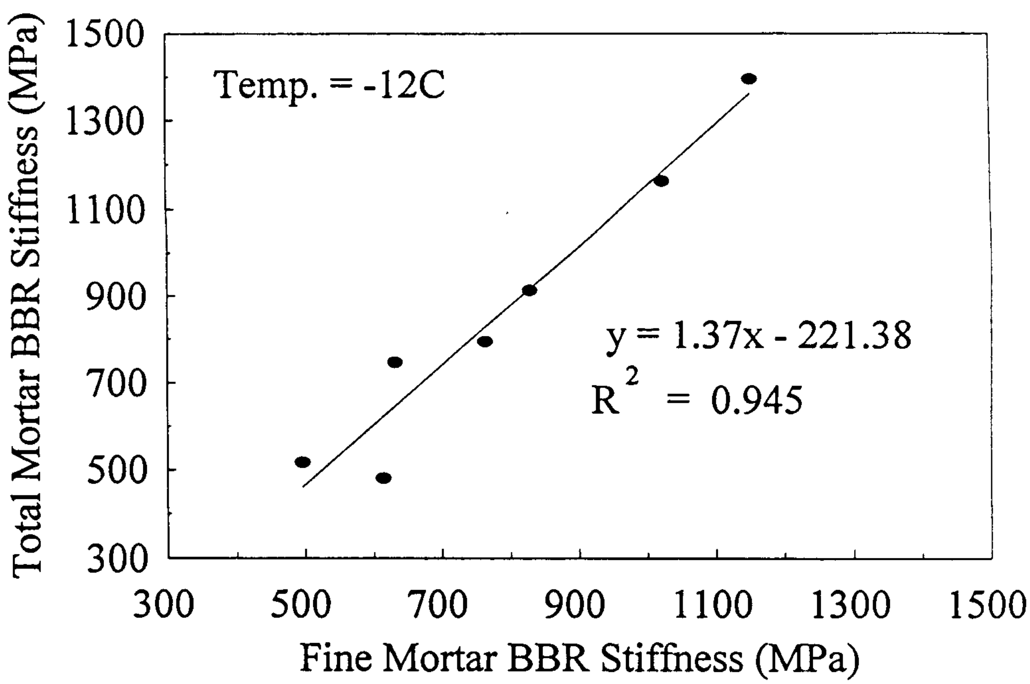

Figure 4.2: Relationship Between Total Mortar Stiffness and Fine Mortar Stiffness at -12°C

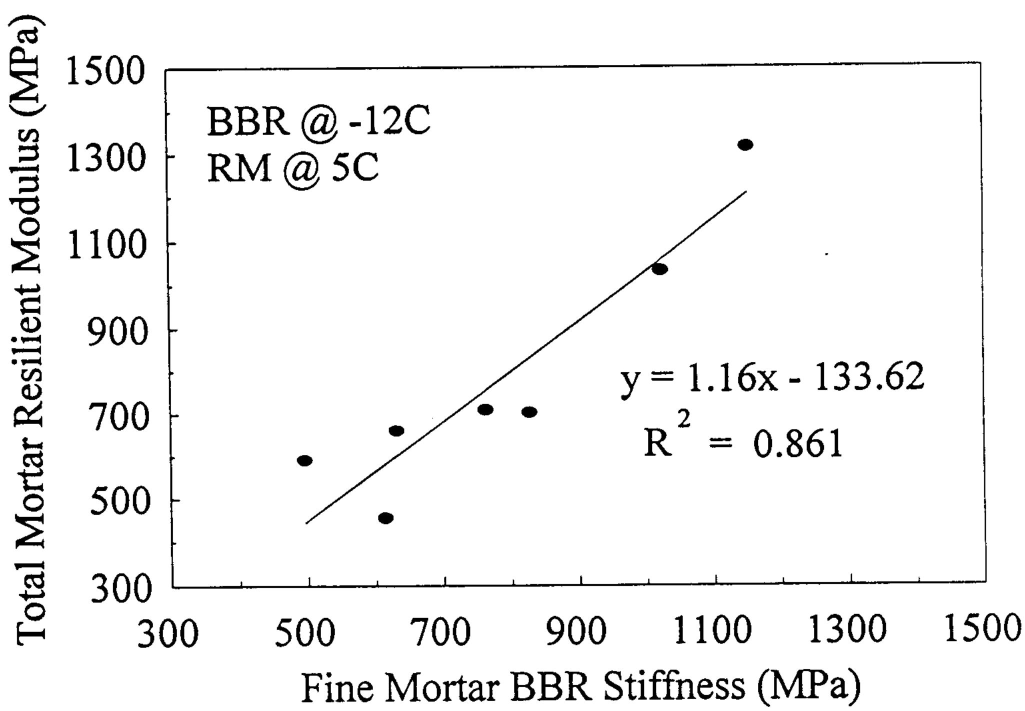

Figure 4.3: Relationship Between Total Mortar Resilient Modulus at 5°C and Fine Mortar Stiffness at -12°C

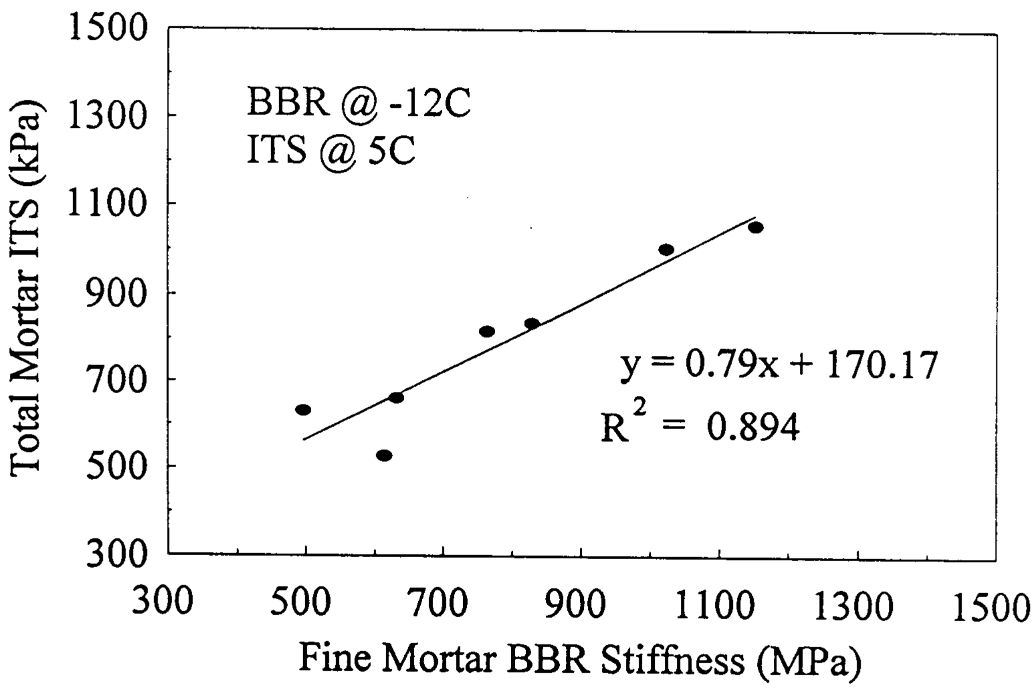

Figure 4.4: Relationship Between Total Mortar Tensile Strength at 5°C and Fine Mortar Stiffness at -12°C

4.2.4.1 Mixing/Blending Procedures

As with the fine mortars, a mixing procedure had to be developed for the total mortars before testing could begin. Since the total mortar fraction had a gradation that was coarser than the fine mortar, it was believed that hand stirring the materials over a hot plate would be sufficient and this was determined to be the case. The appropriate amount of mixture required to make a 63.5-mm (2.5 inch) Marshall specimen was determined assuming that a voidless briquette would be produced. Obviously this assumption was in error since the placement of a mixture with 25 percent asphalt content into a Marshall mold without incorporating any air bubbles was virtually impossible. It was determined that 750 grams of aggregate and 250 grams of asphalt were needed. Individual batches of aggregate were then prepared and heated to mixing temperature. The aggregate consisted of a Georgia granite with either limestone dust or baghouse fines for mineral filler. As stated, the materials were mixed by hand using a sand bath as a heating aid. The mortar was then poured or placed into a Marshall mold which had been coated with glycerin\talc solution release agent. The molds were allowed to cool to room temperature and then placed in a refrigerator at 5°C (41°F) for storage until they were tested. A total of six specimens were prepared for each total mortar combination, three for Indirect Tension Testing and three for Resilient Modulus Testing. In addition, a seventh batch was mixed but not molded in order to determine the Brookfield Viscosity and Bending Bean Rheometer parameters of the mortar.

4.2.4.2 Brookfield Viscometer

The same problems encountered testing the fine mortar with the Brookfield Viscometer were experienced testing the total mortar. In addition, the effect of lowering the asphalt content served only to aggravate those problems and as a result, not all of the viscosity measurements could be obtained. The viscosity values that were obtained most certainly are in error due to the separation of the mixture during testing.

4.2.4.3 Bending Beam Rheometer

The BBR proved to be a viable test method if one could mold the beams. Beam molding was extremely difficult as a result of the 25 percent asphalt content. Some of the mortars were "packed" into the molds to minimize incorporation of voids. However, voids wee present in most all of the beams resulting in loss of cross-sectional area and most assuredly lower observed stiffness values. Like the fine mortar beams, the increase in specific gravity over that of asphalt cement caused the beams to sink in the BBR bath fluid and thus the beams were supporting their own weight as well as the test weight. This probably resulted in slightly lower observed stiffness values as well.

4.2.4.4 Indirect Tension Test

It was observed with the ITT that none of the specimens seemed to fail but instead exhibited deformation under loading until the limit of the equipment was reached. It may be necessary to modify the test procedures to get acceptable answers.

4.2.4.5 Resilient Modulus

No procedural problems were encountered with the RM test.

4.3 MIXTURE DESIGN ANALYSIS RESULTS

Several mixtures were evaluated to determine the effect of aggregate type and gradation on the mixture properties. The gradations evaluated are identified as 1, 2, and 3 as shown in Table 3.1. Fifty blows of a flat-faced, static base mechanical Marshall hammer were used to compact all specimens. Mix designs were first conducted on each of the five aggregates to determine the optimum gradation and optimum binder contents. The procedure basically involved lowering the percent passing the 4.75-mm (# 4) sieve until the VMA was 17 percent or higher and until stone or stone contact was developed based on the dry-rodded weight of coarse aggregate. The asphalt content was then varied until the voids in the total mixture were 3.5 to 4.0 percent. These mix designs are identified on the left side of Figure 3.1. The plots of the VCA and VMA versus percent passing the 4.75-mm (# 4) sieve for each of the five aggregates and the plots as needed of voids versus asphalt cement content are shown in Figures 4.5-4.16.

For the granite aggregate the percent passing the 4.75-mm (#4) sieve must be no more than 26 percent to provide a minimum VMA of 17 percent (Figure 4.5). The percent passing the 4.75-mm (#4) sieve must be 27 percent or lower to provide a VCA in mixture equal to or lower than the 39.4% VCA_{DRC} measured with the dry-rodded test method (Figure 4.6). Based on these two plots, it was determined that the percent passing the 4.75-mm (#4) sieve would be selected at 25 percent passing. The asphalt content of 6.3% used to produce these samples provided voids in

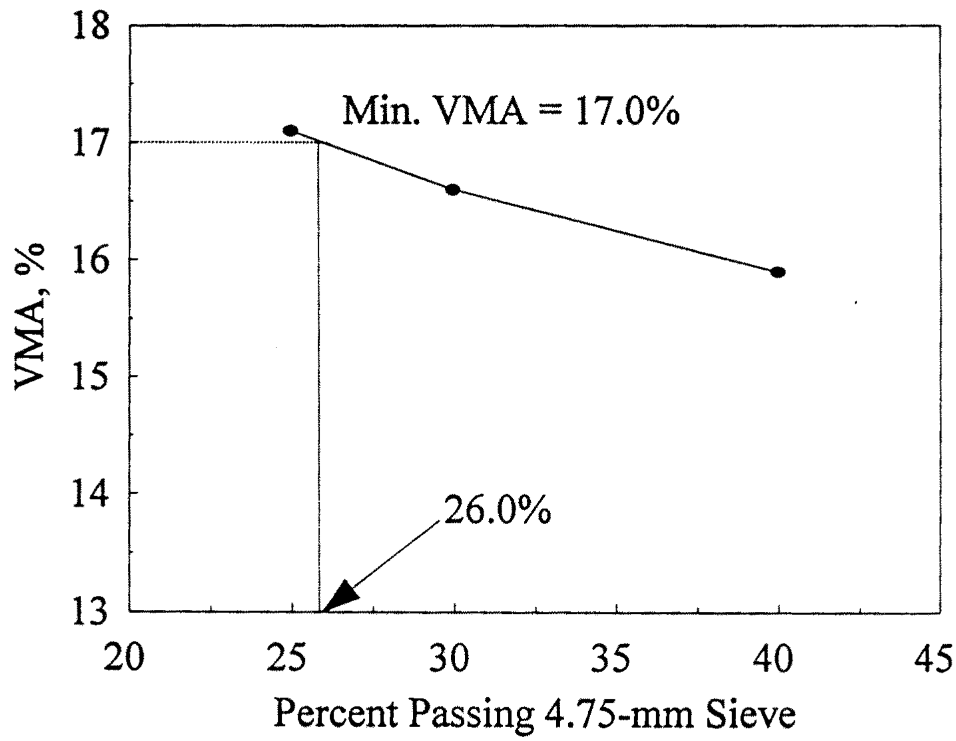

Figure 4.5: VMA Versus Percent Passing the 4.75-mm Sieve for Granite Aggregate

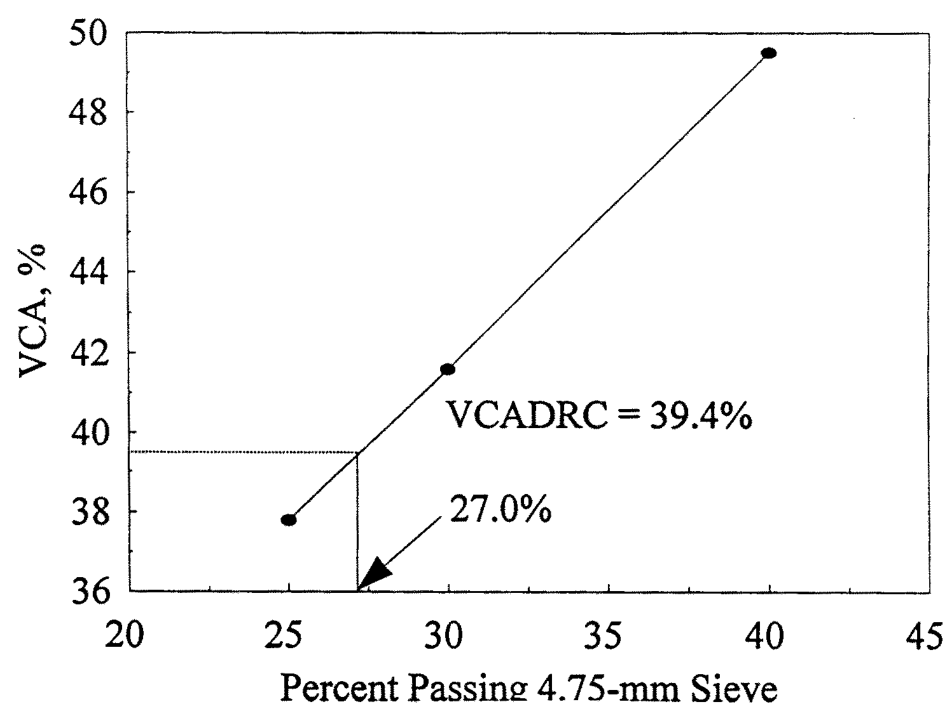

Figure 4.6: VCA Versus Percent Passing 4.75-mm Sieve for Granite Aggregate

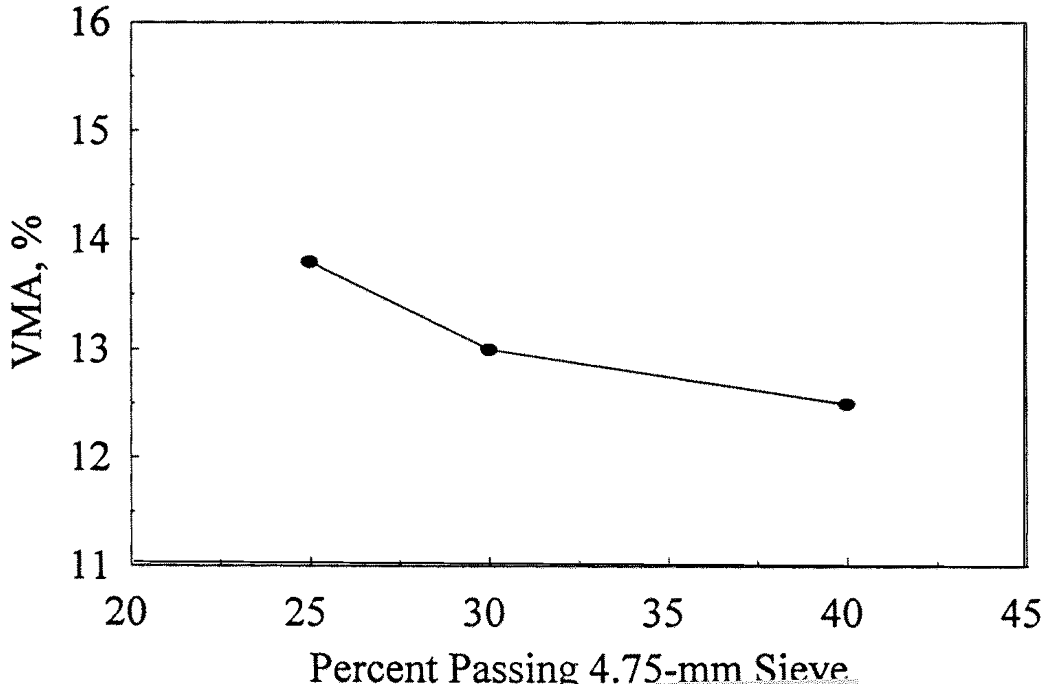

Figure 4.7: VMA Versus Percent Passing the 4.75-mm Sieve for Florida Limestone Aggregate

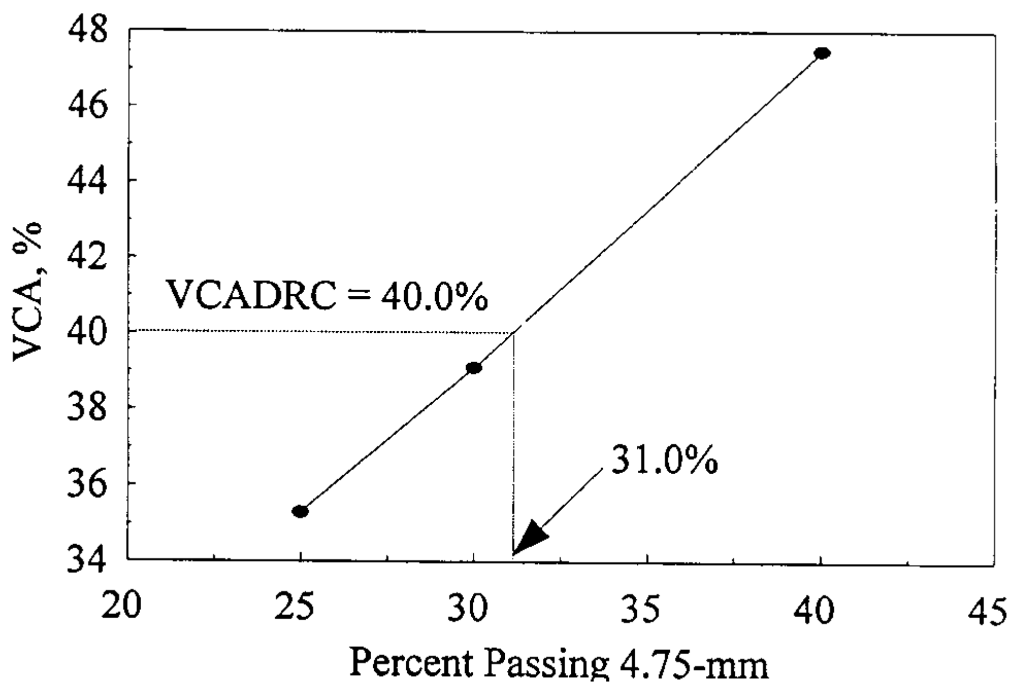

Figure 4.8: VCA Versus Percent Passing the 4.75-mm Sieve for Florida Limestone Aggregate

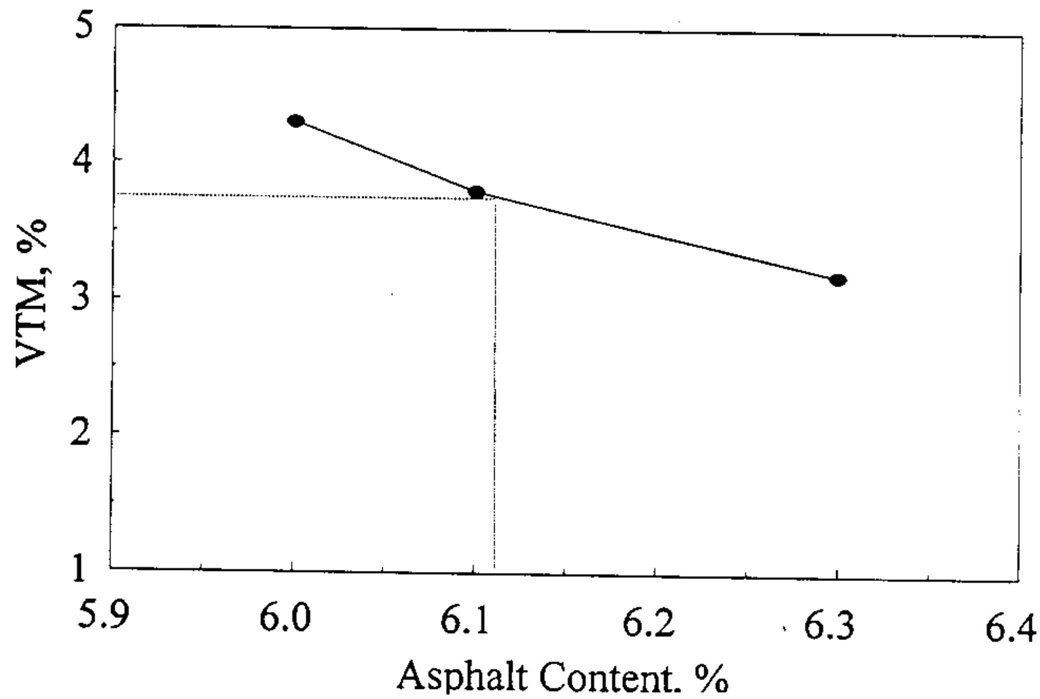

Figure 4.9: Selection of Optimum Asphalt Content for Florida Limestone SMA Mixture

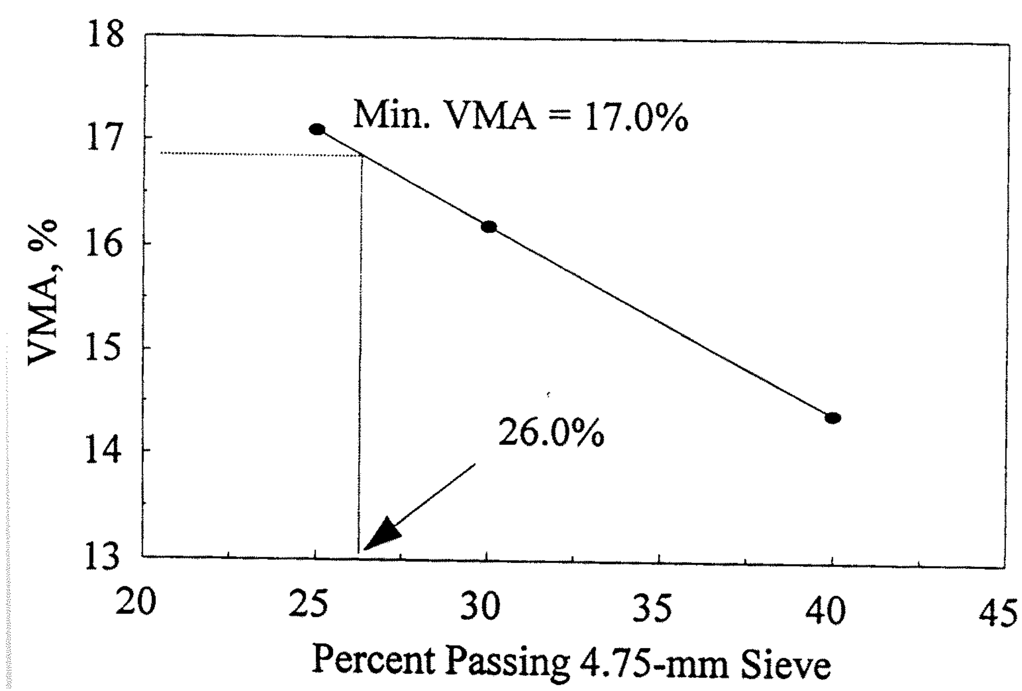

Figure 4.10: VMA Versus Percent Passing the 4.75-mm Sieve for Gravel Aggregate

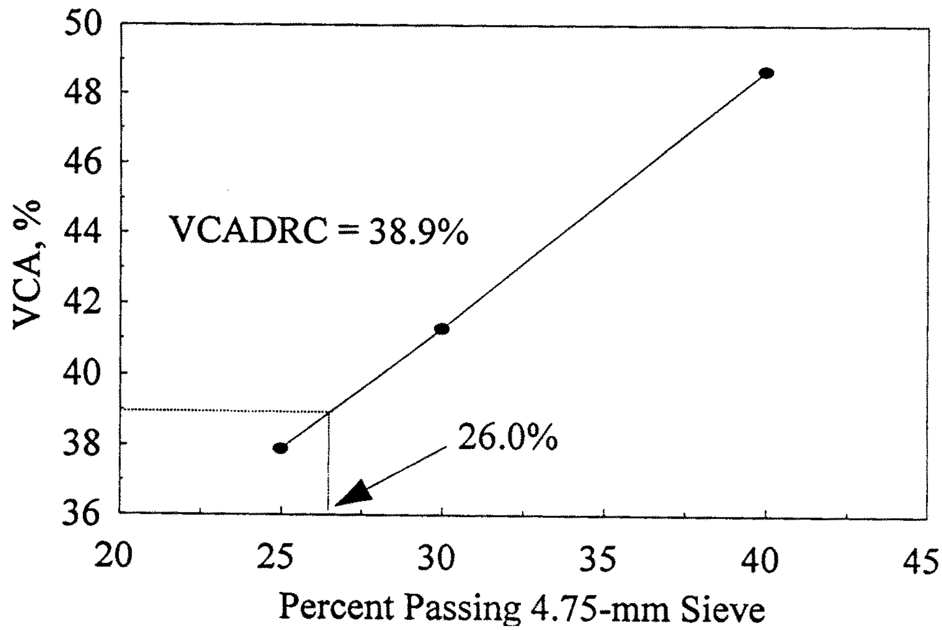

Figure 4.11: VCA Versus Percent Passing the 4.75-mm Sieve for Gravel Aggregate

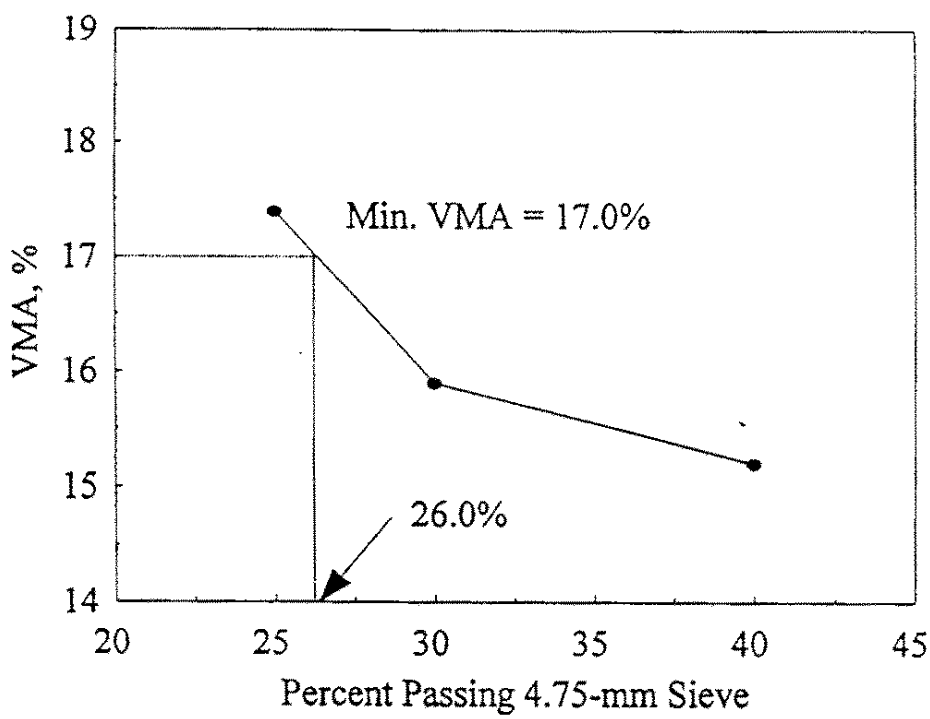

Figure 4.12: VMA Versus Percent Passing the 4.75-mm Sieve for Limestone Aggregate

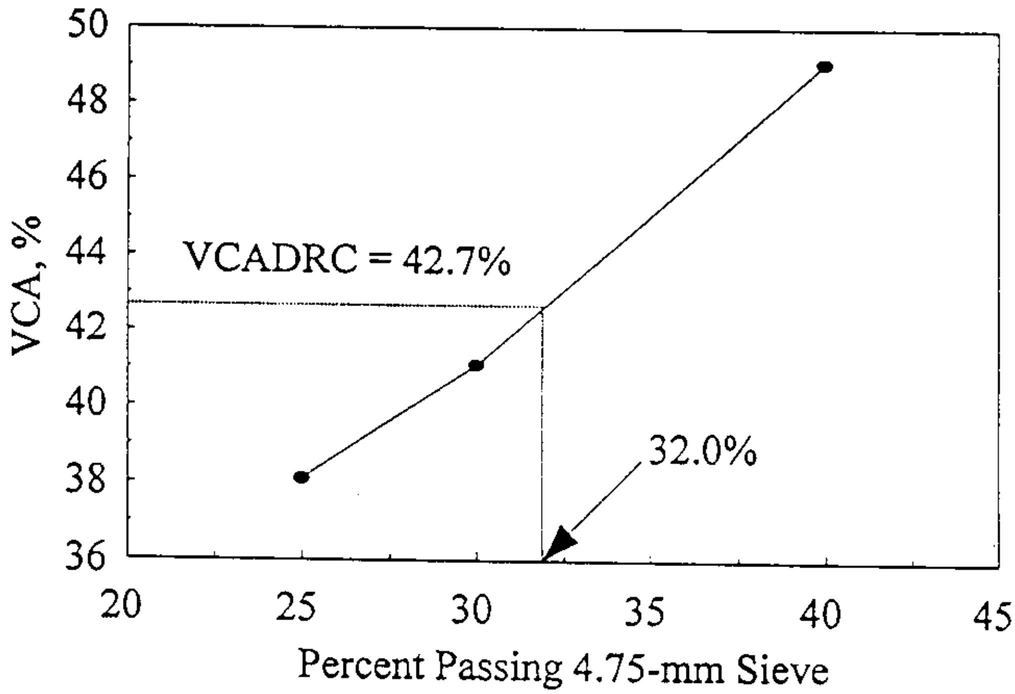

Figure 4.13: VCA Versus Percent Passing the 4.75-mm Sieve for Limestone Aggregate

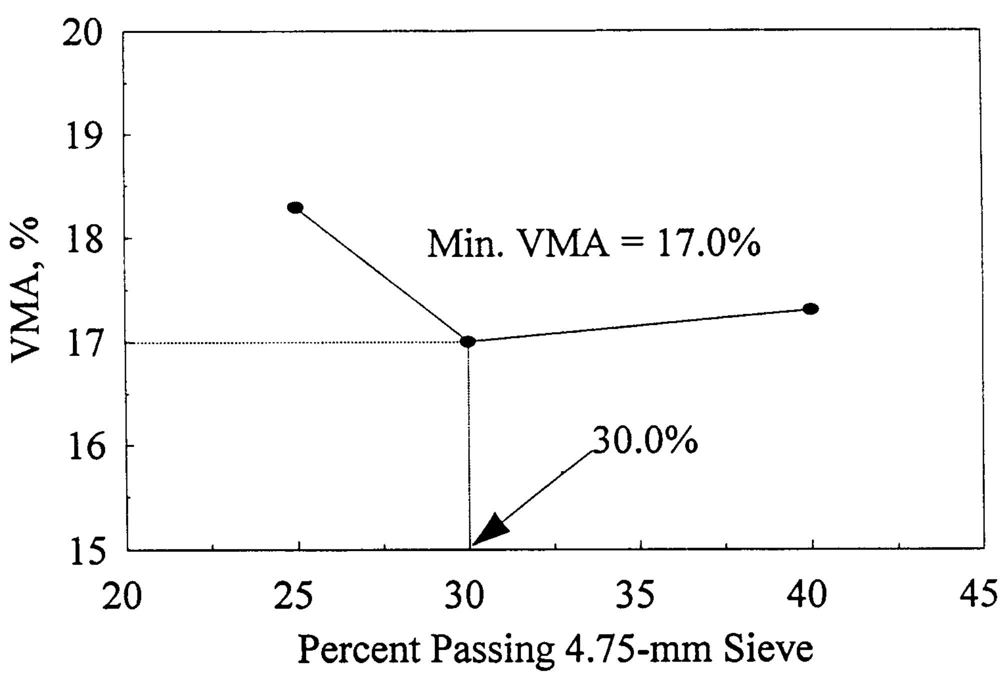

Figure 4.14: VMA Versus Percent Passing the 4.75-mm Sieve for Traprock Aggregate

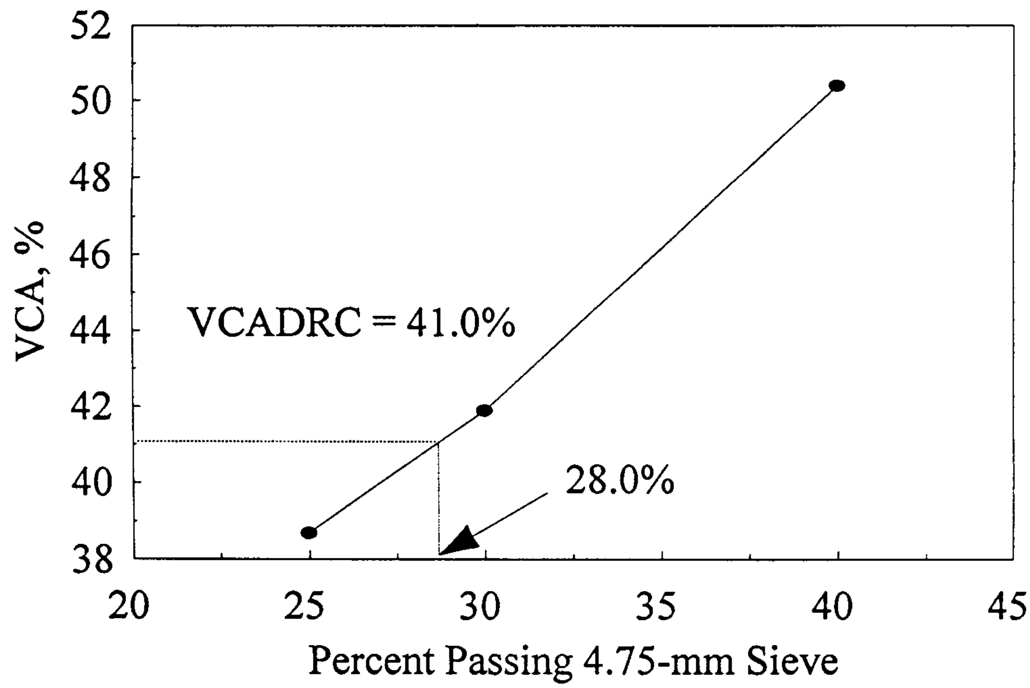

Figure 4.15: VCA Versus Percent Passing the 4.75-mm Sieve for Traprock Aggregate

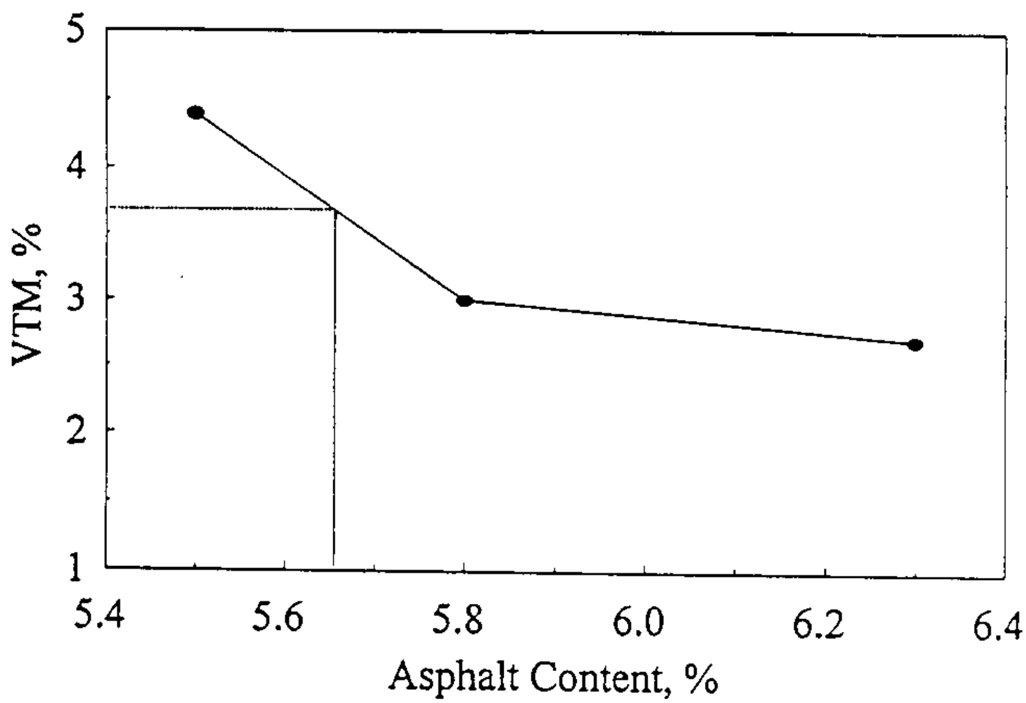

Figure 4.16: VTM Versus Asphalt Content for Traprock Aggregate

the total mix of 3.7%. Hence, 6.3% asphalt content was selected as optimum and there was no need to vary the asphalt content to select the desired voids.

It became clear early in the process that designing a satisfactory SMA mixture with Florida limestone aggregate would be difficult. The VMA was always low for these mixtures. To improve the VMA the percent passing the 9.5-mm (3/8-inch) sieve was reduced from 55 percent to 40 percent to open up the mixture. The percent passing the 4.75-mm (# 4) sieve was then varied from 40 to 30 to 25 percent. As shown in Figure 4.9, the VMA was still much lower than the desired 17 percent. The reason for the low VMA as determined later was the breakdown of aggregate when the mixture was compacted. The VCA criteria could be met for the Florida limestone by using 31 percent or less passing the 4.75-mm (# 4) sieve (Figure 4.8). To provide the best VMA within reason, it was determined to select 25 percent passing the 4.75-mm (# 4) sieve for the SMA mix design. The optimum asphalt content was selected to be 6.1% (Figure 4.9). The high asphalt content for the Florida limestone aggregate is the result of high aggregate absorption. The effective asphalt content for this aggregate is considerably lower than the total asphalt content.

The percent passing the 4.75-mm (#4) sieve for the gravel aggregate had to be 26 percent or lower to meet the minimum VMA requirement of 17 percent (Figure 4.10). The percent passing the 4.75-mm (#4) sieve also had to be 26 percent or lower to meet the VCA requirements determined from the dry rodded weight of the coarse aggregate (Figure 4.11). The percent passing was selected to be 25 percent. The asphalt content of 6.0% (5.8% effective) was determined to produce 3.8% air voids and ws selected as the optimum asphalt content.

The percent passing the 4.75-mm (#4) sieve for the traprock could be anywhere below 40 percent to meet the minimum VMA requirements of 17 percent however, the VMA was marginal down to 30 percent passing (Figure 4.14). The percent passing the 4.75-mm (#4) sieve had to be 28 percent or lower to meet the VCA requirements from the dry rodded test (Figure 4.15). The percent passing the 4.75-mm (#4) sieve was selected to be 25 percent. The optimum asphalt content was selected to be 5.7% (total and effective) from Figure 4.16. The asphalt content is relatively low by weight due to the high specific gravity of aggregate (approximately 3.00). On a volume basis, this asphalt content is similar to the asphalt contents used in the other mixtures. This problem caused by specific gravity of aggregate clearly shows the need to specify minimum VMA as the mixture criteria and not minimum asphalt content by weight.

These five mix designs show that the concept of varying the percent passing the 4.75-mm (#4) sieve to obtain the minimum allowed VMA and the maximum allowed VCA is viable. This method appeared to work with all aggregates (except for Florida limestone which did not meet the VMA requirements and probably should not be used to produce SMA mixtures) but was more difficult with the aggregates that experienced more breakdown such as granite, limestone, and Florida limestone. The gradation that was selected was degraded in the compaction process making it difficult to maintain acceptable VMA with the softer aggregates.

A summary of the mix designs and test results for the five aggregates is provided in Tables 4.19-4.22. Table 4.19 shows that the granite, gravel, limestone and traprock mixtures all meet the minimum VMA requirement of 17 percent. The Florida limestone fell much below the minimum 17 percent due to breakdown of aggregate during compaction. The minimum asphalt content of 6 percent was met for Florida limestone. However, due to the high absorption of this aggregate the effective asphalt content was less than 5 percent. A typical requirement for Marshall stability for SMA is 6230 N (1400 lbs.). The results of tests on these five mixtures

Table 4.19: Mix Design Properties of SMA Mixtures

	Granite	FL Limestone	Gravel	Limestone	Traprock	SMA TWG Guidelines
AC, %	6.3	6.1	6.3	6.0	5.7	6% Min.
Eff. AC, %	5.8	4.7	6.2	5.8	5.7	-
VTM, %	3.7	3.8	3.9	3.8	3.8	3.5-4.0%
VMA, %	17.1	13.9	17.1	17.4	17.9	-
VCA, %	37.8	35.4	38.9	38.1	38.4	-
VCA_{DRC}, %	39.4	40.0	38.7	42.7	41.0	-
VCA/ VCA_{DRC}	0.96	0.88	1.00	0.89	0.94	1.0 Max.
Stability, N	7749	6450	4524	4893	6005	6230 Min.
Flow, 0.25mm	11	14	13	14	17	8-16

Table 4.20(a): Moisture Susceptibility Results for the Five Mix Designs

	Granite	FL Limestone	Gravel	Limestone	Traprock
Uncond. Strength, kPa	906	791	706	671	687
Cond. Strength, kPa	591	498	338	443	567
TSR, %	65.2	63.0	47.9	66.0	82.0

Table 4.20(b): Moisture Susceptibility Results for Dense-Graded Mixtures Using the Five Aggregates

	Granite	FL Limestone	Gravel	Limestone	Traprock
Uncond. Strength, kPa	1041	1049	1029	1285	1054
Cond. Strength, kPa	476	597	490	985	671
TSR, %	45.7	56.9	47.6	74.6	63.7

Table 4.21: Draindown Test Results for the Five Mixture Designs (Specification requires the draindown at anticipated production temperature, 149°C in this case, be no more than 0.3%)

	Percent Draindown				
Temperature, ºC	Granite	FL Limestone	Gravel	Limestone	Traprock
135	0.02	0.11	0.06	0.01	0.01
149	0.02	0.11	0.15	0.03	0.06
163	0.01	0.10	0.16	0.02	0.04

Table 4.22: Gradations for the Five Mixture Designs

Sieve Size (mm)	Percent Passing					
	Granite	FL Limestone	Gravel	Limestone	Traprock	Spec.
19.0	100	100	100	100	100	100
12.5	90	90	90	90	90	85-95
9.5	55	40	55	55	55	75 Max.
4.75	25	25	25	25	25	20-28
2.36	20	20	20	20	20	16-24
1.18	17	17	17	17	17	-
0.60	14	14	14	14	14	12-16
0.30	13	13	13	13	13	12-15
0.15	11	11	11	11	11	-
0.075	10	10	10	10	10	8-10

indicate that the Marshall stability is often much less than this value. For example, the gravel mixture had a Marshall stability as low as 4524 N (1017 lbs.). Only two of the SMA mixtures produced with the five aggregates exceeded the 6230 N (1400 lbs.) minimum stability. The two mixtures that exceeded this minimum stability were the two that had the highest L.A. abrasion. Breakdown of these aggregates may have been more than those with lower L.A. abrasion values resulting in a more dense, higher stability mixture.

The moisture sensitivities of each of the five SMA mixtures as well as the five dense-graded mixtures were tested using AASHTO T283. The test procedure was modified slightly for the SMA specimens in that they were compacted to an air voids range of 6±1 percent. This air void range is more indicative of SMA pavement density at the time of construction. The dense-graded specimens were compacted to the standard 7±1 percent air voids range. Also, the freeze-thaw cycle was not used in the testing.

The results of the AASHTO T283 testing are shown in Tables 4.20(a) and 4.20(b) for the SMA and dense-graded mixtures respectively. The SMA retained tensile strengths range from a low of 48 percent for the gravel to a high of 82 percent for the traprock. The granite and gravel are known to exhibit stripping so it is not unexpected that both the SMA and dense-graded mixtures containing these aggregates had low test results. It is important to note that the TSR values for the SMA and dense-graded mixtures were similar for each of the aggregate types. The TSR values were significantly higher for granite and traprock when used in SMA mixtures. The test results seem to indicate that AASHTO T283 is applicable to SMA mixtures, generally providing similar results between dense and SMA mixtures. Adjustments in the mortar properties may be effective in increasing the TSR ratios for SMA mixtures.

The draindown sensitivity of each of the SMA mixtures was also determined using the test procedure developed by NCAT (see Volume IV of this report). All of the mixtures had good draindown properties (Table 4.21) with none exceeding the recommended 0.3%. It is interesting to note that the two mixtures with the most draindown (Florida limestone and gravel) are also the same two mixes with the lowest retained strength after conditioning.

The selected gradations for each aggregate determined in the mix design process are shown in Table 4.22. All mixtures except Florida limestone had the same gradation. The gradation for Florida limestone was unsuccessfully changed to try to increase the VMA.

Mix designs were conducted for Florida limestone and granite over a range of gradations as shown in Figure 3.1. A total of nine different gradations were evaluated for these two aggregates. For most SMA projects in the U.S., the contractor will have a filler, fine aggregate, and one or more coarse aggregates to blend to produce the job mix formula. The gradation will then be controlled by varying the percent of each aggregate that is used. The first six gradations (Table 3.1) simply looked at varying the percent of coarse and fine aggregate and the amount of filler was held constant. Gradations 7 through 9 looked at holding the fine aggregate and filler contents constant while varying the gradation of the coarse aggregate (in practice, this could be done by having two coarse aggregates and varying the percentage of each). The mix design summaries for the two aggregates and nine gradations are shown in Table 4.23. Note that gradations 5.and 6 show no data for the AASHTO T283 test. This is because it was impossible to get the air voids low enough to meet the requirements of the test. The granite aggregate designs using gradations 5 and 6 were completed prior to those with Florida limestone. The asphalt cement content was raised as high as was practical for both the designs, but still air voids of between three and four percent could not be obtained. In fact, even at the high asphalt cement content was not tried with the Florida limestone.

The data in Table 4.23 clearly shows the effect of changing the percent passing the 4.75-mm (#4) sieve (gradation 1-4) on optimum asphalt content. As the percent passing the 4.75-mm (#4) sieve decreased from 40 percent to 20 percent, the optimum asphalt content increased from 4.3% to 6.5% for granite and from 4.8% to 7.5% for Florida limestone. Interestingly, gradations 7-9 did not follow the expected trend. As the percent passing the 9.5-mm (3/8-inch) sieve was increased from 35 percent to 65 percent, the optimum asphalt content increased from 5.3% to 5.8% for granite and from 6.0% to 6.7% for Florida limestone. The optimum asphalt content does not appear to be very sensitive to the percent passing the 9.5-mm sieve. For comparison, mix designs for dense graded mixes with granite and Florida limestone are shown in Tables 4.24, 4.25 and 4.26. The optimum asphalt content and VMA for the dense graded mixtures are considerably lower than that for the SMA mixtures.

4.4 MIXTURE TEST RESULTS

After mix designs had been developed for the nine gradations and two aggregates (Table 3.1, Figure 3.1) confined, dynamic creep tests were conducted on each of the mixtures at optimum, below optimum, and above optimum asphalt contents to evaluate the sensitivity of the various mixtures to change in the air voids. For comparison purposes, a dense graded mix for each aggregate was produced at various asphalt contents and tested. The results are presented in Tables 4.23 and 4.24 for granite and Florida limestone, respectively.

At the beginning of this study, it was believed that one advantage of SMA mixtures was their low sensitivity to changes in voids. Work has shown that the strength of SMA is not very sensitive to changes in voids and strength of dense mixes are sensitive to changes in voids. Comparisons were made between mixes made with gradations 1 through 9 shown in Table 3.1 and dense graded mixtures. All of these mixtures were tested with the confined, dynamic creep

Table 4.23: Mix Design Summaries for 9 Gradations (Table 3.1) With Granite and Florida Limestone

	Granite Aggregate								
Mix Property	1	2	3	4	5*	6*	7	8	9
Optimum AC, %	4.3	5.8	5.8	6.5	8.3	7.3	5.3	5.5	5.8
Voids, %	4.0	3.6	3.6	3.8	12.1	19.2	3.8	3.7	3.6
VMA, %	13.4	16.7	16.5	18.2	28.2	31.2	16.0	16.3	16.6
VCA ,%	48.0	41.7	37.4	34.6	35.4	31.2	37.0	37.2	37.4
Draindown @ 149º C	0.04	0.11	0.04	0.21	-	-	0.08	0.20	0.22
Uncond. TS, kPa	1103	722	743	776	-	-	853	693	858
Cond. TS, kPa	509	524	451	429	-	-	451	460	468
TSR, %	46.1	72.6	60.7	55.3	-	-	52.9	66.4	54.5
Mix Property	Fl Limestone Aggregate								
Optimum, AC %	4.8	5.0	6.2	7.5	5.5	5.5	6.0	6.0	6.7
Voids, %	3.8	3.5	3.8	3.7	-	-	3.6	4.0	3.8
VMA, %	11.6	11.9	14.4	16.8	25.8	28.1	13.9	14.1	16.8
Mix VCA, %	47.0	38.3	35.8	33.4	33.2	28.1	35.4	35.6	37.6
Draindown @ 149º C	0.07	0.02	0.07	0.04	-	-	0.02	0.34	0.03
Uncond. TS, kPa	1021	907	721	694	-	-	604	707	747
Cond. TS, kPa	591	427	411	359	-	-	416	458	424
TSR, %	57.9	47.1	57.0	51.7	-	-	68.9	64.8	56.8

*Optimum asphalt content could not be established for these mixtures. The asphalt contents shown were selected to provide test results for comparison purposes.

Table 4.24: Average Volumetric Properties of the Dense-Graded Granite Mixture at Various Asphalt Cement Contents

Asphalt Content, %	VTM, %	VMA, %	VCA, %
4.0	5.3	14.1	48.9
4.5	4.0	14.0	48.9
5.0	2.5	13.9	48.7
5.5	1.3	13.9	48.8
6.0	0.9	14.6	49.2

Table 4.25: Average Volumetric Properties of the Dense-Graded Florida Limestone Mixture at Various Asphalt Cement Contents

Asphalt Content, %	VTM, %	VMA, %	VCA, %
5.0	5.0	12.6	55.4
5.5	4.0	12.8	55.5
6.0	2.2	12.2	55.2
6.5	2.0	13.0	55.6
7.0	1.0	13.1	55.7

Table 4.26: Gradations for the Dense-Graded Mixtures With Granite and Florida Limestone

Sieve Size (mm)	Percent Passing	
	Granite	Florida Limestone
19.0	100	100
12.5	96	96
9.5	80	80
4.75	41	41
2.36	29	29
1.18	23	23
0.60	18	18
0.30	13	13
0.15	9	9
0.075	5.3	5.3

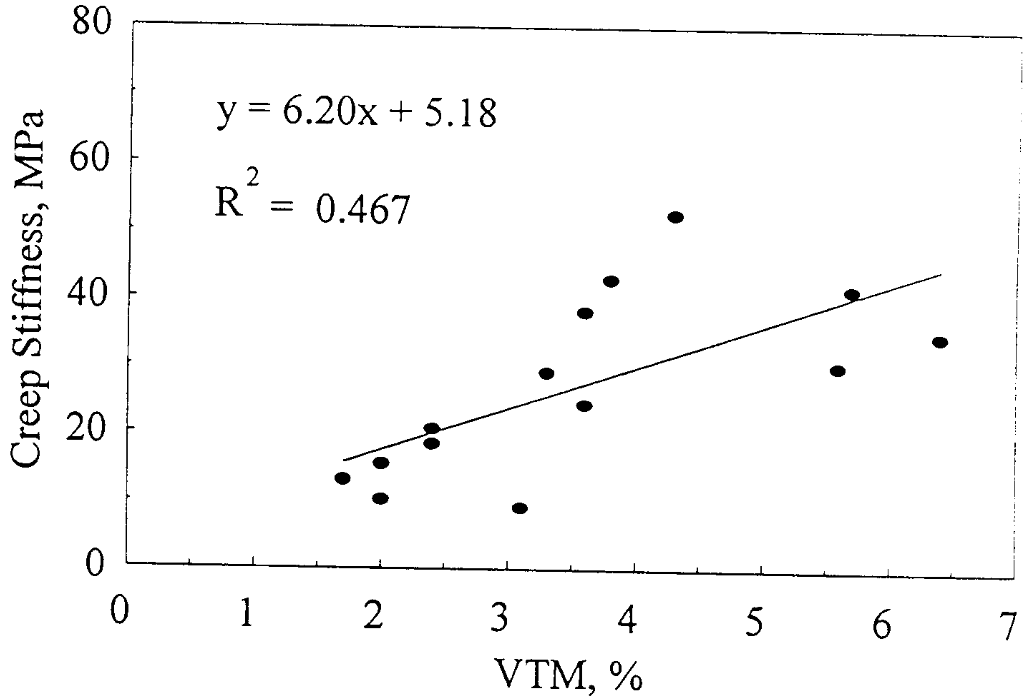

Figure 4.17: Creep Data for Granite Gradation 1

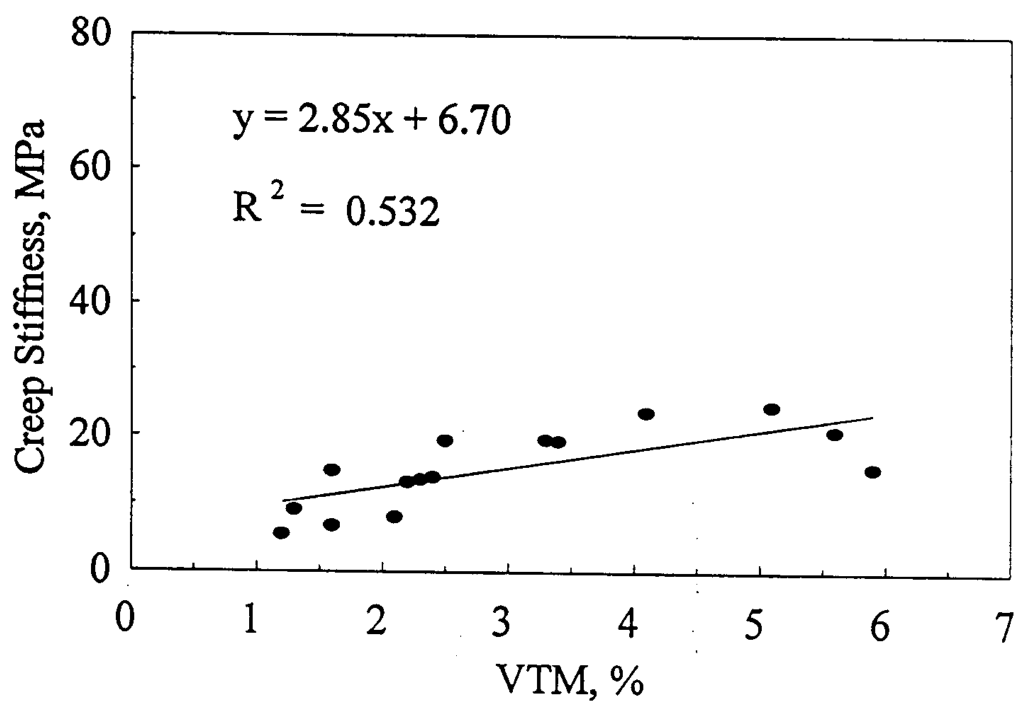

Figure 4.18: Creep Data for Granite Gradation 2

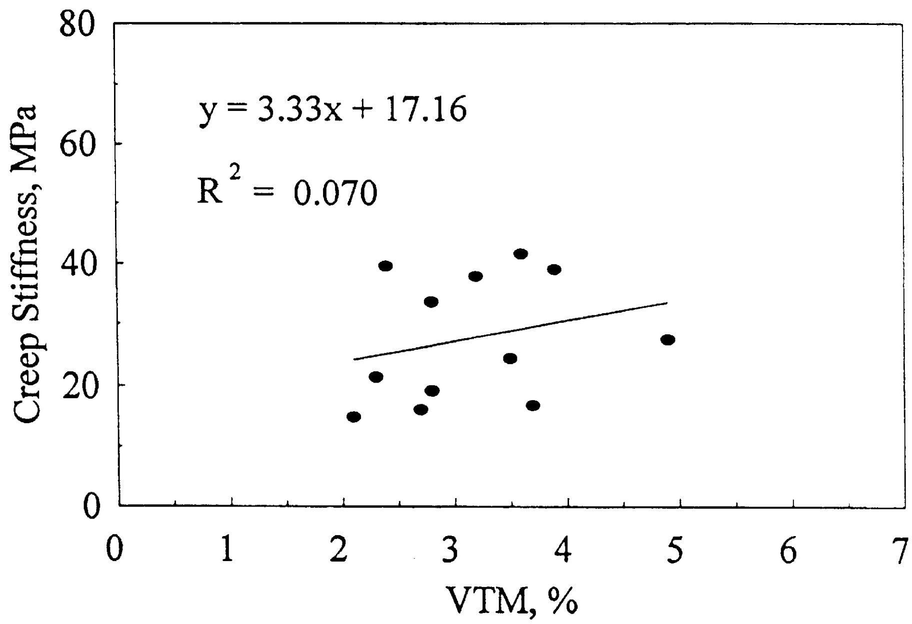

Figure 4.19: Creep Data for Granite Gradation 3

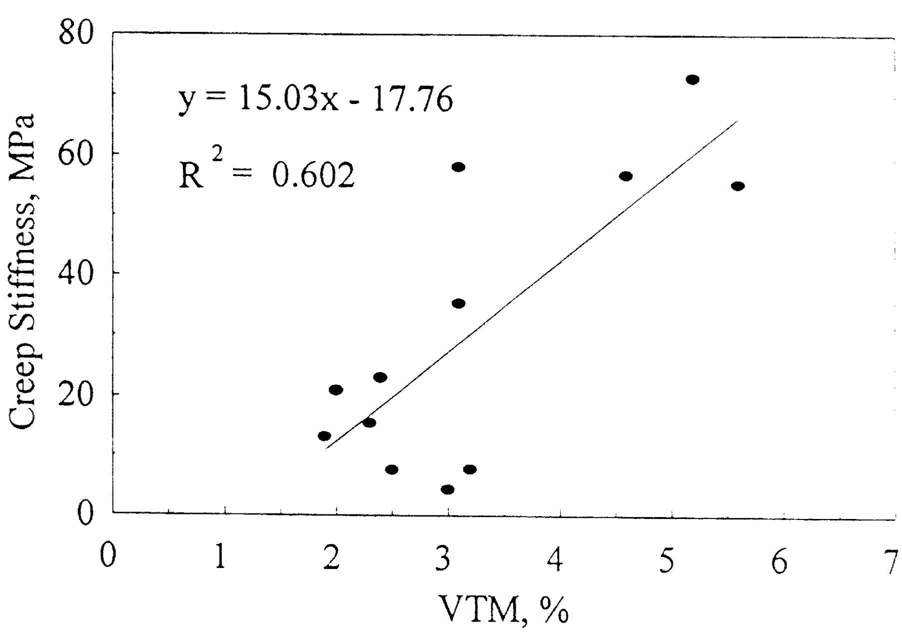

Figure 4.20: Creep Data for Granite Gradation 4

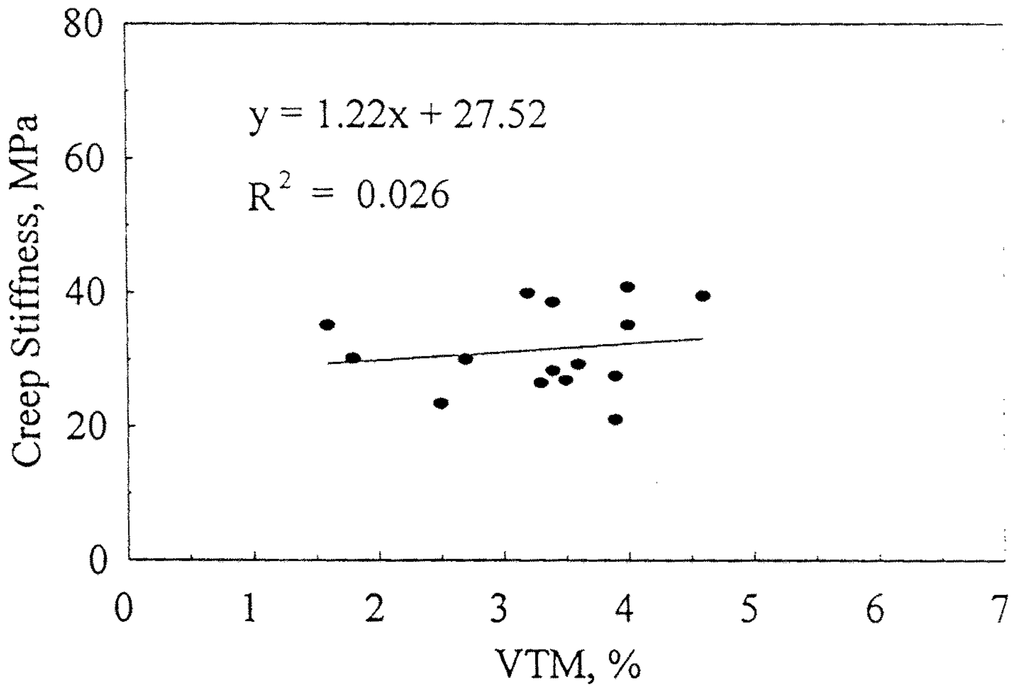

Figure 4.21: Creep Data for Granite Gradation 7

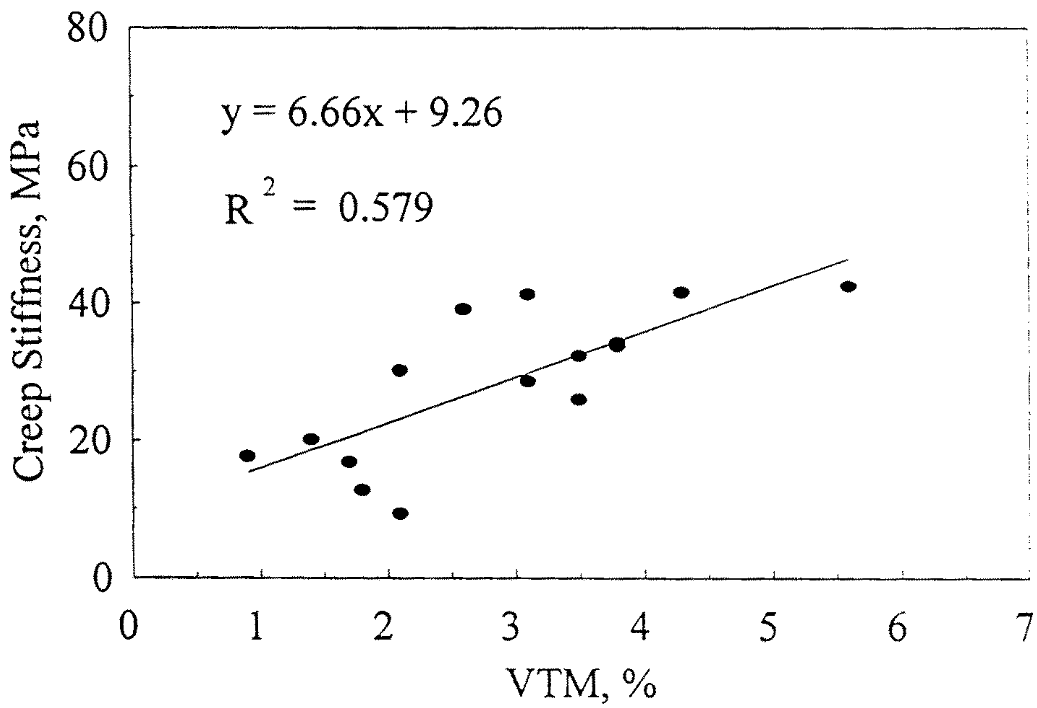

Figure 4.22: Creep Data for Granite Gradation 8

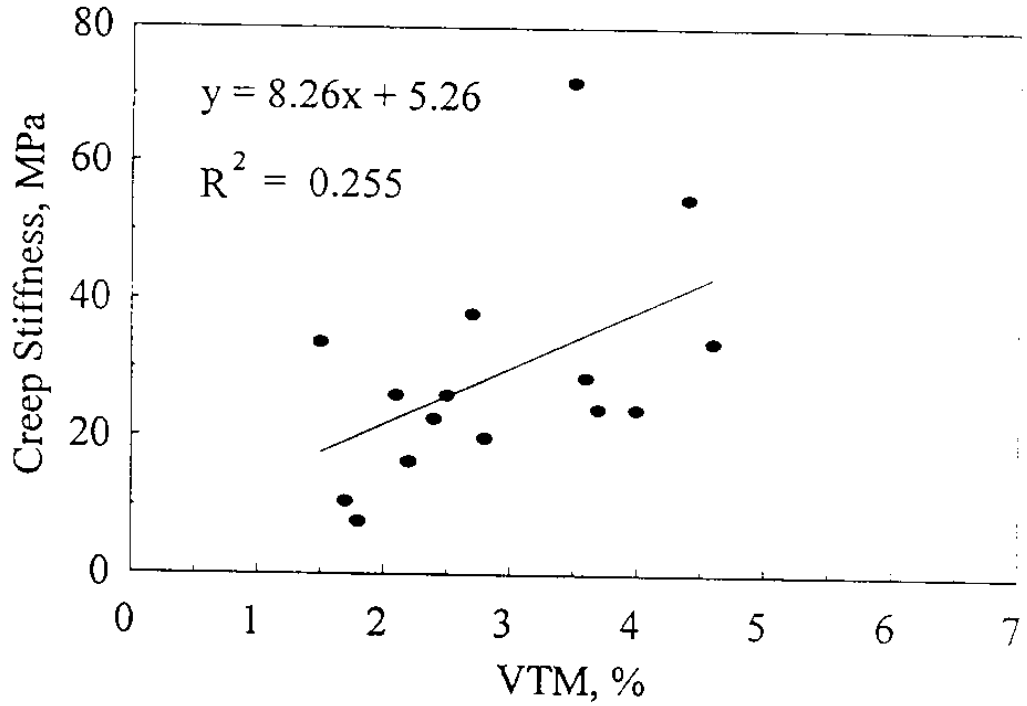

Figure 4.23: Creep Data for Granite Gradation 9

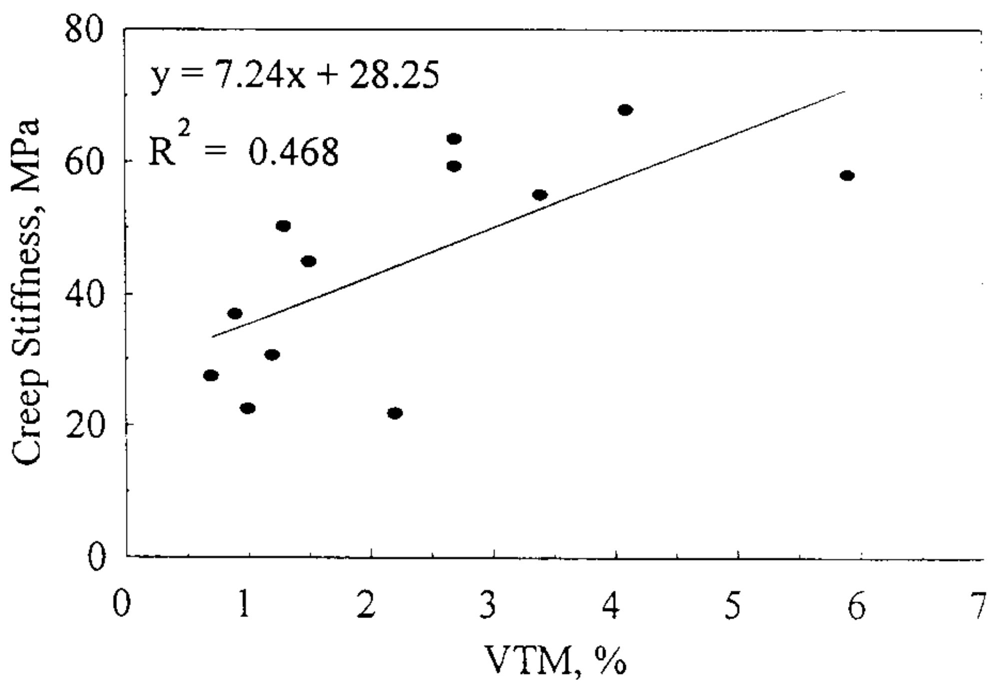

Figure 4.24: Creep Data for Dense Graded Granite Mix

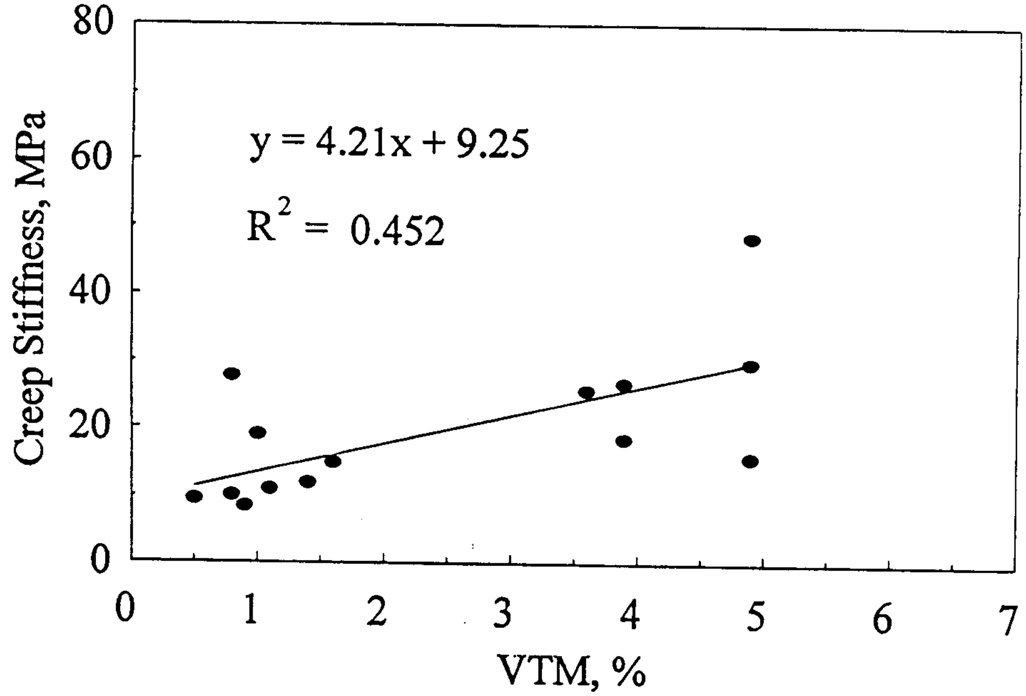

Figure 4.25: Creep Data for Florida Limestone Gradation 1

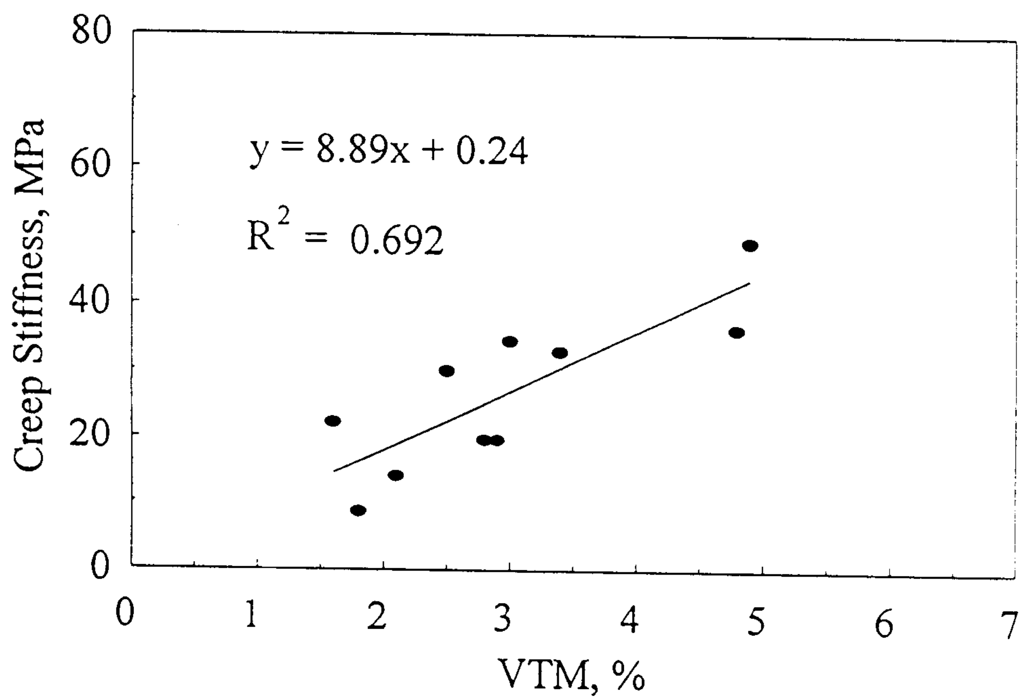

Figure 4.26: Creep Data for Florida Limestone Gradation 2

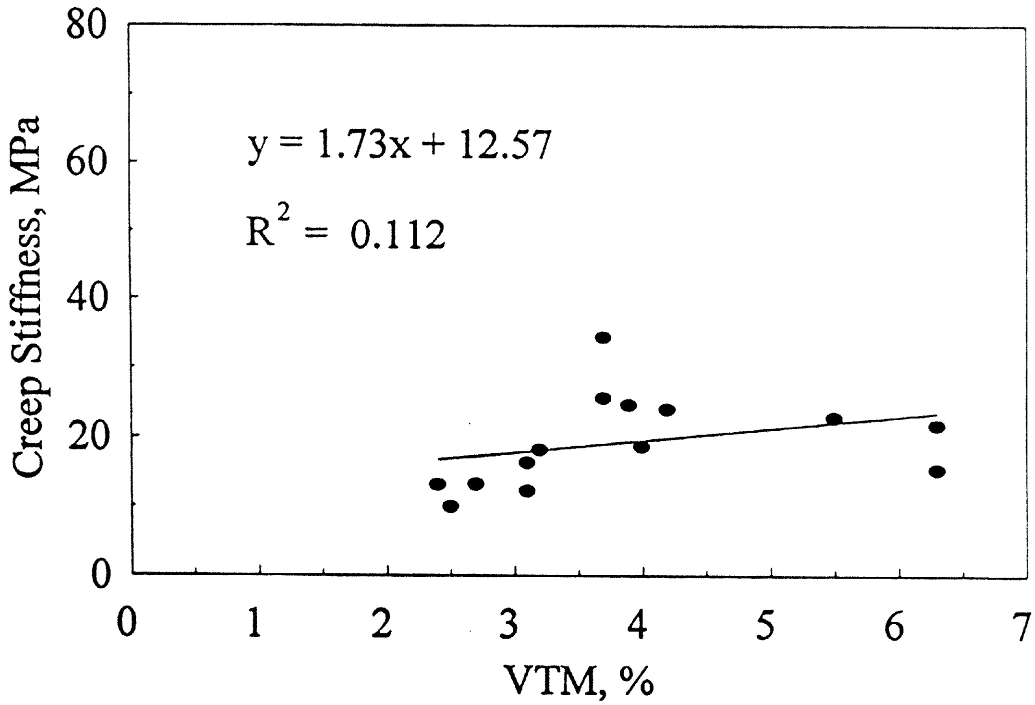

Figure 4.27: Creep Data for Florida Limestone Gradation 3

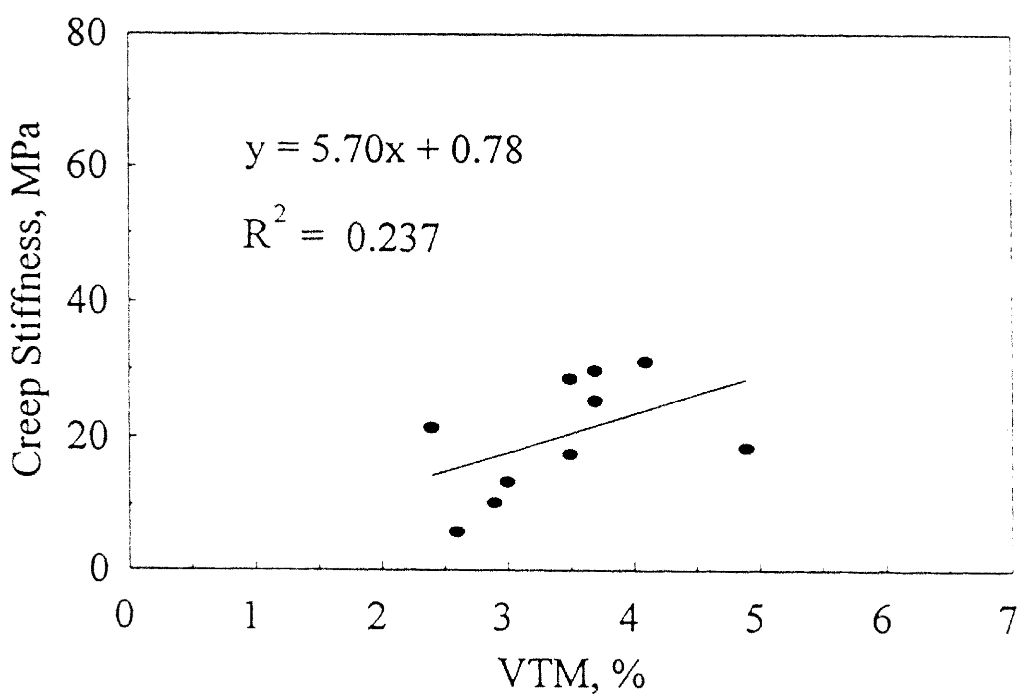

Figure 4.28: Creep Data for Florida Limestone Gradation 4

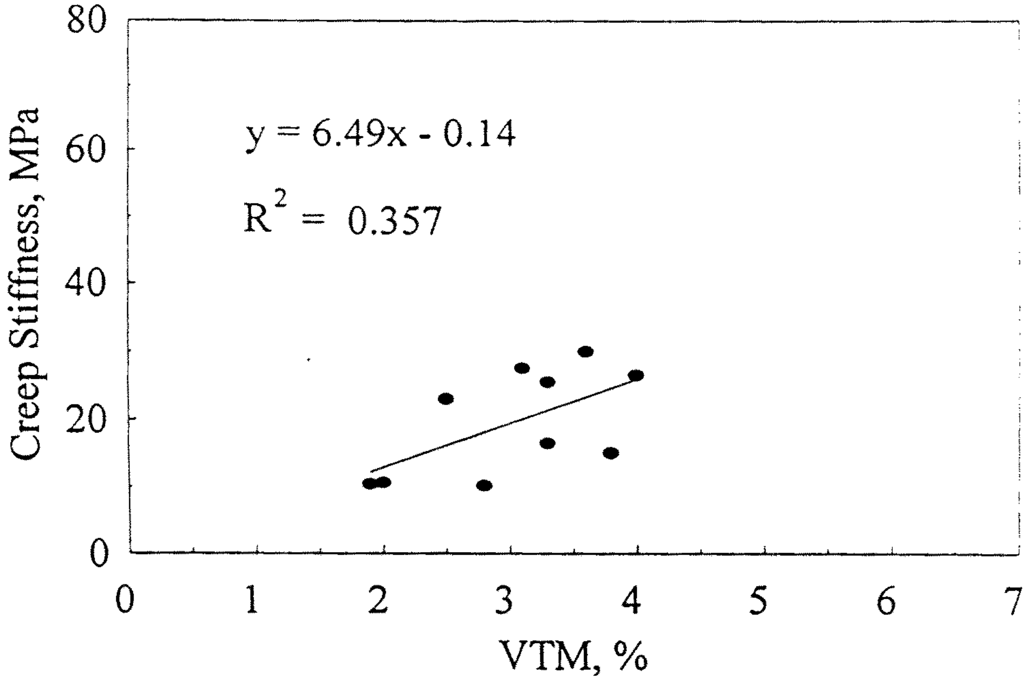

Figure 4.29: Creep Data for Florida Limestone Gradation 7

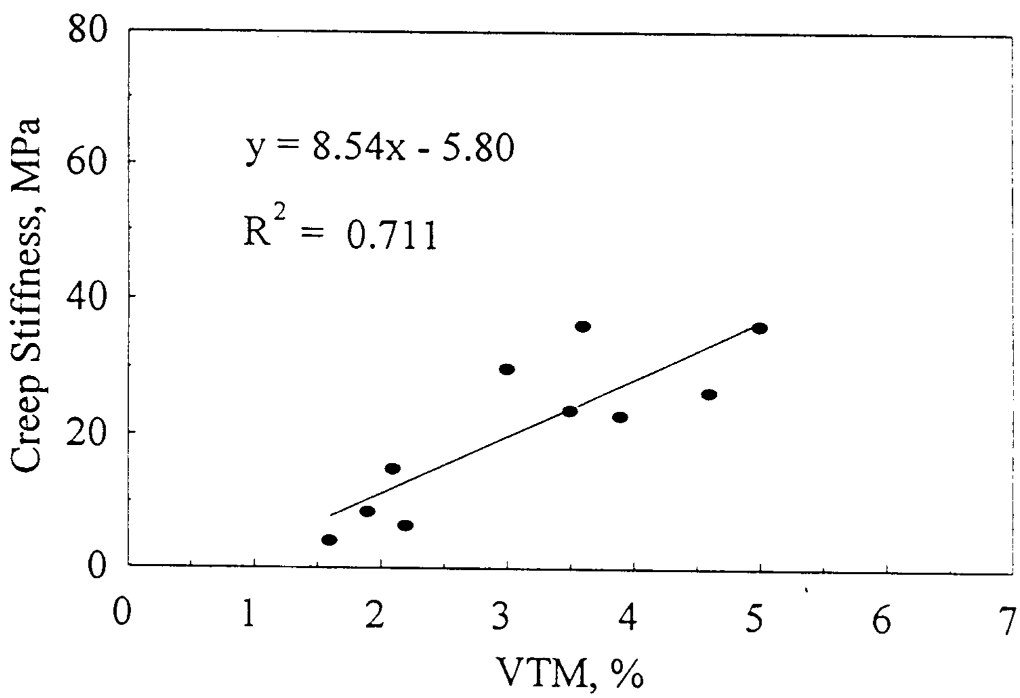

Figure 4.30: Creep Data for Florida Limestone Gradation 8

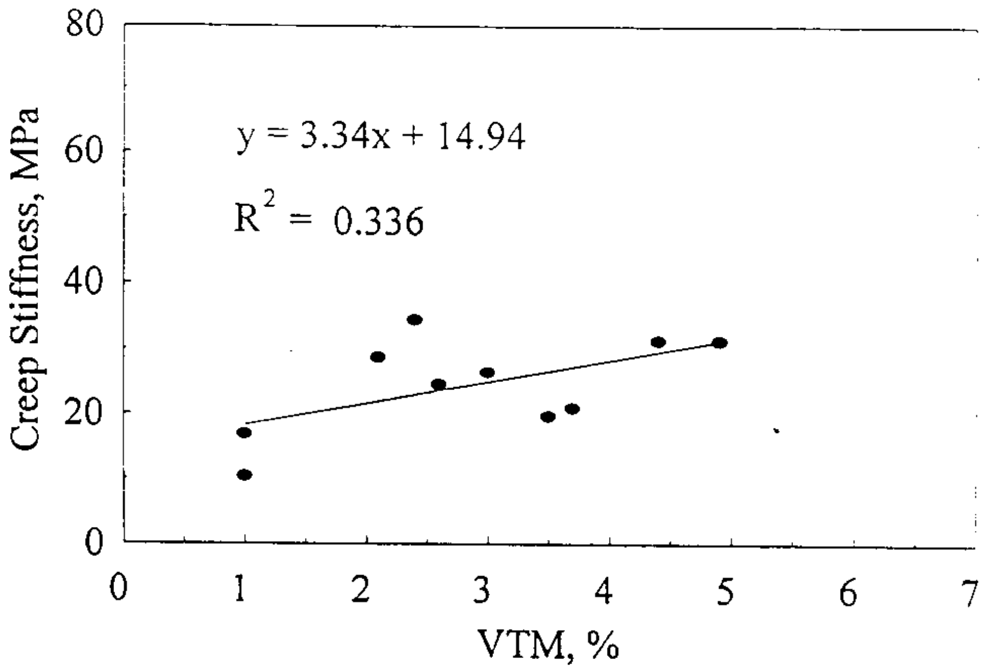

Figure 4.31: Creep Data for Florida Limestone Gradation 9

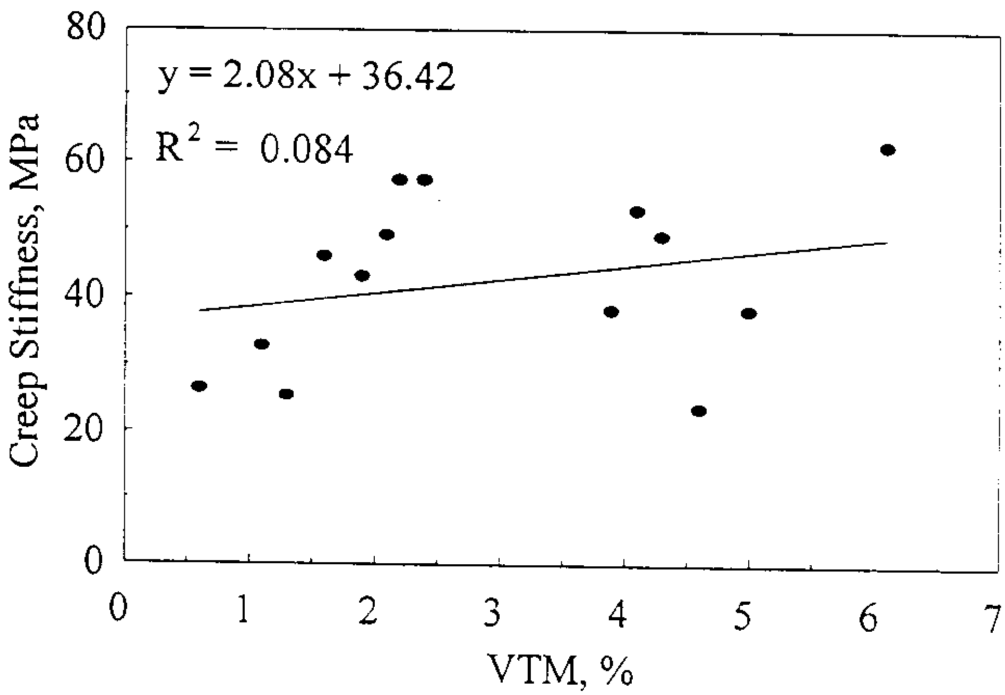

Figure 4.32: Creep Data for Dense Graded Florida Limestone Mix

test. Four inch diameter specimens compacted with 50-blows per face of a flat-faced, static base, mechanical hammer were used in the confined, dynamic creep test. The test setup used 828 kPa (120 psi) normal pressure, 138 kPa (20 psi) confining pressure, 60º C (140º F), and 0.15 load time and 0.95 unload for one hour. The mixtures were produced with optimum asphalt content as well as below and above optimum. Mixtures were produced with gradations 1, 2, 3, 4, 7, 8, and 9 as shown in Table 3.1. A comparison of the results of the SMA mixtures and the dense graded mixtures is provided in Figures 4.17-4.24 for the granite aggregate and in Figures 4.25-4.32 for the Florida limestone aggregate. The sensitivity of the creep stiffness of the mixture to voids is measured by the slope of the best fit line. Figures 4.17-4.24 show the slope of the line for granite for SMA mixtures to be 2.58-10.59 and the slope for the dense graded mixtures is 5.06. The magnitude of the creep stiffness at low voids is greater for the dense mix than for all of the SMA mixtures. The same trend is shown for Florida limestone in Figures 4.25-4.32. This is contrary to the expected trend. The dense graded mix is coarser than most dense mixes and it may be that the sensitivity to voids is much lower due to the coarse mix. The dense mix gradation that passes on the low side of the maximum density line (as recommended by SHRP) was used for this mixture. Past work has shown finer mixtures to be very sensitive to a change in air voids. This work seems to confirm that the coarser gradation recommended by SHRP has low sensitivity to voids (similar to SMA mixtures) which should provide improved performance.

CHAPTER 5 - DISCUSSION OF RESULTS

This study provides a mix design procedure for SMA as well as information on aggregate properties and gradation, and mortar properties. The literature has partially addressed some of these items such as aggregate gradation and volumetric properties of SMA mixtures. Aggregate gradation, mixture properties, and mortar properties were addressed to some extent in Phase I of this study and will be addressed further in Phase II. At the conclusion of Phase I, an evaluation of the present knowledge on SMA was made and a test plan developed for Phase II to fill in the gaps in this knowledge. This revised test plan is provided in Chapter 6.

5.1 AGGREGATE PROPERTIES

The coarse aggregate for an SMA mixture must be sufficiently strong to carry the imposed loads since these mixtures are designed to have stone-on-stone contact. Presently the aggregate test that is commonly used for determining the toughness of the aggregate particles is the L.A. Abrasion test. However, this study has shown that breakdown of the coarse aggregate during compaction is not closely related to the L.A. Abrasion value. There is a rough correlation but aggregates such as limestone with an L.A. Abrasion value between 20 and 30 showed significant breakdown when compacted in the laboratory. A better test procedure is needed to estimate the amount of breakdown that can be experienced in the field. The SHRP gyratory compactor may be able to do this since it has been shown to better simulate traffic than the Marshall hammer and it therefore may do a better job of simulating aggregate breakdown. This problem of aggregate breakdown should be investigated more closely in Phase II of the study. Also, the NCHRP 4-19 project on evaluation of aggregates for HMA will be closely monitored to determine what develops in that study concerning aggregate breakdown, the L.A. Abrasion test, and other tests that may be related to aggregate breakdown.

Since the coarse aggregate must carry the load, fractured faces are required to provide a coarse aggregate structure with high internal friction. 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 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. When high absorptive aggregates are used, the optimum asphalt content should be selected on the high side but within the specification limits to allow for some additional absorption of the asphalt cement during placement and during the life of the pavement. When absorptive aggregates are used, the effective asphalt content needs to be determined to ensure that a sufficiently high asphalt content is used for satisfactory durability.

Even though the presence of flat and elongated particles are known to affect the quality of SMA this effect has been difficult to quantify. A source of aggregate used on an SMA project in Arkansas was crushed using two methods to obtain 1) a cubical shaped aggregate, and 2) a flat and elongated aggregate. Samples of these aggregates have been obtained and will be evaluated in Phase II of the study to help quantify the effect of flat and elongated particles.

The gradation of the aggregate is known to affect the volumetric properties of an SMA mixture. The gradation needs to be controlled to provide the desired VMA (17 minimum), stone-on-stone contact, and satisfactory mortar properties. The maximum aggregate size is typically selected based more on layer thickness than on engineering properties of the mixture. Most mixtures placed to date have used an aggregate with 100 percent passing the 19-mm (3/4 inch) sieve and something less than 100 percent passing the 12.5-mm (1/2 inch) sieve.

The effect of amount of material passing the 4.75-mm (# 4) sieve has been clearly shown in work done by NCAT and the FHWA. As the percent passing the 4.75-mm (# 4) sieve decreases the VMA decreases to a point and then begins to increase once the percent passing the 4.75-mm (# 4) reaches approximately 30 percent (Figure 5.1). The data provided in Figure 5.1 was developed in earlier work at NCAT and confirms the fact that VMA increases with a decrease in percent passing the 4.75-mm sieve once below some minimum amount as shown in Figure 5.2.

The effect of percent passing the 0.075-mm (# 200) sieve on VMA is similar to the effect of the 4.75-mm (#4) sieve but not as dramatic (Figure 5.3). In an SMA mixture, the material passing the 4.75-mm (# 4) sieve acts as a filler as long as stone-on-stone contact exists. Hence, increasing the percent passing the 4.75-mm (#4) sieve reduces the VMA and vice versa. If the percent passing the 4.75-mm (# 4) sieve is held constant and the percent passing the 0.075-mm (# 200) sieve is changed, the VMA will generally change slightly but not to the same degree that occurs when the percent passing the 4.75-mm (# 4) sieve is changed. An increase in the percent passing the 0.075-mm (# 200) sieve will normally reduce the VMA.

Changing the percent passing the 9.5-mm (3/8-inch) sieve also affects the VMA. As the percent changes from 60 to 40 percent, with all other sieve sizes remaining the same, the VMA increases. Contrary to expectation, the higher percentage passing the 9.5-mm (3/8-inch) sieve results in a higher VMA in the SMA mixture (Figure 5.4).

It appears that the percentage passing the 4.75-mm (# 4) sieve can be adjusted until stone- on-stone contact exists. Five methods were tried to determine the VCA at which stone-on-stone contact occurs. The five methods included: Marshall hammer, SHRP gyratory compactor, Kango hammer, vibrating table, and dry-rodded test. The vibrating table and dry-rodded conditions appear to be the best two methods. The SHRP gyratory and Marshall hammer compaction tended to break down the aggregate too much. The Kango hammer was inconsistent and did not compact the samples enough and thus should not be considered for further testing. The dry rodded condition appears to be the easiest of the methods to use and provides reasonable results. It appears to be the most appropriate method for determining the VCA at which stone-on-stone contact occurs.

5.2 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 (#8) sieve), asphalt cement, and stabilizer. If a satisfactory mortar specification is developed, the specific

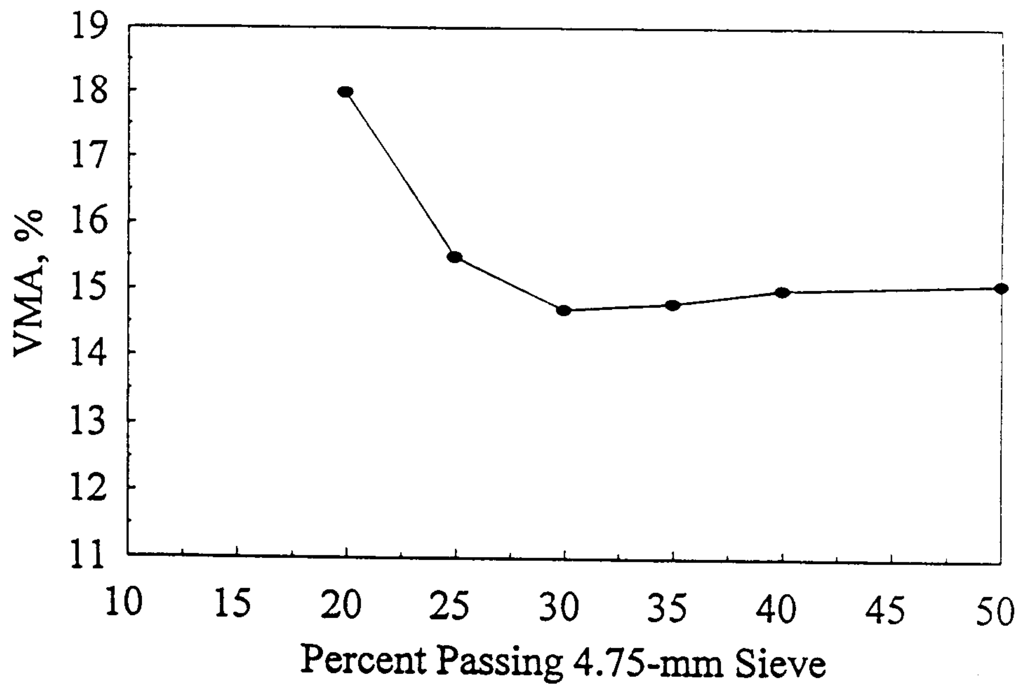

Figure 5.1: Effect of Percent Passing the 4.75-mm Sieve on VMA (69)

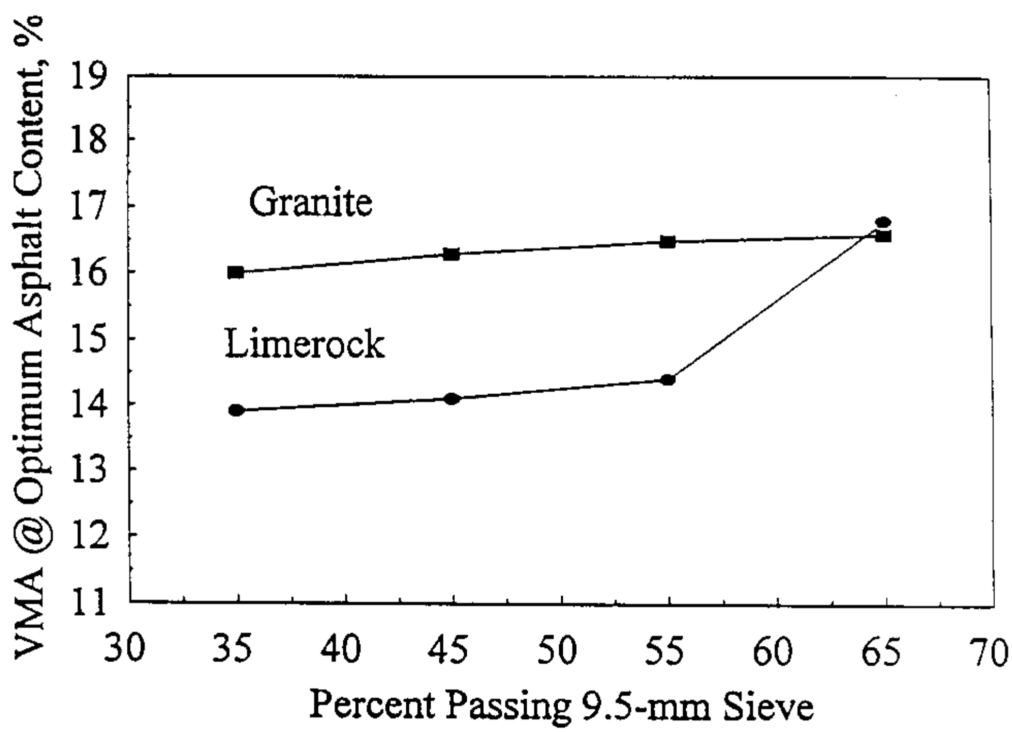

Figure 5.2: Effect of Percent Passing the 4.75-mm Sieve on VMA

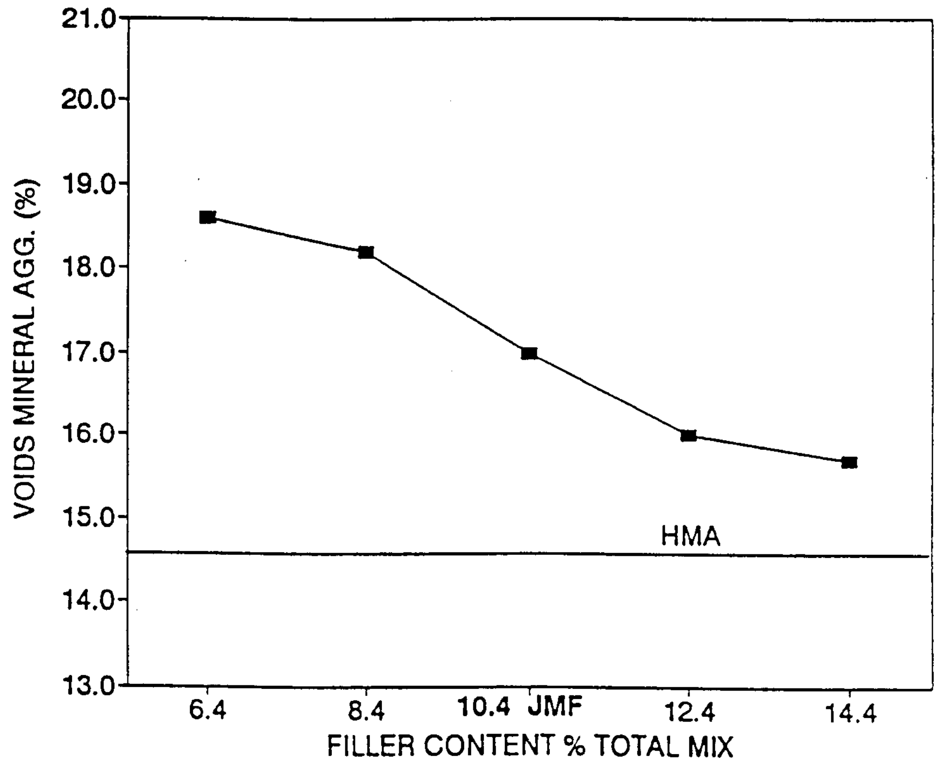

Figure 5.3: Effect of Filler Content on VMA (48)

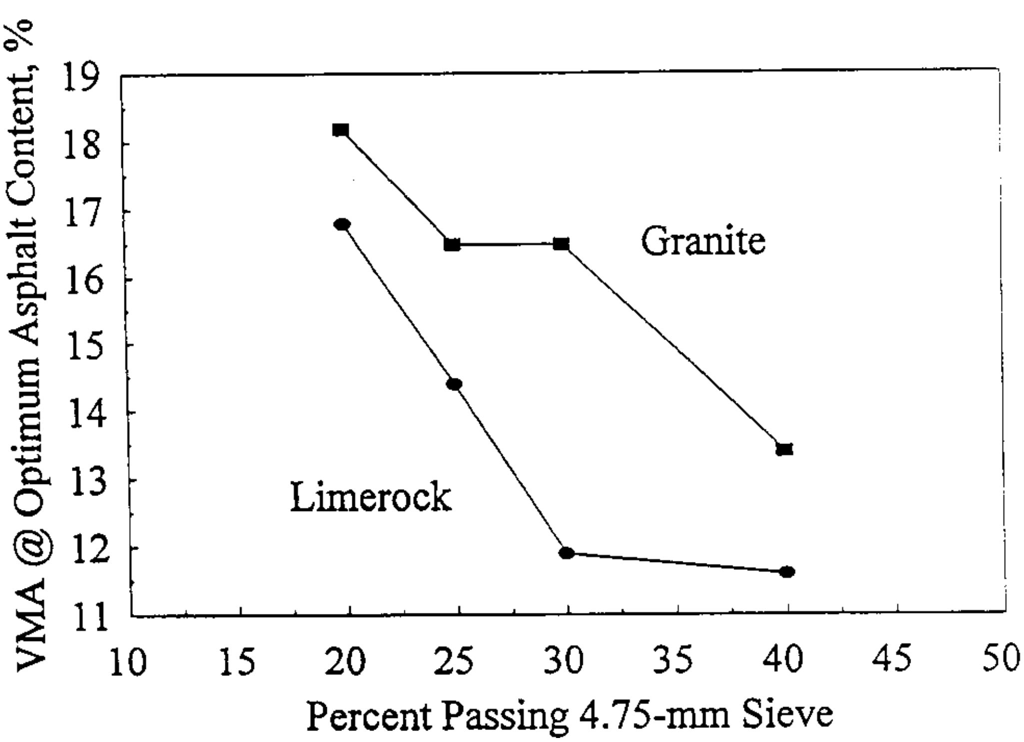

Figure 5.4: Effect of Percent Passing the 9.5-mm Sieve on VMA

requirements for fine aggregates, 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. Realistically, some material specifications for fiber, filler, and fine aggregate will likely always be required but a good mortar specification will reduce the number of requirements for these material specifications. For analysis in the laboratory, the mortar was divided into fine and total mortar fractions. 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 mortar testing did indicate that some of the SHRP binder tests can be used to evaluate the fine mortar and to establish criteria. The dynamic shear and bending beam rheometers, and direct tension device appear to be satisfactory tests for evaluating the fine mortar. The addition of filler always increased the stiffness of the binders, especially at high temperatures. The baghouse fines stiffened the binder more than the limestone dust. The stiffness is of major concern at the lower temperatures because of the low temperature cracking problem. The stiffness of the binders after the addition of filler and fiber were up to six times higher than the stiffness of the neat asphalt cements at the low temperatures. The tests did show a range of results, however, with the addition of baghouse fines increasing the stiffness by approximately 30 percent more than the addition of limestone dust. These SHRP 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 mortar stiffness will be much better than simply specifying the allowable size of the filler.

Surprisingly, some of the direct tension tests on the fine mortar met the recommended SHRP requirements for binders. One of the modified asphalts met the requirements even when baghouse fines or limestone dust was added. The stress produced was almost always 2-3 times higher for the asphalt binders containing filler than for the asphalt binder alone. Because of the wide range of strain values, it appears that this test has potential in evaluating the low temperature properties of fine mortars.

The fine mortar properties are closely related to the total mortar properties. In the laboratory during mix design, it is much easier to prepare and test fine mortars than total mortars. 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. Some of the work in Phase II of this study will be directed at developing criteria for these mortar tests. The existing SHRP criteria for binders will be too harsh in some cases for the fine mortar and adjustments will need to be made. The SHRP test methods, with minor changes, seem satisfactory for testing the fine mortars, only the criteria may need to be changed.

5.3 MIX DESIGNS

The mix design procedure recommended in Volume IV of this report was basically followed to develop the designs for this part of the study. The mix design procedures are relatively straightforward and do not require any additional equipment other than that required for testing of HMA. Some aggregates do breakdown excessively under laboratory compaction. The amount of breakdown in the laboratory needs to be compared to that which occurs in the field to determine if there are significant differences. Based on the laboratory work, it appears that with hard aggregates these differences in the lab and in the field will be small. However, with soft aggregates this difference may be significant but soft aggregates probably should not be used to produce SMA.

All mix designs for this phase of the work were performed with little or no evaluation of the mortar properties (as part of the mix design procedure). The mortar is an important part of the mix design and criteria needs to be established for the mortar. Criteria will be presented at the conclusion of Phase II of the project.

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

The voids in the coarse aggregate concept for obtaining stone-on-stone contact appears to be valid. The dry-rodded method of obtaining VCA used for mix design in this phase of the study is easy to perform and appears to be repeatable. This method should continue to be used to establish VCA criteria for the mixture.

The tensile strength ratio for the modified Lottman test generally appears to be approximately equal or slightly higher than that for dense graded mixtures. Moisture susceptibility will be further evaluated under Phase II of the study.

5.4 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. Of these four tests, the dynamic creep test has the most promise to predict the rutting performance of SMA. There is also no good method presently being used to measure the rut resistance of dense graded mixtures so one should not expect a test to be available at this time for SMA. The SHRP simple shear tester has the potential to solve this problem. NCHRP 9-7 is working on field tests for controlling the quality of dense graded mixes. The test(s) developed under this study should be evaluated to determine their effectiveness for SMA mixtures. Since major efforts have been undertaken through SHRP and NCHRP 9-7 to develop performance based tests, additional work under the SMA project to develop a new test is not justified; however, evaluation of existing tests has been done and will continue to be done under Phase II of the study.

Earlier work at NCAT has shown that dense graded mixtures are more sensitive to a change in voids than SMA mixtures. One intent of the creep testing was to show this sensitivity. The creep testing showed that the SMA and dense mixtures had about the same sensitivity to change in voids but the dense mixtures always had less permanent deformation. It should be noted that the dense mixtures had gradations similar to the SMA mixtures and this may help to explain the good performance with dense mixtures.

At the present time, performance of SMA mixtures is controlled by specifying the aggregate properties, binder properties, stabilizer type and amount, gradation, and volumetric properties. This approach is also being used for dense graded mixtures. Several existing tests including SHRP simple shear will be evaluated under Phase II of this study and compared to the results of laboratory wheel tracking tests. The wheel tracking test will evaluate the rutting potential of the SMA mixtures as well as the moisture susceptibility.

CHAPTER 6 - PHASE II EXPERIMENTAL DESIGN

6.1 VISION STATEMENT

The emphasis of this study is to develop a simple, straightforward design procedure for SMA that is repeatable and that can be used by any agency or laboratory that is equipped to do hot mix asphalt (HMA) testing. This design method must select a high quality SMA mixture as the end product. This design procedure is envisioned as one method with two separate compaction options. The design can be done using either a flat-faced, static base Marshall hammer, or a Superpave gyratory compactor. Whichever compaction method is chosen, the design procedure contains the same five basic steps.

1. Select and test materials to ensure they meet the required specifications. This includes aggregate testing, asphalt binder testing using the Superpave binder equipment, and testing of the stabilizing additive.
2. Select an optimum aggregate gradation for the mixture that will provide stone-on-stone contact.
3. Test the mortar to determine if it meets specifications designed to ensure mixture durability and resistance to thermal cracking.
4. Test the final mixture for moisture susceptibility and draindown performance.
5. Test the final mixture to determine its ability to resist rutting.

Of course each of these basic steps involves much more detail, but in their general form, they serve as the end product vision currently being used to guide this research project.

6.2 OVERVIEW OF PHASE I WORK

Phase I of this study has provided answers to many questions and identified several areas that need additional research. Phase I has shown that the SHRP binder tests can be used to evaluate the mortar quality but did not establish criteria for these tests. Tests also showed that the dry-rodded condition of the coarse aggregate is a good procedure for determining where stone-on-stone contact begins. Other findings indicated that significant breakdown of the coarse aggregate in an SMA mixture occurs when compacted with a Marshall hammer and to a lesser extent with the SHRP gyratory compactor. Work needs to be performed to determine how much breakdown actually occurs during placement and to ensure that the laboratory compaction method provides similar results.

After evaluating the results from Phase I of this study, it has been concluded that the following items should be investigated in Phase II of this study:

1. Correlate aggregate breakdown during laboratory compaction to field results. Aggregates will be obtained from several SMA projects for this study. Samples will be prepared to meet the job mix formula and compacted using various techniques in the laboratory (Marshall, SHRP gyratory) and the breakdown compared to that being obtained in the field during compaction. Tests to determine VCA and to establish the condition at which stone-on-stone contact exists will be compared with these results.
2. Establish specification limits for mortar tests. Phase I of the study has shown that

SHRP binder tests can be used to evaluate the fine mortar. Limits for these tests will be established. Various mortar properties will be obtained by varying the percentages of filler, fiber, and asphalt content and by varying the properties of each of these components. For example, fine fillers and coarse fillers will be evaluated. SMA mixtures will be prepared with these various mortars and subjected to tests to evaluate quality of these mixtures.

3. Evaluate moisture susceptibility of SMA mixtures. A number of mixtures were evaluated in Phase I and many of these mixtures showed low retained strengths. Phase II will identify the severity of this problem and look at ways to improve the water susceptibility of SMA mixtures.
4. Evaluate the effect of particle shape (flat and elongated) on quality of SMA mixtures. Aggregates have been obtained from one source that used two crushing methods. One of these aggregate stockpiles consists of cube shaped material and the other consists of flat and elongated particles. These aggregates will be mixed at various proportions to evaluate the effect of flat and elongated particles.
5. Establish specification limits for SMA mixture tests. A number of tests will be conducted on SMA mixtures to evaluate their quality. Some of these tests are being developed at the present time and some are conventional tests. Tests that will be used to evaluate the SMA mixtures include: SHRP simple shear, wheel tracking test, dynamic creep, and other tests developed for use with SHRP QC/QA.

After completion of Phase I, it became clear that a number of questions as mentioned above needed to be answered to provide a good SMA mix design procedure. Task 5 and 6 will be directed at providing answers to some of these questions. The recommended test plan is a significant modification to the tentative plan for Tasks 5 and 6 developed prior to start of Phase I.

6.3 TASK 5

The goal of Task 5 is to finalize the mix design procedure. To accomplish this goal the following items are needed:

1. Adapt SHRP level 1 mix design procedure to be used for SMA.
2. Evaluate breakdown of aggregate during mix production, laydown, and compaction and compare to lab compaction.
3. Do extensive mortar testing so that tentative specifications can be developed.
4. Look at a number of aggregates to ensure that the procedure works satisfactory for a wide range of materials.
5. Look at effect of flat and elongated particles.
6. Evaluate moisture susceptibility of SMA mixes.

Evaluation of the mortar is a very important part of Phase II of this project. Four fillers having different particle sizes will be selected for evaluation as shown in Table 6.1. The filler content will be varied so that the effect on mortar properties can be determined. It is anticipated that two of these fillers will meet the present requirements of no more than 5 percent smaller than the 0.02-mm size and two of the fillers will not meet this requirement. The fillers will be mixed

Table 6.1: Mortar Test Plan for Phase II

	FILLER TYPE AND PERCENTAGE IN MIX*												
Asphalt Cement and Stabilizer	Filler 1				Filler 2			Filler 3			Filler 4		
	0%	8%	10%	12%	8%	10%	12%	8%	10%	12%	8%	10%	12%
AC - No Stabilizer	X	-	X	-	-	X	-	-	X	-	-	X	-
AC M1	X	X	X	X	-	X	-	-	X	-	-	X	-
AC M2	X	-	X	-	-	X	-	-	X	-	-	X	-
AC Fiber 1	X	X	X	X	X	X	X	X	X	X	X	X	X
AC Fiber 2	X	-	X	-	-	X	-	-	X	-	-	X	-

NOTE: Two (2) repetitions of each mixture identified above with an X will be tested as shown below:

DSR on Original Asphalt - Low/High Temperatures
DSR after TFOT - Low/High Temperatures
DSR after PAV - Low/High Temperatures
BBR after PAV - Low/High Temperatures

*Proportions based on identified filler percentage in mix, 6% asphalt cement, and designated amount of stabilizer.

with AC with no modifier, asphalt cement with two different modifiers, and asphalt cement with two different fibers. These mortars will be tested at both high and low temperatures as shown in Table 6.1. This data, along with the mixture data that will be determined in Phase II, will be used to establish criteria for the fine mortar.

After the mortar testing has been completed, the tests shown in Figures 6.1 through 6.4 will be accomplished. These tests will allow the mix design method to be evaluated for a range of aggregates. This will also provide a range of aggregates for moisture susceptibility testing. At the end of these tests, six mixes will be selected for tests with the SHRP shear tester and with the wheel tracking device, and the indirect tensile creep. The mixtures selected for these final two tests will have a range of properties and will be expected to have varying test results in the SHRP shear tester and the wheel tracking device. These last two tests will be conducted as part of Task 6.

The testing shown in Figure 6.1 will also allow development of the procedure for SHRP level 1. The eight mix designs to be performed with the SHRP gyratory compactor will be conducted at three compaction levels to help establish criteria for compaction. This will result in 24 SHRP level 1 mix designs. After these tests and other data are collected, the preferred compaction effort can be selected.

States that will be performing SMA projects during the next year will be contacted for data. The data needed will include gradation of aggregate going into plant, gradation of aggregate after mixing in the plant and gradation of aggregate after placement. A minimum of five projects will be selected. The materials from these projects will be brought back to the laboratory to evaluate aggregate breakdown on the compaction process (Marshall and SHRP). This will determine if breakdown in the laboratory is similar to breakdown in the field.

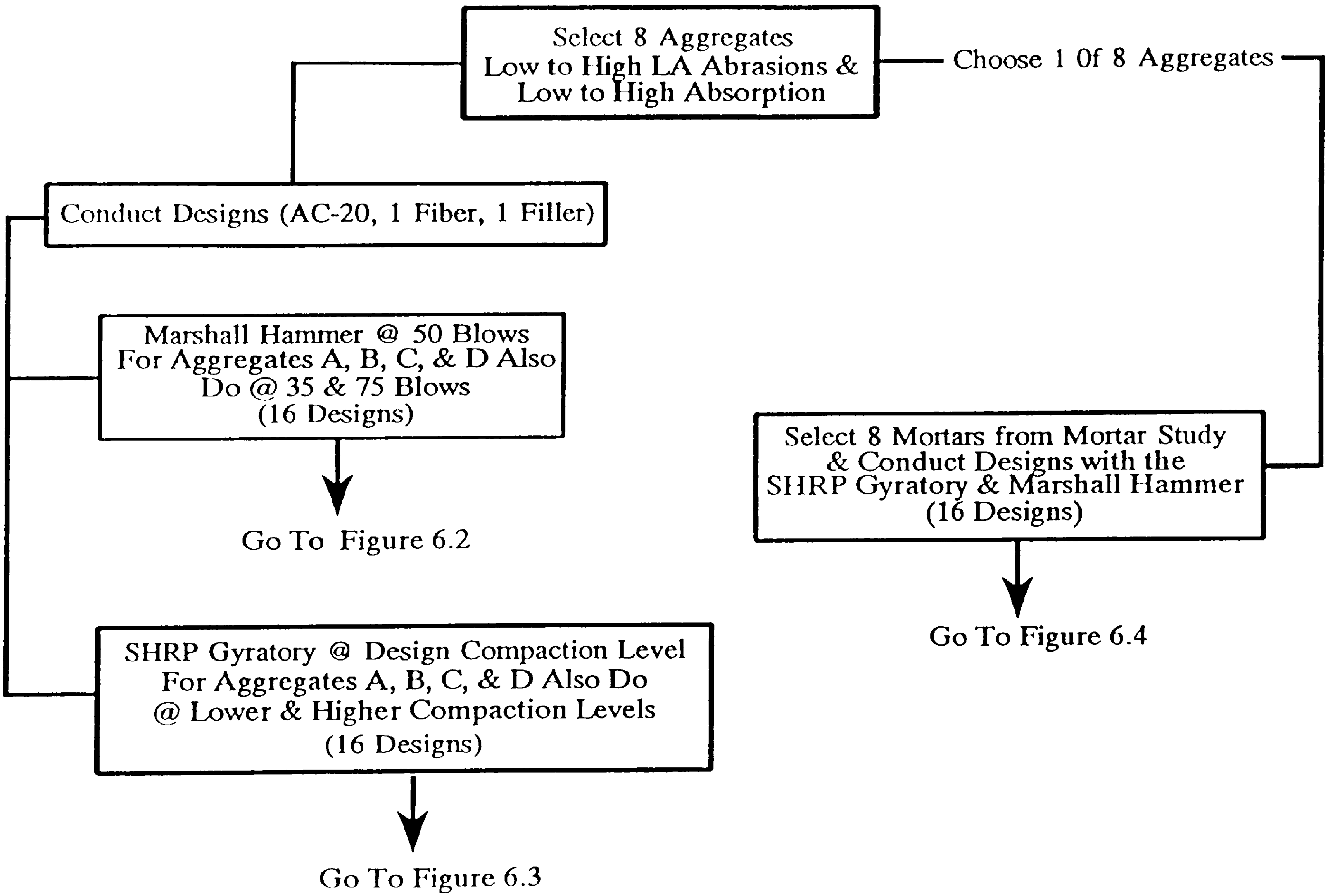

Figure 6.1: SMA Mix Design and Evaluation Test Plan Overview

There is a requirement limiting the amount of flat and elongated particles in SMA mixtures. There is no data to show the effect of these flat and elongated particles. Samples of aggregates from one source in Arkansas have been obtained. These aggregates were crushed using two methods with one method providing cube-shaped aggregate and the other providing flat and elongated particles. The test plan shown in Table 6.2 will be conducted to help understand what problems may occur when flat and elongated particles are used.

Table 6.2: Test Plan for Flat and Elongated Particles

Aggregate Mixes	Sma Mix Design	Gradations after Compaction	Water Susceptibility Tests
100% A1	√	√	√
100% A2	√	√	√
75% A1 - 25% A2	√	√	√
50% A1 - 50% A2	√	√	√
25% A1 - 75% A2	√	√	√

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

6.4 TASK 6

This task will be accomplished to analyze the mixture properties and to establish criteria or modify existing criteria as needed. The SHRP shear testing, torture tests with a wheel tracking device and indirect tensile creep testing will be accomplished in this task. The test plan for these two tests is shown in Figures 6.1-6.4.

6.5 TASK 7

After all testing is accomplished and the analysis completed, the results will be published in a final report. This report will contain a detailed mix design procedure along with criteria for the recommended tests.

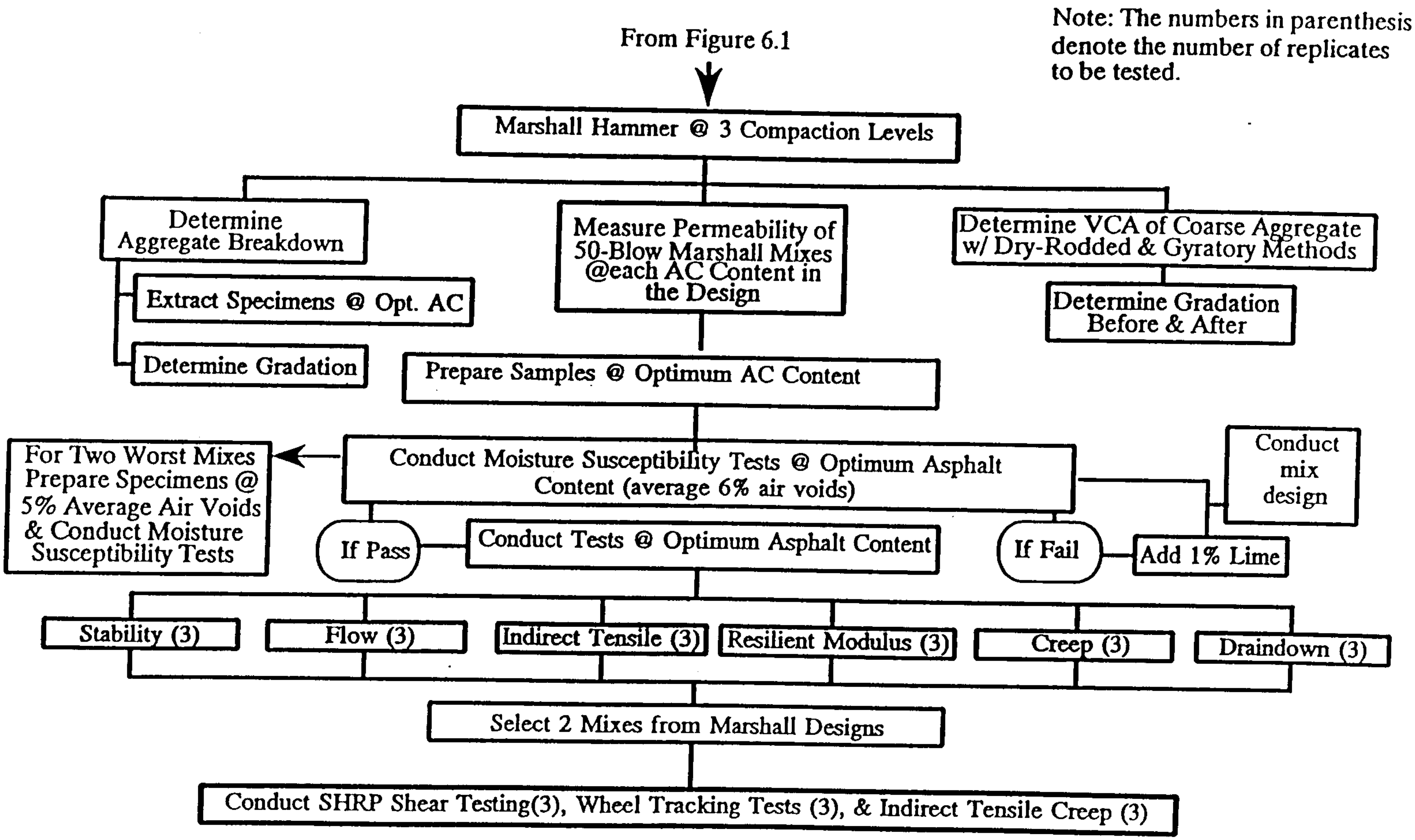

Figure 6.2: Test Plan for SMA Mix Design and Evaluation Using a Marshall Hammer

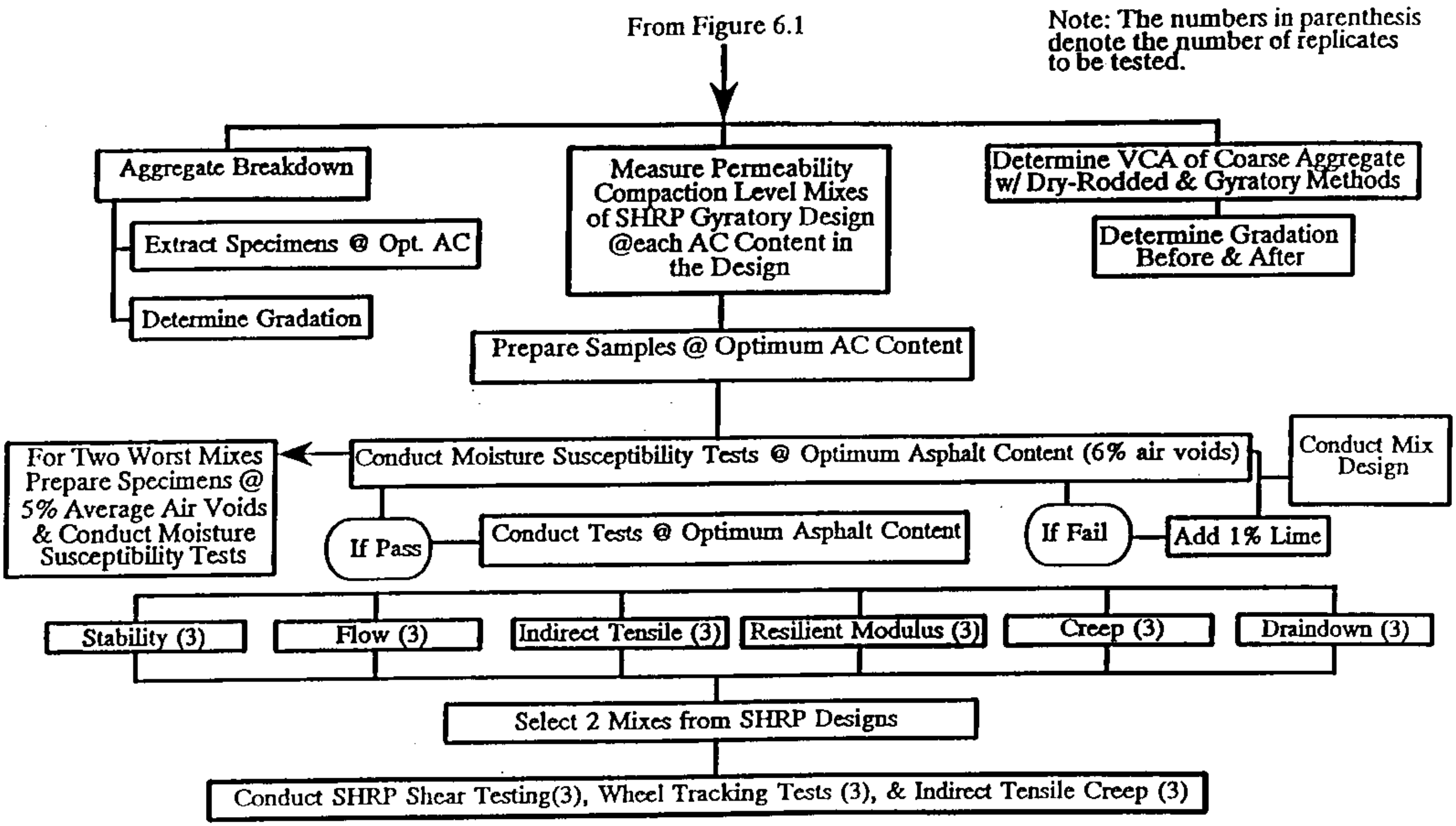

Figure 6.3: Test Plan for SMA Mix Design and Evaluation Using the SHRP Gyratory

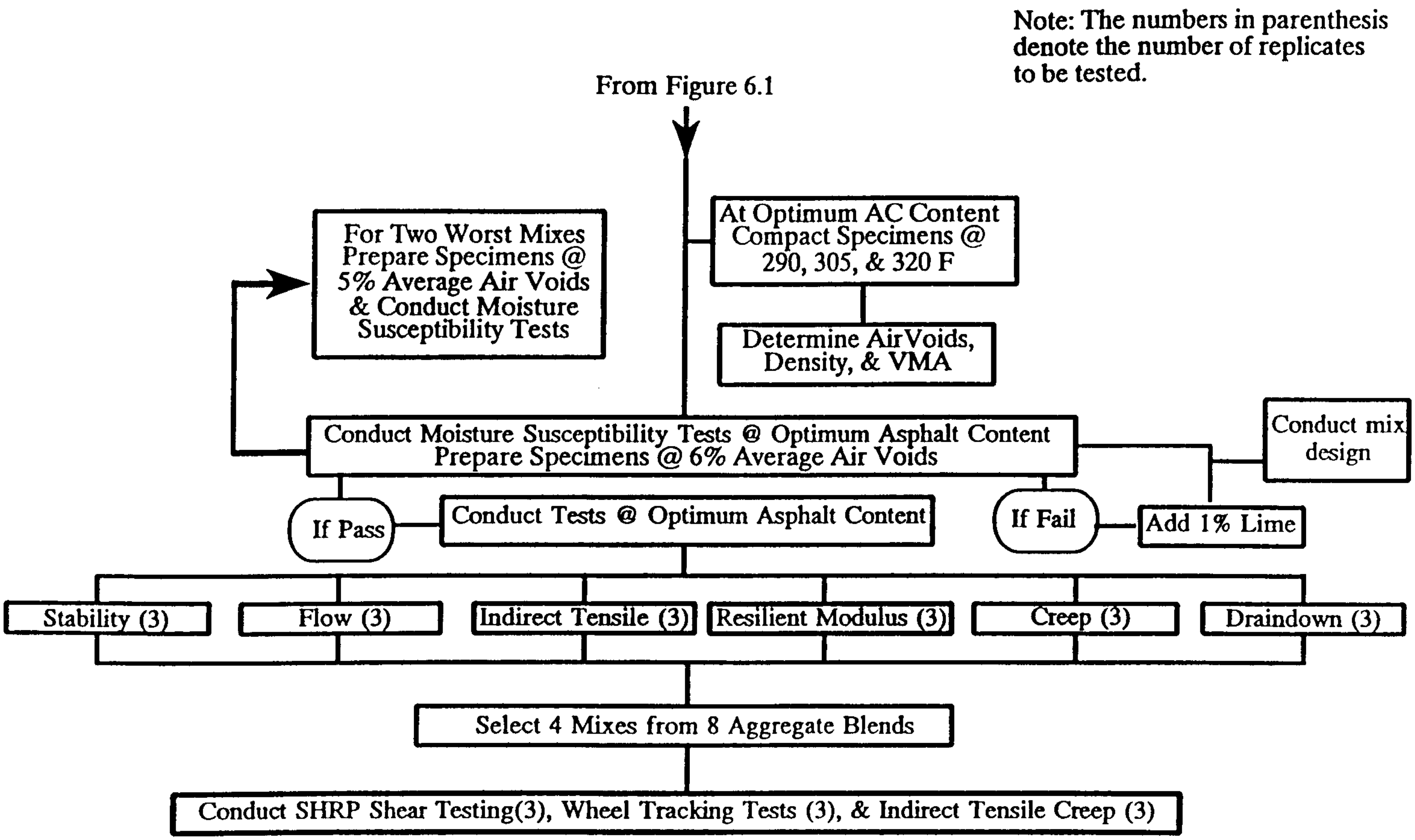

Figure 6.4: Test Plan for SMA Mortar Design and Evaluation

CHAPTER 7 - CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

1. The dry-rodded test for coarse aggregate is acceptable for measuring the VCA for stone-on-stone contact. The Marshall hammer and SHRP Gyratory compactor cause excessive breakdown and are therefore not acceptable unless this breakdown is shown to be similar to that occurring in the field. The Kango compactor does not densify the aggregate sufficiently to be an effective device.
2. Excessive breakdown in some aggregates may prevent them from being used in SMA. An example of an aggregate with excessive breakdown when compacted as an SMA mixture with a Marshall hammer is Florida limestone.
3. SHRP binder tests including dynamic shear, bending beam, and the direct tension device can be used to evaluate the quality of the fine mortar. The Brookfield viscometer has limited use for measuring the stiffness of the mortar. The properties of the fine mortar are related to the total mortar, hence, testing of the total mortar is not required.
4. The moisture susceptibility test results (tensile strength ratios) for the SMA mixtures generally appear to be equal to or slightly higher than that for dense graded mixtures.
5. The creep test was not effective in showing the benefits of SMA mixtures over dense graded mixtures.
6. The Marshall stability test should not be used as a specification requirement for SMA. However, if it is used the requirement should be lowered from 6200 N (1400 lbs.) to 5300 N (1200 lbs.).
7. Based on work under Phase I, it appears that a good aggregate skeleton can be obtained by comparing the VCA in the SMA mixture to the VCA in the dry-rodded condition for coarse aggregate only. Mortar properties can be controlled by using the existing SHRP binder tests. At the present time, the best control of the mixture is the volumetric properties (voids, VMA, and VCA).

7.2 RECOMMENDATIONS

1. Look at breakdown of aggregate during plant production and compaction and after traffic. Use compaction method in lab that simulates this breakdown.
2. Look at varying mortar properties to evaluate water susceptibility and rutting potential.
3. Make SMA mixes with various properties to test in SHRP Shear Tester (SST) and in wheel tracking devices.
4. Look at effect of flat and elongated count on quality of SMA mixture. Aggregate has been received from a source in Arkansas with some of the material cube shaped and some flat and elongated. The different shapes were produced by different methods of crushing.
5. Set limits on mortar tests for BBR, DSR, and DT.
6. Evaluate SHRP Level I for adaptation to SMA.

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APPENDIX A -
Mix Design Results for the Five Aggregates

Table A1: Volumetric Data from Granite Trial Blend Number 1

JOB NUMBER	PROJECT: NCHRP 9-8	BLEND DESCRIPTION	DATE:
AC Sp. Gr. (Gb) - 1.029	Effective Sp. Gr. Of Aggregate (Gse) = 2.724 Bulk Sp. Gr. Of Agg. (Gsb) = 2.677	Percent passing #4: 49 GRANITE GRADATION #1 (LHS) Unit Wt. Of CA in DRC (pcf): 101.0 Unit Wt. Of CA in DRC (kg/m^3): 1617.9	T 07-05-94

Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS In Air (gm)	WEIGHTS In Water (gm)	WEIGHTS SSD (gm)	MIX VOL Volume (cc)	SPECIFIC GRAVITIES Bulk (Gmb)	SPECIFIC GRAVITIES TMD (Gmm)	VOLUMES Aggregate Volume (cc)	VOLUMES AC by Volume (%)	VOIDS Unit Weight (pcf)	VOIDS Total (%)	VOIDS VMA (%)	VOIDS Filled (%)	VOIDS VCA (%)	VOIDS VCA drc (%)	VOIDS VCA/VCA dre	STABILT Measured (lb)	Flow (0.1 in)
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	T	U
						(F-E)	D / (F-E)		(100-B) x 1 / (Gmb)	BxI / (Gb)	(1x62.4)	100(1-1/3)	(100-k)	100(O-N) / O					
6.3-1	6.3	2.489	1223.1	714.9	1224.5	509.6	2.400	2.468	84.0	14.7	149.8	2.8	16.0	82.8	49.6	39.5	1.255	1675	15
6.3-2	6.3	2.491	1221.0	711.8	1221.1	509.3	2.397	2.468	83.9	14.7	149.6	2.9	16.1	82.2	49.7	39.5	1.25	1750	17
6.3-3	6.3	1.499	1227.1	718.3	1227.2	508.9	2.411	2.468	84.4	14.8	150.5	2.3	15.6	85.3	49.4	39.5	1.250	1875	17
AVG.	6.3											2.6	15.9	83.4	49.5	39.5	1.254	1767	16

Computed By: Scott R. Todd Checked By:

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

Table A2: Volumetric Data from Granite Trial Blend Number 2

JOB NUMBER			PROJECT: NCHRP 9-8						BLEND DESCRIPTION	Percent passing #4: 30 GRANITE GRADATION #1 (LHS) Unit Wt. Of CA in DRC (pcf): 101.0 Unit Wt. Of CA in DRC (kg/m^3): 1617.9								DATE:	
AC Sp. Gr. (Gb) - 1.029			Effective Sp. Gr. Of Aggregate (Gse) = 2.707 Bulk Sp. Gr. Of Agg. (Gsb) = 2.674															T 07-05-94	
			WEIGHTS			MIX VOL	SPECIFIC GRAVITIES		VOLUMES		VOIDS							STABILT	
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 dre	Measured (lb)	Flow (0.1 in)
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	T	U
						(F-E)	D / (F-E)		(100-B) x 1 / (Gmb)	BxI / (Gb)	(1x62.4)	100(1-1/3)	(100-k)	100(O-N) / O					
6.3-1	6.3	2.576	1224.5	707.2	1227.1	519.9	2.355	2.455	82.5	14.4	147.0	4.1	17.5	76.7	42.2	39.4	1.071	1600	14
6.3-2	6.3	2.521	1222.9	712.5	1223.5	511.0	2.393	2.455	83.9	14.7	149.3	2.5	16.1	84.4	41.3	39.4	1.047	1750	13
6.3-3	6.3	2.541	1222.6	712.2	1223.9	511.7	2.389	2.455	83.7	14.6	149.1	2.7	16.3	83.6	41.4	39.4	1.050	1475	13
AVG.	6.3											3.1	16.6	81.6	41.6	39.4	1.056	1475	13
Computed By: Scott R. Todd						Checked By:													

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

Table A3: Volumetric Data from Granite Trial Blend Number 3

JOB NUMBER	PROJECT: NCHRP 9-8	BLEND DESCRIPTION	DATE:
AC Sp. Gr. (Gb) - 1.029	Effective Sp. Gr. Of Aggregate (Gse) = 2.707 Bulk Sp. Gr. Of Agg. (Gsb) = 2.672	Percent passing #4: 25 GRANITE GRADATION #1 (LHS) Unit Wt. Of CA in DRC (pcf): 101.0 Unit Wt. Of CA in DRC (kg/m^3): 1617.9	T 07-05-94

			WEIGHTS			MIX VOL	SPECIFIC GRAVITIES		VOLUMES		VOIDS							STABILT	
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 dre	Measured (lb)	Flow (0.1 in)
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	T	U
						(F-E)	$\frac{D}{(F-E)}$		$\frac{(100-B) \times 1}{(Gmb)}$	$\frac{BxI}{(Gb)}$	(1x62.4)	100(1-1/3)	(100-k)	$\frac{100(O-N)}{O}$					
6.3-1	6.3	2.551	1225.1	710.2	1226.4	516.2	2.373	2.455	83.2	14.5	148.1	3.3	16.8	80.2	37.6	39.4	0.954	1700	11
6.3-2	6.3	2.565	1224.3	707.5	1225.9	518.4	2.362	2.455	82.8	14.5	147.4	3.8	17.2	77.9	37.9	39.4	0.962	1925	11
6.3-3	6.3	2.553	1219.7	704.7	1221.4	516.7	2.361	2.455	82.8	14.5	147.3	3.8	17.2	77.7	37.9	39.4	0.963	1600	11
AVG.	6.3											3.7	17.1	78.6	37.8	39.4	0.959	1742	11

Computed By: Scott R. Todd Checked By:

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

Table A4: Volumetric Data from Florida Limestone Trial Blend Number 1

JOB NUMBER			PROJECT: NCHRP 9-8						BLEND DESCRIPTION	Percent passing #4: 40 GRANITE GRADATION #1 (LHS) Unit Wt. Of CA in DRC (pcf): 101.0 Unit Wt. Of CA in DRC (kg/m³): 1617.9								DATE:	
AC Sp. Gr. (Gb) - 1.029			Effective Sp. Gr. Of Aggregate (Gse) = 2.497 Bulk Sp. Gr. Of Agg. (Gsb) = 2.421															T 07-05-94	
			WEIGHTS			MIX VOL	SPECIFIC GRAVITIES		VOLUMES		VOIDS							STABILT	
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 dre	Measured (lb)	Flow (0.1 in)
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	T	U
						(F-E)	D / (F-E)		(100-B) x 1 / (Gmb)	BxI / (Gb)	(1x62.4)	100(1-1/3)	(100-k)	100(O-N) / O					
6.3-1	6.3	2.648	1217.9	681.7	1219.7	538.0	2.264	2.291	87.6	13.9	141.3	1.2	12.4	90.4	47.7	40.1	1.182		
6.3-2	6.3	2.651	1219.2	681.7	1220.3	538.6	2.264	2.291	87.6	13.9	141.3	1.2	12.4	90.4	47.4	40.1	1.182		
6.3-3	6.3	2.664	1218.0	679.3	1219.8	540.5	2.253	2.291	87.2	13.8	140.6	1.6	12.8	87.2	47.7	40.1	1.188		
AVG.	6.3											1.3	12.5	89.3	47.5	40.1	1.184	ERR	ERR
Computed By: Scott R. Todd						Checked By:													

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

Table A5: Volumetric Data from Florida Limestone Trial Blend Number 2

JOB NUMBER | PROJECT: NCHRP 9-8 | BLEND DESCRIPTION: Percent passing #4: 30; GRANITE; GRADATION #1 (LHS) Unit Wt. Of CA in DRC (pcf): 101.0; Unit Wt. Of CA in DRC (kg/m^3): 1617.9 | DATE:T 07-05-94

AC Sp. Gr. (Gb) - 1.029 | Effective Sp. Gr. Of Aggregate (Gse) = 2.511 Bulk Sp. Gr. Of Agg. (Gsb) = 2.422 | T 07-05-94

			WEIGHTS			MIX VOL	SPECIFIC GRAVITIES		VOLUMES		VOIDS							STABILT	
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 dre	Measured (lb)	Flow (0.1 in)
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	T	U
						(F-E)	D / (F-E)		(100-B) x 1 / (Gmb)	BxI / (Gb)	(1x62.4)	100(1-1/3)	(100-k)	100(O-N) / O					
6.3-1	6.3	2.676	1218.8	680.1	1221.5	541.4	2.251	2.302	87.1	13.8	140.5	2.2	12.9	82.9	39.0	40.2	0.972		
6.3-2	6.3	2.666	1211.6	673.9	1214.2	540.3	2.242	2.302	86.8	13.7	139.9	2.6	13.2	80.5	39.3	40.2	0.978		
6.3-3	6.3	2.673	1220.2	680.9	1223.3	542.4	2.250	2.302	87.0	13.8	140.4	2.3	13.0	82.5	39.1	40.2	0.973		
AVG.	6.3											2.4	13.0	81.9	39.1	40.2	0.975	ERR	ERR

Computed By: Scott R. Todd   Checked By:

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

Table A6: Volumetric Data from Florida Limestone Trial Blend Number 3

JOB NUMBER	PROJECT: NCHRP 9-8	BLEND DESCRIPTION	Percent passing #4: 25 GRANITE GRADATION #1 (LHS) Unit Wt. Of CA in DRC (pcf): 101.0 Unit Wt. Of CA in DRC (kg/m^3): 1617.9	DATE:T 07-05-94
AC Sp. Gr. (Gb) - 1.029	Effective Sp. Gr. Of Aggregate (Gse) = 2.511 Bulk Sp. Gr. Of Agg. (Gsb) = 2.422			T 07-05-94

Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOL	SPECIFIC GRAVITIES		VOLUMES		VOIDS							STABILT	
			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 dre	Measured (lb)	Flow (0.1 in)
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	T	U
						(F-E)	D / (F-E)		(100-B) x 1 / (Gmb)	BxI / (Gb)	(1x62.4)	100(1-1/3)	(100-k)	100(O-N) / O					
6.3-1	6.3	2.719	1221.1	675.4	1224.6	549.2	2.223	2.281	86.3	13.6	138.7	2.5	13.7	81.6	35.3	40.0	0.883		
6.3-2	6.3	2.752	1220.6	674.2	1224.7	550.5	2.217	2.281	86.1	13.6	138.4	2.8	13.9	79.9	35.5	40.0	0.887		
6.3-3	6.3	2.749	1218.6	674.4	1222.4	548.0	2.224	2.281	86.3	13.6	138.8	2.5	13.7	81.7	35.3	40.0	0.883		
AVG.	6.3											2.6	13.8	81.1	35.3	40.0	0.884	ERR	ERR

Computed By: Scott R. Todd Checked By:

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

Table A7: Volumetric Data from Florida Limestone Trial Blend Number 3 with Various Asphalt Cement Contents

JOB NUMBER			PROJECT: NCHRP 9-8						BLEND DESCRIPTION LIMEROCK GRADATION #3 W/ 40% PASS. 3/8" (LHS)			Percent passing #4: 25 Unit Wt. Of CA in DRC (pcf): 101.0 Unit Wt. Of CA in DRC (kg/m^3): 1448.1						DATE:T 07-05-94 T 06-16-94	
AC Sp. Gr. (Gb) - 1.029			Effective Sp. Gr. Of Aggregate (Gse) = 2.502 Bulk Sp. Gr. Of Agg. (Gsb) = 2.414																
			WEIGHTS			MIX VOL	SPECIFIC GRAVITIES		VOLUMES		VOIDS							STABILT	
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 dre	Measured (lb)	Flow (0.1 in)
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	T	U
						(F-E)	D / (F-E)		(100-B) x 1 / (Gmb)	BxI / (Gb)	(1x62.4)	100(1-1/3)	(100-k)	100(O-N) / O					
6.0-1	6.0		1157.7	638.0	1163.3	525.3	2.204	2.303	85.8	12.9	137.5	4.3	14.2	69.7	35.6	40.0	0.892		
6.0-1	6.0		1152.0	635.0	1158.7	523.7	2.200	2.303	85.7	12.8	137.3	4.5	14.3	68.7	35.8	40.0	0.895		
6.0-1	6.0		1158.2	638.7	1163.7	525.0	2.206	2.303	85.9	12.9	137.7	4.2	14.1	70.1	35.6	40.0	0.890		
AVG.	6.0											4.3	14.2	69.5	35.7	40.0	0.892	ERR	ERR
6.1-1	6.1		1175.3	645.9	1180.1	534.2	2.200	2.301	85.6	13.0	137.3	4.4	14.4	69.6	35.8	40.0	0.896		
6.1-2	6.1		1168.2	645.1	1172.2	527.1	2.216	2.301	86.2	13.1	138.3	3.7	13.8	73.3	35.3	40.0	0.885		
6.1-3	6.1		1176.2	651.9	1180.7	528.8	2.224	2.301	86.5	13.2	138.8	3.3	13.5	75.3	35.1	40.0	0.879		
AVG.	6.1											3.8	13.9	72.7	35.4	40.0	0.887	ERR	ERR
6.3-1	6.3		1170.0	649.4	1174.5	525.1	2.228	2.295	86.5	13.6	139.0	2.9	13.5	78.4	35.1	40.0	0.879		
6.3-2	6.3		1167.1	646.4	1170.1	523.2	2.231	2.295	86.6	13.7	139.2	2.8	13.4	79.1	35.1	40.0	0.878		
6.3-3	6.3		1163.5	640.5	1168.1	527.6	2.205	2.295	85.6	13.5	137.6	3.9	14.4	72.9	35.8	40.0	0.896		
AVG.	6.3											3.2	13.8	76.8	35.3	40.0	0.884	ERR	ERR
Computed By: Scott R. Todd						Checked By:													

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

Table A8: Volumetric Data from Gravel Trial Blend Number 1

JOB NUMBER			PROJECT: NCHRP 9-8						BLEND DESCRIPTION	Percent passing #4: 40 GRANITE GRADATION #1 (LHS) Unit Wt. Of CA in DRC (pcf): 100.0 Unit Wt. Of CA in DRC (kg/m^3): 1601.8								DATE:T 07-05-94 T 08-27-94	
AC Sp. Gr. (Gb) - 1.029			Effective Sp. Gr. Of Aggregate (Gse) = 2.595 Bulk Sp. Gr. Of Agg. (Gsb) = 2.564																
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOL	SPECIFIC GRAVITIES		VOLUMES		VOIDS							STABILT	
			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 dre	Measured (lb)	Flow (0.1 in)
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	T	U
						(F-E)	D / (F-E)		(100-B) x 1 / (Gmb)	BxI / (Gb)	(1x62.4)	100(1-1/3)	(100-k)	100(O-N) / O					
6.3-1	6.3		1153.2	661.9	1153.6	491.7	2.345	2.368	87.5	14.4	146.3	1.0	14.3	93.3	48.6	37.5	1.297	1400	13
6.3-2	6.3		1158.1	664.4	1158.7	494.3	2.343	2.3687	85.6	14.3	146.2	1.1	14.4	92.6	48.6	37.5	1.298	1550	17
6.3-3	6.3		1175.1	673.2	1176.1	502.9	2.337	2.368	85.4	14.3	145.8	1.3	14.6	91.1	48.8	37.5	1.301	1250	18
AVG.	6.3											1.1	14.4	92.3	48.7	37.5	1.299	1400	16
Computed By: Scott R. Todd						Checked By:													

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

Table A9: Volumetric Data from Gravel Trial Blend Number 2

JOB NUMBER

PROJECT: NCHRP 9-8

BLEND DESCRIPTION Percent passing #4: 30
GRANITE
GRADATION #1 (LHS) Unit Wt. Of CA in DRC (pcf): 100.0
Unit Wt. Of CA in DRC (kg/m^3): 1601.8

DATE:T 07-05-94
T 09-27-94

AC Sp. Gr. (Gb) - 1.029

Effective Sp. Gr. Of Aggregate (Gse) = 2.600 Bulk Sp. Gr. Of Agg. (Gsb) = 2.578

Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOL	SPECIFIC GRAVITIES		VOLUMES		VOIDS							STABILT	
			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 dre	Measured (lb)	Flow (0.1 in)
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	T	U
						(F-E)	D / (F-E)		(100-B) x 1 / (Gmb)	BxI / (Gb)	(1x62.4)	100(1-1/3)	(100-k)	100(O-N) / O					
6.3-1	6.3		1168.6	666.3	1169.6	503.3	2.322	2.372	84.4	14.2	144.9	2.1	15.6	86.5	40.9	37.8	1.063	1000	13
6.3-2	6.3		1171.0	661.1	1172.5	511.4	2.290	2.372	83.2	14.0	142.9	3.5	16.8	79.3	41.7	37.8	1.104	800	14
6.3-3	6.3		1167.0	661.9	1168.1	506.2	2.305	2.372	83.8	14.1	143.9	2.8	16.2	82.7	41.3	37.8	1.094	1250	14
AVG.	6.3											2.8	16.2	82.8	41.3	37.8	1.094	1017	14

Computed By: Scott R. Todd Checked By:

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

Table A10: Volumetric Data from Granite Trial Blend Number 3

JOB NUMBER			PROJECT: NCHRP 9-8						BLEND DESCRIPTION GRAVEL GRADATION #3 (LHS) Percent passing #4: 25									DATE:	
AC Sp. Gr. (Gb) = 1.029			Effective Sp. Gr. Of Aggregate (Gse) = 2.595 Bulk Sp. Gr. Of Agg. (Gsb) = 2.574						Unit Wt. Of CA in DRC (pcf): 100.0 Unit Wt. Of CA in DRC (kg/m^3): 1601.8									T 09-27-94	
			WEIGHTS			MIX VOL	SPECIFIC GRAVITIES		VOLUMES		VOIDS							STABILITY	
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 dre	Measured (lb)	Flow (0.1 in)
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	T	U
						(F-E)	D / (F-E)		(100-B) x 1 / (Gmb)	BxI / (Gb)	(1x62.4)	100(1-I/J)	(100-k)	100(O-N) / O					
6.3-1	6.3		1162.8	654.6	1224.5	509.6	2.282	2.368	83.1	14.0	142.4	3.6	16.9	78.5	37.7	37.7	1.000	950	12
63-2	6.3		1162.9	653.3	1221.1	510.7	2.777	2.368	82.9	13.9	142.1	3.8	17.1	77.6	37.8	37.7	1.003	1100	14
63-3	6.3		1164.1	653.0	1227.2	513.0	2.269	2.368	82.6	13.9	141.6	4.2	17.4	76.0	38.0	37.7	1.009	1000	12
AVG.	6.3											3.9	17.1	77.4	37.9	37.7	1.004	1017	13

Computed By: Scott R. Todd Checked By:

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

Table A11: Volumetric Data from Limestone Trial Blend Number 1

JOB NUMBER	PROJECT: NCHRP 9-8	BLEND DESCRIPTION LIMESTONE GRADATION #1 (LHS) Percent passing #4: 40 Unit Wt. Of CA in DRC (pcf): 97.7 Unit Wt. Of CA in DRC (kg/m^3): 1565.0	DATE: W 06-31-94
AC Sp. Gr. (Gb) = 1.029	Effective Sp. Gr. Of Aggregate (Gse) = 2.750 Bulk Sp. Gr. Of Agg. (Gsb) = 2.734		

Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOL	SPECIFIC GRAVITIES		VOLUMES		VOIDS							STABILITY	
			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 dre	Measured (lb)	Flow (0.1 in)
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	T	U
						(F-E)	D / (F-E)		(100-B) x 1 / (Gmb)	BxI / (Gb)	(1x62.4)	100(1-I/J)	(100-k)	100(O-N) / O					
6.0-1	6.0		1151.4	685.2	1152.5	467.3	2.464	2.499	84.7	14.4	153.7	1.4	15.3	90.8	49.2	42.7	1.152	1050	20
6.0-2	6.0		1156.4	688.1	1157.0	468.9	2.466	2.499	84.8	14.4	153.9	1.3	15.2	91.4	49.1	42.7	1.150	1200	22
6.0-3	6.0		1155.8	687.8	1156.2	468.4	2.468	2.499	84.8	14.4	154.0	1.3	15.2	91.7	49.1	42.7	1.150	1450	21
AVG.	6.0											1.3	15.2	91.3	49.1	42.7	1.151	1233	21

Computed By: Scott R. Todd Checked By:

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

Table A12: Volumetric Data from Limestone Trial Blend Number 2

JOB NUMBER	PROJECT: NCHRP 9-8	BLEND DESCRIPTION LIMESTONE GRADATION #1 (LHS) Percent passing #4: 30 Unit Wt. Of CA in DRC (pcf): 97.7 Unit Wt. Of CA in DRC (kg/m^3): 1565.0	DATE: W 06-31-94
AC Sp. Gr. (Gb) = 1.029	Effective Sp. Gr. Of Aggregate (Gse) = 2.755 Bulk Sp. Gr. Of Agg. (Gsb) = 2.738		

Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS In Air (gm)	WEIGHTS In Water (gm)	WEIGHTS SSD (gm)	MIX VOL Volume (cc)	SPECIFIC GRAVITIES Bulk (Gmb)	SPECIFIC GRAVITIES TMD (Gmm)	VOLUMES Aggregate Volume (cc)	VOLUMES AC by Volume (%)	VOIDS Unit Weight (pcf)	VOIDS Total (%)	VOIDS VMA (%)	VOIDS Filled (%)	VOIDS VCA (%)	VOIDS VCA drc (%)	VOIDS VCA/VCA dre	STABILITY Measured (lb)	Flow (0.1 in)
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	T	U
						(F-E)	D / (F-E)		(100-B) x 1 / (Gmb)	BxI / (Gb)	(1x62.4)	100(1-I/J)	(100-k)	100(O-N) / O					
6.0-1	6.0		1152.9	682.2	1153.7	471.5	2.445	2.503	83.9	14.3	152.6	2.3	16.1	85.6	41.2	42.8	0.964	1000	13
6.0-2	6.0		1164.4	691.1	1165.3	474.1	2.456	2.503	84.3	14.3	153.3	1.9	15.7	88.0	41.0	42.8	0.958	1125	13
6.0-3	6.0		1183.5	700.9	1184.6	483.7	2.447	2.503	84.0	14.3	152.7	2.2	16.0	86.0	41.2	42.8	0.963	950	14
AVG.	6.0											2.1	15.9	86.5	41.1	42.8	0.962	1025	13

Computed By: Scott R. Todd   Checked By:

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

Table A13: Volumetric Data from Limestone Trial Blend Number 2

JOB NUMBER			PROJECT: NCHRP 9-8						BLEND DESCRIPTION LIMESTONE GRADATION #3 (LHS) Percent passing #4: 25									DATE:	
AC Sp. Gr. (Gb) = 1.029			Effective Sp. Gr. Of Aggregate (Gse) = 2.747 Bulk Sp. Gr. Of Agg. (Gsb) = 2.735						Unit Wt. Of CA in DRC (pcf): 97.7 Unit Wt. Of CA in DRC (kg/m^3): 1565.0									W 06-31-94	
Specimen Number	Asphalt Content (%)	Average Thickness (Inches)	WEIGHTS			MIX VOL	SPECIFIC GRAVITIES		VOLUMES		VOIDS							STABILTY	
			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	Measured (lb)	Flow (0.1 in)
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	T	U
						(F-E)	D/(F-E)		(100-B) x 1/(Gmb)	BxI/(Gb)	(1x62.4)	100(1-I/J)	(100-k)	100(O-N)/O					
6.0-1	6.0		1188.6	694.8	1190.6	495.8	2.397	2.497	82.4	14.0	149.6	4.0	17.6	77.3	38.2	42.7	0.894	1050	14
6.0-2	6.0		1180.6	688.7	1182.7	494.0	2.390	2.497	82.1	13.9	149.1	4.3	17.9	76.0	38.4	42.7	0.899	1000	13
6.0-3	6.0		1189.9	700.5	1191.8	491.3	2.422	2.497	83.2	14.1	151.1	3.0	16.8	82.1	37.6	42.7	0.879	1250	14
AVG.	6.0											3.8	17.4	78.5	36.1	42.7	0.891	1100	14
Computed By: Scott R. Todd						Checked By:													

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

Table A14: Volumetric Data from Traprock Trial Blend Number 1

JOB NUMBER			PROJECT: NCHRP 9-8						BLEND DESCRIPTION TRAPROCK GRADATION #1 (LHS) Percent passing #4: 40									DATE:	
AC Sp. Gr. (Gb) = 1.029			Effective Sp. Gr. Of Aggregate (Gse) = 2.932 Bulk Sp. Gr. Of Agg. (Gsb) = 2.947						Unit Wt. Of CA in DRC (pcf): 106.2 Unit Wt. Of CA in DRC (kg/m³): 1733.2									W 09-06-94	
			WEIGHTS			MIX VOL	SPECIFIC GRAVITIES		VOLUMES		VOIDS							STABILITY	
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 dre	Measured (lb)	Flow (0.1 in)
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	T	U
						(F-E)	D/(F-E)		(100-B) x 1/(Gmb)	BxI/(Gb)	(1x62.4)	100(1-I/J)	(100-k)	100(O-N)/O					
6.3-1	6.3		1141.3	703.4	1143.4	440.0	2.594	2.626	82.5	15.9	161.9	1.2	17.5	93.0	50.5	41.1	1.228	1050	18
6.3-2	6.3		1156.9	714.7	1157.2	442.5	2.614	2.626	83.1	16.0	163.1	0.4	16.9	97.4	50.1	41.1	1.219	1200	16
6.3-3	6.3		1162.3	715.6	1163.1	447.5	2.597	2.626	82.6	15.9	162.1	1.1	17.4	93.7	50.5	41.1	1.227	1050	15
AVG.	6.3											0.9	17.3	94.7	50.4	41.1	1.225	1100	16
Computed By: Scott R. Todd						Checked By:													

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

Table A15: Volumetric Data from Traprock Trial Blend Number 2

JOB NUMBER			PROJECT: NCHRP 9-8						BLEND DESCRIPTION TRAPROCK GRADATION #2 (LHS) Percent passing #4: 30									DATE:	
AC Sp. Gr. (Gb) = 1.029			Effective Sp. Gr. Of Aggregate (Gse) = 2.943 Bulk Sp. Gr. Of Agg. (Gab) = 2.940						Unit Wt. Of CA in DRC (pcf): 106.2 Unit Wt. Of CA in DRC (kg/m^3): 1733.2									W 09-06-94	
			WEIGHTS			MIX VOL	SPECIFIC GRAVITIES		VOLUMES		VOIDS							STABILITY	
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 dre	Measured (lb)	Flow (0.1 in)
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	T	U
						(F-E)	D / (F-E)		(100-B) x 1 / (Gmb)	BxI / (Gb)	(1x62.4)	100(1-I/J)	(100-k)	100(O-N) / O					
6.3-1	6.3		1166.4	719.1	1167.0	447.9	2.604	2.634	83.0	15.9	162.5	1.1	17.0	93.3	41.9	41.1	1.022	1125	14
6.3-2	6.3		1170.5	720.8	1171.0	450.2	2.600	2.634	82.9	15.9	162.2	1.3	17.1	92.5	42.0	41.1	1.025	1250	14
6.3-3	6.3		1168.2	722.0	1169.4	447.4	2.611	2.634	83.2	16.0	162.9	0.9	16.8	94.8	41.7	41.1	1.019	1400	20
AVG.	6.3											1.1	17.0	93.5	41.9	41.1	1.022	1258	16
Computed By: Scott R. Todd						Checked By:													

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

Table A16: Volumetric Data from Traprock Trial Blend Number 3

JOB NUMBER			PROJECT: NCHRP 9-8						BLEND DESCRIPTION TRAPROCK GRADATION #3 (LHS) Percent passing #4: 25									DATE:	
AC Sp. Gr. (Gb) = 1.029			Effective Sp. Gr. Of Aggregate (Gse) = 2.943 Bulk Sp. Gr. Of Agg. (Gab) = 2.939						Unit Wt. Of CA in DRC (pcf): 106.2 Unit Wt. Of CA in DRC (kg/m^3): 1733.2									W 09-06-94	
			WEIGHTS			MIX VOL	SPECIFIC GRAVITIES		VOLUMES		VOIDS							STABILITY	
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 dre	Measured (lb)	Flow (0.1 in)
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	T	U
						(F-E)	D / (F-E)		(100-B) x 1 / (Gmb)	BxI / (Gb)	(1x62.4)	100(1-I/J)	(100-k)	100(O-N) / O					
6.3-1	6.3		1161.7	707.9	1163.8	455.9	2.548	2.634	81.2	15.6	159.0	3.3	18.8	82.6	39.1	41.1	0.954	1200	14
6.3-2	6.3		1159.3	709.2	1160.8	451.6	2.567	2.634	81.8	15.7	160.2	2.5	18.2	86.0	38.6	41.1	0.943	1300	14
6.3-3	6.3		1167.6	714.6	1168.2	453.6	2.574	2.634	82.1	15.8	160.6	2.3	17.9	87.3	38.5	41.1	0.939	1300	19
AVG.	6.3											2.7	18.3	85.3	38.7	41.1	0.945	1267	16
Computed By: Scott R. Todd						Checked By:													

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

Table A17: Volumetric Data from Traprock Trial Blend Number 3 with Various Asphalt Cement Contents

JOB NUMBER			PROJECT: NCHRP 9-8						BLEND DESCRIPTION TRAPROCK GRADATION #3 (LHS) Percent passing #4: 25										DATE:	
AC Sp. Gr. (Gb) = 1.029			Effective Sp. Gr. Of Aggregate (Gse) = 2.943 Bulk Sp. Gr. Of Agg. (Gsb) = 2.939						Unit Wt. Of CA in DRC (pcf): 106.2; Unit Wt. Of CA in DRC (kg/m^3): 1733.2										W 09-12-94	
			WEIGHTS			MIX VOL	SPECIFIC GRAVITIES		VOLUMES		VOIDS								STABILITY	
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 dre	Measured (lb)	Flow (0.1 in)
A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	T	U
						(F-E)	D/(F-E)		(100-B) x 1/(Gmb)	BxI/(Gb)	(1x62.4)	100(1-I/J)	(100-k)	100(O-N)/O					
5.5-1	5.5		1151.1	702.0	1153.3	451.3	2.551	2.693	82.0	13.6	159.2	5.3	18.0	70.6	38.5	41.0	0.940		
5.5-2	5.5		1154.4	711.7	1155.9	444.2	2.599	2.693	83.6	13.9	162.2	3.5	16.4	78.7	37.3	41.0	0.911		
5.5-3	5.5		1144.7	702.2	1146.5	444.3	2.576	2.693	82.8	13.8	160.8	4.3	17.2	74.8	37.9	41.0	0.924		
AVG.	5.5											4.4	17.2	74.7	37.9	41.0	0.925		
5.7-1	5.7		1140.6	694.8	1142.0	447.2	2.551	2.661	81.8	14.1	159.2	4.2	18.2	77.1	38.6	41.0	0.943	1250	17
5.7-2	5.7		1134.1	692.7	1135.3	442.6	2.562	2.661	82.2	14.2	159.9	3.7	17.8	79.2	38.3	41.0	0.936	1300	15
5.7-3	5.7		1154.8	706.2	1156.6	450.4	2.564	2.661	82.3	14.2	160.0	3.6	17.7	79.4	38.3	41.0	0.935	1500	19
AVG.	5.7											3.8	17.9	78.6	38.4	41.0	0.938	1350	17
5.8-1	5.8		1150.4	704.0	1153.4	449.4	2.560	2.656	82.0	14.4	159.7	3.6	18.0	79.8	38.5	41.0	0.939		
5.8-2	5.8		1152.3	709.8	1154.5	444.7	2.591	2.656	83.1	14.6	161.7	2.4	16.9	85.6	37.7	41.0	0.920		
5.8-3	5.8		1152.0	706.3	1153.0	446.7	2.579	2.656	82.7	14.5	160.9	2.9	17.3	83.3	38.0	41.0	0.928		
AVG.	5.8											3.0	17.4	82.9	38.1	41.0	0.929		
6.3-1	6.3		1161.7	707.9	1163.8	455.9	2.548	2.634	81.2	15.6	159.0	3.3	18.8	82.6	39.1	41.1	0.954	1200	14
6.3-1	6.3		1159.3	709.2	1160.8	451.6	2.567	2.634	81.8	15.7	160.2	2.5	18.2	86.0	38.6	41.1	0.943	1300	14
6.3-1	6.3		1167.6	714.6	1168.2	453.6	2.574	2.634	82.1	15.8	160.6	2.3	17.9	87.3	38.5	41.1	0.939	1300	19
AVG.	6.3											2.7	18.3	85.3	38.7	41.1	0.945	1267	16

Computed By: Scott R. Todd Checked By:

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

APPENDIX B -
Mix Design Results for the Nine Gradations, Two Aggregates

Table B1: Mix Design Data for Granite Gradation Number 1

Job Number:			Project: NCHRP 9-8						Blend Description:		Granite Gradation #1		Percent passing #4:		40			Date:
AC Sp. Gr. (Gb) = 1.029			Effective Sp. Gr. of Aggregate (Gse) = 2.724 Bulk Sp. Gr. of Agg. (Gsb) = 2.700										Unit wt. of CA in DRC (pcf): Unit wt. of CA in DRC (kg/m3)				101.0 1617.9	T 12-13-94
Specimen Number	Asphalt Content (%)	Average Thickness (inches)	Weights			Mix Vol	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)x1 / (Gsb)	Bx1 / (Gb)	(1x62.4)	100 (1-I/J)	(100-K)	100 (O-N) / O				
3.8-1	3.8		1133.4	667.2	1139.7	472.5	2.399	2.564	85.5	8.9	149.7	6.4	14.5	55.7	48.7	40.0	1.217	
3.8-2	3.8		1139.9	673.7	1145.0	471.3	2.419	2.564	86.2	8.9	150.9	5.7	13.8	59.0	48.3	40.0	1.207	
3.8-3	3.8		1136.7	671.5	1141.2	469.7	2.420	2.564	86.2	8.9	151.0	5.6	13.8	59.2	48.3	40.0	1.206	
AVG	3.8											5.9	14.0	58.0	48.4	40.0	1.210	
4.3-1	4.3		1145.4	679.7	1147.6	467.9	2.448	2.544	86.8	10.2	152.8	3.8	13.2	71.5	47.9	40.0	1.198	
4.3-2	4.3		1140.5	677.4	1142.3	464.9	2.453	2.544	87.0	10.3	153.1	3.6	13.0	72.6	47.8	40.0	1.195	
4.3-3	4.3		1138.8	674.3	1142.1	467.8	2.434	2.544	86.3	10.2	151.9	4.3	13.7	68.6	48.2	40.0	1.205	
AVG	4.3											3.9	13.3	70.9	48.0	40.0	1.199	
4.8-1	4.8		1153.4	682.1	1155.9	473.8	2.434	2.524	85.8	11.4	151.9	3.6	14.2	74.9	48.5	40.0	1.212	
4.8-2	4.8		1150.6	683.9	1151.2	467.3	2.462	2.524	86.8	11.5	153.6	2.4	13.2	81.4	47.9	40.0	1.197	
4.8-3	4.8		1152.4	682.8	1154.8	472.0	2.442	2.524	86.1	11.4	152.4	3.3	13.9	76.5	48.3	40.0	1.208	
AVG	4.8											3.1	13.8	77.6	48.3	40.0	1.206	
5.3-1	5.3		1153.1	684.3	1154.1	469.8	2.454	2.505	86.1	12.6	153.2	2.0	13.9	85.5	48.3	40.0	1.208	
5.3-2	5.3		1162.0	687.2	1162.6	475.4	2.444	2.505	85.7	12.6	153.2	2.4	14.3	83.0	48.6	40.0	1.213	
AVG	5.3											2.2	14.1	84.3	48.5	40.0	1.211	
5.8-1	5.8		1159.9	685.7	1160.3	474.6	2.444	2.486	85.3	13.8	152.5	1.7	14.7	88.5	48.8	40.0	1.220	
5.8-2	5.8		1153.4	680.6	1153.8	473.2	2.437	2.486	85.0	13.7	152.1	2.0	15.0	86.9	49.0	40.0	1.224	
5.8-3	5.8		1159.1	679.7	1160.9	481.2	2.409	2.486	84.0	13.6	150.3	3.1	16.0	80.5	49.6	40.0	1.239	
AVG	5.8											2.3	15.2	85.3	49.1	40.0	1.228	
Computed by: Scott R. Todd					Checked by:													

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

Table B2: Mix Design Data for Granite Gradation Number 2

Job Number: | Project: NCHRP 9-8 | Blend Description: Granite Gradation #2 | Percent passing #4: 30 | Date: T 12-13-94

AC Sp. Gr. (Gb) = 1.029 | Effective Sp. Gr. of Aggregate (Gse) = 2.707, Bulk Sp. Gr. of Agg. (Gsb) = 2.690 | Unit wt. of CA in DRC (pcf): 101.0 | Unit wt. of CA in DRC (kg/m3): 1617.9

Specimen Number	Asphalt Content (%)	Average Thickness (inches)	Weights			Mix Vol	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)x1 / (Gsb)	Bx1 / (Gb)	(1x62.4)	100 (1-I/J)	(100-K)	100 (O-N) / O			
5.3-1	5.3	2.389	1159.9	683.0	1161.3	478.3	2.365	2.492	83.2	12.2	147.6	5.1	16.8	69.5	41.7	39.8	1.049
5.3-2	5.3	2.455	1186.0	698.0	1188.7	490.7	2.353	2.492	82.8	12.1	146.8	5.6	17.2	67.5	42.0	39.8	1.056
5.3-3	5.3	2.420	1164.9	684.1	1166.7	482.6	2.344	2.492	82.5	12.1	146.3	5.9	17.5	66.1	42.2	39.8	1.061
AVG	5.3											5.5	17.1	67.7	42.0	39.8	1.055
5.8-1	5.8		1157.4	674.7	1158.5	483.8	2.392	2.473	83.8	13.5	149.3	3.3	16.2	79.9	41.4	39.8	1.039
5.8-2	5.8		1153.8	669	1155.6	486.6	2.371	2.473	83.0	13.4	148.0	4.1	17.0	75.7	41.9	39.8	1.052
5.8-3	5.8		1161.9	678.1	1164.4	486.3	2.389	2.473	83.7	13.5	149.1	3.4	16.3	79.3	41.4	39.8	1.041
AVG	5.8											3.6	16.5	78.3	41.6	39.8	1.044
6.3-1	6.3		1174.6	686.0	1175.9	489.9	2.398	2.455	83.5	14.7	149.6	2.3	16.5	85.8	41.5	39.8	1.044
6.3-2	6.3		1160.6	676.6	1161.6	485.0	2.393	2.455	83.4	14.7	149.3	2.5	16.6	84.8	41.7	39.8	1.047
6.3-3	6.3		1183.1	690.5	1184.2	493.7	2.396	2.455	83.5	14.7	149.5	2.4	16.5	85.6	41.6	39.8	1.045
AVG	6.3											2.4	16.6	85.4	41.6	39.8	1.045
6.8-1	6.8		1159.0	676.4	1159.8	483.4	2.398	2.437	83.1	15.8	149.6	1.6	16.9	90.5	41.9	39.8	1.052
6.8-2	6.8		1176.7	684.2	1177.6	493.4	2.385	2.437	82.6	15.8	148.8	2.1	17.4	87.7	42.2	39.8	1.059
6.8-3	6.8		1162.0	675.3	1163.0	487.7	2.383	2.437	82.5	15.7	148.7	2.2	17.5	87.2	42.2	39.8	1.061
AVG	6.8											2.0	17.3	88.5	42.1	39.8	1.057
7.3-1	7.3		1158.5	674.0	1159.2	485.2	2.388	2.419	82.3	16.9	149.0	1.3	17.7	92.7	42.4	39.8	1.066
7.3-2	7.3		1172.1	680.6	1173.1	492.5	2.380	2.419	82.0	16.9	148.5	1.6	18.0	91.0	42.6	39.8	1.070
7.3-3	7.3		1173.3	682.7	1173.7	491.0	2.390	2.419	82.3	17.0	149.1	1.2	17.7	93.1	42.4	39.8	1.064
AVG	7.3											1.4	17.8	92.3	42.4	39.8	1.067

Computed by: Scott R. Todd   Checked by:

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

Table B3: Mix Design Data for Granite Gradation Number 3

Job Number: | Project: NCHRP 9-8 | Blend Description: Granite Gradation #3 | Percent passing #4: 25 | Date: F 07-29-94

AC Sp. Gr. (Gb) = 1.029 | Effective Sp. Gr. of Aggregate (Gse) = 2.707 | Bulk Sp. Gr. of Agg. (Gsb) = 2.690 | Unit wt. of CA in DRC (pcf): 101.0 | Unit wt. of CA in DRC (kg/m3) 1617.9

Specimen Number	Asphalt Content (%)	Average Thickness (inches)	Weights			Mix Vol	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)x1 / (Gsb)	Bx1 / (Gb)	(1x62.4)	100 (1-I/J)	(100-K)	100 (O-N) / O			
5.3-1	5.3		1158.2	678.0	1160.1	482.1	2.402	2.491	84.6	12.4	149.9	3.6	15.4	76.9	36.6	39.8	0.919
5.3-2	5.3		1193.1	697.0	1195.6	498.6	2.393	2.491	84.2	12.3	149.3	3.9	15.8	75.0	36.8	39.8	0.925
5.3-3	5.3		1185.9	687.7	1188.1	500.4	2.370	2.491	83.4	12.2	147.9	4.9	16.6	70.7	37.4	39.8	0.940
AVG	5.3											4.1	15.9	74.2	36.9	39.8	0.928
5.8-1	5.8		1158.0	673.9	1159.9	486.0	2.383	2.473	83.4	13.4	148.7	3.7	16.6	78.0	37.4	39.8	0.940
5.8-3	5.8		1169.3	681.3	1171.5	490.2	2.385	2.473	83.5	13.4	148.8	3.5	16.5	78.5	37.4	39.8	0.939
AVG	5.8											3.6	16.5	78.2	37.4	39.8	0.939
6.3-1	6.3		1162.9	675.0	1164.2	489.2	2.377	2.455	82.8	14.6	148.3	3.2	17.2	81.6	37.9	39.8	0.952
6.3-2	6.3		1157.8	674.8	1159.0	484.2	2.391	2.455	83.3	14.6	149.2	2.6	16.7	84.4	37.5	39.8	0.943
6.3-3	6.3		1160.6	677.6	1161.9	484.3	2.396	2.455	83.5	14.7	149.5	2.4	16.5	85.6	37.4	39.8	0.940
AVG	6.3											2.7	16.8	83.9	37.6	39.8	0.945
6.8-1	6.8		1158.2	670.2	1159.2	489.0	2.369	2.436	82.1	15.7	147.8	2.8	17.9	84.6	38.5	39.8	0.966
6.8-2	6.8		1160.3	672.5	1162.1	489.6	2.370	2.436	82.1	15.7	147.9	2.7	17.9	84.8	38.4	39.8	0.965
6.8-3	6.8		1164.2	672.5	1165.7	493.2	2.361	2.436	81.8	15.6	147.3	3.1	18.2	83.0	38.7	39.8	0.972
AVG	6.8											2.9	18.0	84.1	38.5	39.8	0.968
7.3-1	7.3		1163.6	670.0	1165.0	495.0	2.351	2.419	81.0	16.7	146.7	2.8	19.0	85.1	39.2	39.8	0.986
7.3-2	7.3		1171.7	676.9	1172.6	495.7	2.364	2.419	81.5	16.8	147.5	2.3	18.5	87.7	38.9	39.8	0.978
7.3-3	7.3		1172.0	678.4	1173.1	494.7	2.369	2.419	81.6	16.8	147.8	2.1	18.4	88.8	38.8	39.8	0.974
AVG	7.3											2.4	18.6	87.2	39.0	39.8	0.979

Computed by: Scott R. Todd   Checked by:

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

Table B4: Mix Design Data for Granite Gradation Number 4

Job Number:			Project: NCHRP 9-8						Blend Description:	Granite Gradation #4		Percent passing #4:		20				Date:
AC Sp. Gr. (Gb) = 1.029			Effective Sp. Gr. of Aggregate (Gse) = 2.699 Bulk Sp. Gr. of Agg. (Gsb) = 2.686									Unit wt. of CA in DRC (pcf): Unit wt. of CA in DRC (kg/m3)				101.0 1617.9		H 09-15-94
Specimen Number	Asphalt Content (%)	Average Thickness (inches)	Weights			Mix Vol	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)x1 / (Gsb)	Bx1 / (Gb)	(1x62.4)	100 (1-I/J)	(100-K)	100 (O-N) / O			
6.0-1	6.0		1146.6	658.7	1150.6	491.9	2.331	2.460	81.6	13.6	145.5	5.2	18.4	71.5	34.7	39.7	0.875
6.0-2	6.0		1150.7	657.8	1153.3	495.5	2.322	2.460	81.3	13.5	144.9	5.6	18.7	70.1	35.0	39.7	0.881
6.0-3	6.3		1158.8	669.0	1162.1	493.1	2.350	2.460	82.2	13.7	146.6	4.5	17.8	74.8	34.2	39.7	0.861
AVG	6.0											5.1	18.3	72.2	34.6	39.7	0.872
6.5-1	6.5		1164.9	668.6	1166.6	498.0	2.339	2.441	81.4	14.8	146.0	4.2	18.6	77.5	34.9	39.7	0.878
6.5-2	6.5		1167.4	675.2	1169.0	493.8	2.364	2.441	82.3	14.9	147.5	3.1	17.7	82.2	34.2	39.7	0.860
6.5-3	6.5		1161.8	667.9	1163.5	495.6	2.344	2.441	81.6	14.8	146.3	4.0	18.4	78.5	34.7	39.7	0.874
AVG	6.5											3.8	18.2	79.4	34.6	39.7	0.871
7.0-1	7.0		1130.5	646.5	1135.2	488.7	2.313	2.424	80.1	15.7	144.3	4.6	19.9	77.1	35.9	39.7	0.905
7.0-2	7.0		1179.1	678.2	1180.3	502.1	2.348	2.424	81.3	16.0	146.5	3.1	18.7	83.3	35.0	39.7	0.880
7.0-3	7.0		1149.4	660.9	1150.7	489.8	2.347	2.424	81.3	16.0	146.4	3.2	18.7	83.0	35.0	39.7	0.881
AVG	7.0											3.6	19.1	81.1	35.3	39.7	0.889
7.5-1	7.5		1160.1	667.9	1161.2	493.3	2.352	2.406	81.0	17.1	146.7	2.3	19.0	88.1	35.2	39.7	0.887
7.5-2	7.5		1189.8	686.5	1190.6	504.1	2.360	2.406	81.3	17.2	147.3	1.9	18.7	89.8	35.0	39.7	0.881
7.5-3	7.5		1137.1	656.0	1138.4	482.4	2.357	2.406	81.2	17.2	147.1	2.0	18.8	89.2	35.1	39.7	0.883
AVG	7.5											2.1	18.9	89.1	35.1	39.7	0.884
8.0-1	8.0		1179.5	672.2	1181.0	508.8	2.318	2.389	79.4	18.0	144.7	3.0	20.6	85.6	36.5	39.7	0.919
8.0-2	8.0		1168.9	668.5	1170.2	501.7	2.330	2.389	79.8	18.1	145.4	2.5	20.2	87.7	36.2	39.7	0.911
8.0-3	8.0		1187.1	678.6	1187.9	509.3	2.331	2.389	79.8	18.1	145.4	2.4	20.2	87.9	36.1	39.7	0.910
AVG	8.0											2.6	20.3	87.1	36.3	39.7	0.913

Computed by: Scott R. Todd Checked by:

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

Table B5: Mix Design Data for Granite Gradation Number 5

Job Number:			Project: NCHRP 9-8							Blend Description: Granite Gradation #5							Date:	
AC Sp. Gr. (Gb) = 1.029			Effective Sp. Gr. of Aggregate (Gse) = 2.719 Bulk Sp. Gr. of Agg. (Gsb) = 2.686														M 08-08-94	
Specimen Number	Asphalt Content (%)	Average Thickness (inches)	Weights			Mix Volumes		Specific Gravities		Volumes			Voids					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Volume Correlation Ratio	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	Measured (lb)	Correc-ted (lb)	Flow (.01 lb)
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)		D / (F-E)		(100-B)x1 / (Gsb)	Bx1 / (Gb)	(1x62.4)	100 (1-I/J)	(100-K)	100 (O-N) / O			
6.3-1	6.3	2.375	1024.2	578.8	1028.3	449.5		2.100	2.464	73.3	12.9	131.1	14.8	26.7	44.8			
6.3-2	6.3	2.428	1028.2	583.2	1035.9	452.7		2.063	2.464	72.0	12.6	128.7	16.3	28.0	41.9			
6.3-3	6.3	2.434	1045.7	590.1	1051.2	461.1		2.092	2.464	73.0	12.8	130.6	15.1	27.0	44.2			
AVG	6.3												15.4	27.3	43.6			
6.8-1	6.8	2.460	1019.0	569.8	1026.3	456.5		2.017	2.446	70.0	13.3	125.9	17.5	30.0	41.6			
6.8-2	6.8	2.416	1018.6	569.3	1026.2	456.9		2.053	2.446	71.2	13.6	128.1	16.1	28.8	44.2			
6.8-3	6.8	2.476	1045.2	582.2	1048.8	466.6		2.056	2.446	71.3	13.6	128.3	15.9	28.7	44.4			
AVG	6.8												16.5	29.1	43.4			
7.3-1	7.3	2.386	1049.1	591.3	1051.7	460.4		2.141	2.428	74.3	14.2	133.6	11.8	25.7	54.1			
7.3-2	7.3	2.430	1043.1	582.9	1046.1	463.2		2.091	2.428	72.5	14.8	130.5	13.9	27.5	49.4			
7.3-3	7.3	2.442	1065.5	596.5	1068.7	472.2		2.125	2.428	73.7	14.0	132.6	12.5	26.3	52.5			
AVG	7.3												12.7	26.5	52.0			
7.8-1	7.8	2.436	1033.2	572.7	1036.9	464.2		2.066	2.410	70.9	15.7	128.9	14.3	29.1	50.9			
7.8-2	7.8	2.522	1060.2	588.8	1063.7	474.9		2.047	2.410	70.3	15.5	127.8	15.0	29.7	49.4			
7.8-3	7.8	2.449	1064.2	591.1	1067.1	476.0		2.116	2.410	72.6	15.0	132.1	12.2	27.4	55.5			
AVG	7.8												13.8	28.7	51.9			
8.3-1	8.3	2.464	1060.9	586.1	1063.2	477.1		2.097	2.393	71.6	16.9	130.9	12.4	28.4	56.5			
8.3-2	8.3	2.391	1034.3	577.1	1037.6	460.5		2.107	2.393	71.9	17.0	131.5	12.0	28.1	57.4			
8.3-3	8.3	2.498	1080.3	603.3	1083.3	480.0		2.106	2.393	71.9	17.0	131.4	12.0	28.1	57.3			
AVG	8.3												12.1	28.2	57.1			
Computed by: Scott R. Todd						Checked by:												

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

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

Table B6: Mix Design Data for Granite Gradation Number 6

Job Number:			Project: NCHRP 9-8							Blend Description: Granite Gradation #6							Date:	
AC Sp. Gr. (Gb) = 1.029			Effective Sp. Gr. of Aggregate (Gse) = 2.753 Bulk Sp. Gr. of Agg. (Gsb) = 2.664														M 08-08-94	
Specimen Number	Asphalt Content (%)	Average Thickness (inches)	Weights			Mix Volumes		Specific Gravities		Volumes			Voids					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Volume Correlation Ratio	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	Measured (lb)	Correc-ted (lb)	Flow (.01 lb)
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)		D / (F-E)		(100-B)x1 / (Gsb)	Bx1 / (Gb)	(1x62.4)	100 (1-I/J)	(100-K)	100 (O-N) / O			
5.3-1	5.3	0.000	0.0	0.0	0.0	0.0			2.522	0.0	0.0	0.0						
5.3-2	5.3	0.000	0.0	0.0	0.0	0.0			2.522	0.0	0.0	0.0						
5.3-3	5.3	0.000	0.0	0.0	0.0	0.0			2.522	0.0	0.0	0.0						
AVG	5.3																	
5.8-1	5.8	2.279	930.8	0.0	0.0	0.0		1.989	2.503	70.3	11.2	124.1	20.5	29.7	30.8			
5.8-3	5.8	2.356	951.8	0.0	0.0	0.0		1.968	2.503	69.6	11.1	122.8	21.4	30.4	29.7			
AVG	5.8												21.0	30.0	30.2			
6.3-1	6.3	2.363	960.7	0.0	0.0	0.0		1.980	2.484	70.0	11.2	123.6	20.3	30.0	32.3			
6.3-2	6.3	2.318	931.7	0.0	0.0	0.0		1.958	2.484	ERR	ERR	122.2	21.2	ERR	ERR			
6.3-3	6.3	2.326	938.1	0.0	0.0	0.0		1.964	2.484	69.5	11.1	122.6	20.9	30.5	31.5			
AVG	6.3												20.8	ERR	ERR			
6.8-1	6.8	2.369	956.6	0.0	0.0	0.0		1.967	2.465	68.8	13.0	122.7	20.2	31.2	35.2			
6.8-2	6.8	2.356	950.7	0.0	0.0	0.0		1.965	2.465	68.8	13.0	122.6	20.3	31.2	35.1			
6.8-3	6.8	2.300	945.9	0.0	0.0	0.0		2.003	2.465	70.1	13.2	125.0	18.7	29.9	37.4			
AVG	6.8												19.7	30.8	35.9			
7.3-1	7.3	2.341	954.3	0.0	0.0	0.0		1.985	2.447	69.1	14.1	123.9	18.9	30.9	39.0			
7.3-2	7.3	2.357	948.7	0.0	0.0	0.0		1.960	2.447	68.2	13.9	122.3	19.9	31.8	37.4			
7.3-3	7.3	2.363	962.9	0.0	0.0	0.0		1.985	2.447	69.1	14.1	123.8	18.9	30.9	38.9			
AVG	7.3												19.2	31.2	38.4			

Computed by: Scott R. Todd | Checked by:

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

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

Table B7: Mix Design Data for Granite Gradation Number 7

Job Number:			Project: NCHRP 9-8						Blend Description: Granite Gradation #7 Percent passing #4: 25							Date:	
AC Sp. Gr. (Gb) = 1.029			Effective Sp. Gr. of Aggregate (Gse) = 2.689 Bulk Sp. Gr. of Agg. (Gsb) = 2.686						Unit wt. of CA in DRC (pcf): 101.0 Unit wt. of CA in DRC (kg/m3) 1617.9							M 08-15-94	
Specimen Number	Asphalt Content (%)	Average Thickness (inches)	Weights			Mix Vol	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)x1 / (Gsb)	Bx1 / (Gb)	(1x62.4)	100 (1-I/J)	(100-K)	100 (O-N) / O			
4.8-1	4.8		1138.0	669.5	1147.8	478.3	2.379	2.495	84.3	11.1	148.5	4.6	15.7	70.4	36.8	39.7	0.926
4.8-2	4.8		1142.1	668.2	1145.1	476.9	2.395	2.495	84.9	11.2	149.4	4.0	15.1	73.4	36.3	39.7	0.915
4.8-3	4.8		1156.0	675.6	1157.7	482.1	2.398	2.495	85.0	11.2	149.6	3.9	15.0	74.1	36.3	39.7	0.913
AVG	4.8											4.2	15.3	72.6	36.5	39.7	0.918
5.3-1	5.3		1154.1	673.2	1155.7	482.5	2.392	2.477	84.3	12.3	149.3	3.4	15.7	78.1	36.8	39.7	0.926
5.3-2	5.3		1152.2	670.0	1154.0	484.0	2.381	2.477	83.9	12.3	148.5	3.9	16.1	75.8	37.1	39.7	0.933
5.3-3	5.3		1149.9	668.2	1151.7	483.5	2.378	2.477	83.9	12.2	148.4	4.0	16.1	75.3	37.1	39.7	0.935
AVG	5.3											3.8	16.0	76.4	37.0	39.7	0.931
5.8-1	5.8		1149.4	668.1	1151.1	483.0	2.380	2.458	83.5	13.4	148.5	3.2	16.5	80.7	37.4	39.7	0.942
5.8-2	5.8		1141.9	663.7	1144.5	480.8	2.375	2.458	83.3	13.4	148.2	3.4	16.7	79.8	37.5	39.7	0.945
5.8-3	5.8		1153.0	668.2	1155.0	486.8	2.369	2.458	83.1	13.4	147.8	3.6	16.9	78.5	37.7	39.7	0.949
AVG	5.8											3.4	16.7	79.7	37.5	39.7	0.946
6.3-1	6.3		1157.1	671.7	1158.8	487.1	2.375	2.441	82.9	14.5	148.2	2.7	17.1	84.3	37.8	39.7	0.953
6.3-2	6.3		1158.6	668.8	1160.6	491.8	2.356	2.441	82.2	14.4	147.0	3.5	17.8	80.4	38.4	39.7	0.966
6.3-3	6.3		1142.7	660.0	1144.3	484.3	2.359	2.441	82.3	14.4	147.2	3.3	17.7	81.1	38.3	39.7	0.964
AVG	6.3											3.2	17.5	82.0	38.2	39.7	0.961
6.8-1	6.8		1163.1	672.2	1164.5	492.3	2.363	2.423	82.0	15.6	147.4	2.5	18.0	86.2	38.5	39.7	0.970
6.8-2	6.8		1145.1	666.3	1146.5	480.2	2.385	2.423	82.7	15.8	148.8	1.6	17.3	90.8	37.9	39.7	0.956
6.8-3	6.8		1162.8	675.6	1164.2	488.6	2.380	2.423	82.6	15.7	148.5	1.8	17.4	89.8	38.1	39.7	0.959
AVG	6.8											2.0	17.6	88.9	38.2	39.7	0.961
Computed by: Scott R. Todd					Checked by:												

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

Table B8: Mix Design Data for Granite Gradation Number 8

Job Number:			Project: NCHRP 9-8						Blend Description:		Granite Gradation #8		Percent passing #4:		25	Date:	
AC Sp. Gr. (Gb) = 1.029			Effective Sp. Gr. of Aggregate (Gse) = 2.690 Bulk Sp. Gr. of Agg. (Gsb) = 2.686										Unit wt. of CA in DRC (pcf): Unit wt. of CA in DRC (kg/m3)		101.0 1617.9	H 08-18-94	
Specimen Number	Asphalt Content (%)	Average Thickness (inches)	Weights			Mix Vol	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)x1 / (Gsb)	Bx1 / (Gb)	(1x62.4)	100 (1-I/J)	(100-K)	100 (O-N) / O			
5.0-1	5.0		1124.1	648.0	1126.5	478.5	2.349	2.489	83.1	11.4	146.6	5.6	16.9	66.8	37.7	39.7	0.949
5.0-2	5.0		1143.8	670.2	1146.3	476.1	2.402	2.489	85.0	11.7	149.9	3.5	15.0	76.9	36.3	39.7	0.914
5.0-3	5.0		1138.2	664.7	1140.1	475.4	2.394	2.489	84.7	11.6	149.4	3.8	15.3	75.1	36.5	39.7	0.919
AVG	5.0											4.3	15.8	72.9	36.8	39.7	0.927
5.5-1	5.5		1183.3	686.4	1186.7	500.3	2.365	2.471	83.2	12.6	147.6	4.3	16.8	74.5	37.6	39.7	0.947
5.5-2	5.5		1180.5	686.5	1183.1	496.6	2.377	2.471	83.6	12.7	148.3	3.8	16.4	78.8	37.3	39.7	0.939
5.5-3	5.5		1184.8	692.7	1187.7	495.0	2.394	2.471	84.2	12.8	149.4	3.1	15.8	80.1	36.8	39.7	0.928
AVG	5.5											3.7	16.3	77.1	37.2	39.7	0.938
6.1-1	6.1		1183.4	684.7	1185.4	500.7	2.363	2.449	82.6	14.0	147.5	3.5	17.4	79.9	38.0	39.7	0.958
6.1-2	6.1		1180.9	687.7	1182.7	495.0	2.386	2.449	83.4	14.1	148.9	2.6	16.6	84.4	37.4	39.7	0.943
6.1-3	6.1		1180.7	685.6	1183.3	497.7	2.372	2.449	82.9	14.1	148.0	3.1	17.1	81.7	37.8	39.7	0.952
AVG	6.1											3.1	17.0	82.0	37.8	39.7	0.951
6.8-1	6.8		1159.4	673.2	1160.4	487.2	2.380	2.424	82.6	15.7	148.5	1.8	17.4	89.5	38.1	39.7	0.959
6.8-2	6.8		1170.7	678.0	1171.5	493.5	2.372	2.424	82.3	15.7	148.0	2.1	17.7	87.9	38.3	39.7	0.964
6.8-3	6.8		1169.0	677.6	1170.2	492.6	2.373	2.424	82.3	15.7	148.1	2.1	17.7	88.1	38.2	39.7	0.963
AVG	6.8											2.0	17.6	88.5	38.2	39.7	0.962
7.3-1	7.3		1163.5	673.0	1164.8	491.8	2.366	2.406	81.6	16.8	147.6	1.7	18.4	90.9	38.8	39.7	0.976
7.3-2	7.3		1171.9	678.8	1172.9	494.1	2.372	2.406	81.9	16.8	148.0	1.4	18.1	92.2	38.6	39.7	0.972
7.3-3	7.3		1178.2	685.2	1179.5	494.3	2.384	2.406	82.3	16.9	148.7	0.9	17.7	94.7	38.3	39.7	0.965
AVG	7.3											1.3	18.1	92.6	38.6	39.7	0.971
Computed by: Scott R. Todd					Checked by:												

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

Table B9: Mix Design Data for Granite Gradation Number 9

Job Number:			Project: NCHRP 9-8						Blend Description:		Granite Gradation #9		Percent passing #4:		25		Date:
AC Sp. Gr. (Gb) = 1.029			Effective Sp. Gr. of Aggregate (Gse) = 2.701 Bulk Sp. Gr. of Agg. (Gsb) = 2.686									Unit wt. of CA in DRC (pcf): Unit wt. of CA in DRC (kg/m3)			101.0 1617.9		T 08-16-94
Specimen Number	Asphalt Content (%)	Average Thickness (inches)	Weights			Mix Vol	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)x1 / (Gsb)	Bx1 / (Gb)	(1x62.4)	100 (1-I/J)	(100-K)	100 (O-N) / O			
5.3-1	5.3		1169.1	680.7	1170.2	489.5	2.388	2.487	84.2	12.3	149.0	4.0	15.8	74.9	36.8	39.7	0.928
5.3-2	5.3		1151.2	669.1	1153.1	484.0	2.379	2.487	83.9	12.3	148.4	4.4	16.1	73.0	37.1	39.7	0.935
5.3-3	5.3		1167.0	676.5	1168.6	492.1	2.371	2.487	83.6	12.2	148.0	4.6	16.4	71.7	37.3	39.7	0.939
AVG	5.3											4.3	16.1	73.2	37.1	39.7	0.934
5.8-1	5.8		1169.2	679.5	1170.8	491.3	2.380	2.468	83.5	13.4	148.5	3.6	16.5	78.4	37.4	39.7	0.942
5.8-2	5.8		1156.6	671.4	1157.9	486.5	2.377	2.468	83.4	13.4	148.3	3.7	16.6	77.9	37.5	39.7	0.944
5.8-3	5.8		1163.6	676.3	1165.1	488.8	2.381	2.468	83.5	13.4	148.5	3.5	16.5	78.5	37.4	39.7	0.942
AVG	5.8											3.6	16.6	78.3	37.4	39.7	0.942
6.3-1	6.3		1165.8	678.9	1167.1	488.2	2.388	2.450	83.3	14.6	149.0	2.5	16.7	84.8	37.5	39.7	0.945
6.3-2	6.3		1168.0	678.9	1169.2	490.3	2.382	2.450	83.1	14.6	148.7	2.8	16.9	83.6	37.7	39.7	0.949
6.3-3	6.3		1168.9	679.7	1170.1	490.4	2.384	2.450	83.1	14.6	148.7	2.7	16.9	83.9	37.6	39.7	0.948
AVG	6.3											2.7	16.8	84.1	37.6	39.7	0.947
6.8-1	6.8		1180.3	684.0	1181.3	497.3	2.373	2.432	82.4	15.7	148.1	2.4	17.6	86.3	38.2	39.7	0.963
6.8-2	6.8		1171.3	680.6	1172.3	491.7	2.382	2.432	82.7	15.7	148.6	2.1	17.3	88.2	38.0	39.7	0.957
6.8-3	6.8		1173.7	680.8	1174.4	493.6	2.378	2.432	82.5	15.7	148.4	2.2	17.5	87.3	38.1	39.7	0.960
AVG	6.8											2.2	17.5	87.3	38.1	39.7	0.960
7.3-1	7.3		1161.5	673.6	1162.1	488.5	2.378	2.414	82.1	16.9	148.4	1.5	17.9	91.6	38.5	39.7	0.968
7.3-2	7.3		1167.5	676.0	1167.9	491.9	2.373	2.414	81.9	16.8	148.1	1.7	18.1	90.7	38.6	39.7	0.971
7.3-3	7.3		1172.8	678.9	1173.6	494.7	2.371	2.414	81.8	16.8	147.9	1.8	18.2	90.1	38.6	39.7	0.973
AVG	7.3											1.7	18.1	90.8	38.6	39.7	0.971
Computed by: Scott R. Todd					Checked by:												

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

Table B10: Mix Design Data for Granite Dense Gradation

Job Number:			Project: NCHRP 9-8						Blend Description:		Granite Dense Gradation		Percent passing #4:		40.5	Date:	
AC Sp. Gr. (Gb) = 1.029			Effective Sp. Gr. of Aggregate (Gse) = 2.694 Bulk Sp. Gr. of Agg. (Gsb) = 2.679										Unit wt. of CA in DRC (pcf): Unit wt. of CA in DRC (kg/m3)		0.0 0.0	W 09-14-94	
Specimen Number	Asphalt Content (%)	Average Thickness (inches)	Weights			Mix Vol	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)x1 / (Gsb)	Bx1 / (Gb)	(1x62.4)	100 (1-I/J)	(100-K)	100 (O-N) / O			
4.0-1	4.0		1181.0	692.2	1184.2	492.6	2.397	2.530	85.9	9.3	149.6	5.2	14.1	62.8	48.9	0.0	0.000
4.0-2	4.0		1187.3	693.7	1192.3	498.6	2.381	2.530	85.3	9.3	148.6	5.9	14.7	59.9	49.2	0.0	0.000
4.0-3	4.0		1219.3	718.1	1223.5	505.4	2.413	2.530	86.5	9.4	150.5	4.6	13.5	65.7	48.6	0.0	0.000
AVG	4.0											5.3	14.1	62.8	48.9	0.0	0.000
4.5-1	4.5		1189.2	699.7	1189.8	490.1	2.426	2.511	86.5	10.6	151.4	3.4	13.5	75.1	48.5	0.0	0.000
4.5-2	4.5		1200.4	705.0	1203.4	498.4	2.409	2.511	85.9	10.4	150.3	4.1	14.1	71.1	48.9	0.0	0.000
4.5-3	4.5		1192.4	699.0	1195.9	496.9	2.400	2.511	85.5	10.5	149.7	4.4	14.5	69.3	49.1	0.0	0.000
AVG	4.5											4.0	14.0	71.8	48.9	0.0	0.000
5.0-1	5.0		1197.5	705.0	1198.8	493.8	2.425	2.492	86.0	11.8	151.3	2.7	14.0	80.8	48.8	0.0	0.000
5.0-2	5.0		1197.6	705.7	1199.4	493.7	2.426	2.492	86.0	11.8	151.4	2.7	14.0	81.0	48.8	0.0	0.000
5.0-3	5.0		1208.1	712.8	1208.6	495.8	2.437	2.492	86.4	11.8	152.0	2.2	13.6	83.7	48.6	0.0	0.000
AVG	5.0											2.5	13.9	81.8	48.7	0.0	0.000
5.5-1	5.5		1201.8	709.1	1202.4	493.3	2.436	2.473	85.9	13.0	152.0	1.5	14.1	89.4	48.9	0.0	0.000
5.5-2	5.5		1201.8	710.1	1202.0	491.9	2.443	2.473	86.2	13.1	152.5	1.2	13.8	91.3	48.7	0.0	0.000
5.5-3	5.5		1201.8	711.1	1204.3	493.2	2.441	2.473	86.1	13.0	152.3	1.3	13.9	90.6	48.8	0.0	0.000
AVG	5.5											1.2	13.9	90.4	48.8	0.0	0.000
6.0-1	6.0		1208.5	711.8	1209.0	497.2	2.431	2.455	85.3	14.2	151.7	130	14.7	93.2	49.3	0.0	0.000
6.0-2	6.0		1211.5	713.7	1211.8	498.1	2.432	2.455	85.3	14.2	151.8	0.9	14.7	93.7	49.2	0.0	0.000
6.0-3	6.0		1211.9	715.2	1212.2	497.0	2.438	2.455	85.6	14.2	152.2	0.7	14.4	95.3	49.1	0.0	0.000
AVG	6.0											0.9	14.6	94.1	49.2	0.0	0.000
Computed by: Scott R. Todd					Checked by:												

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

Table B11: Mix Design Data for Florida Limestone Gradation Number 1

Job Number:			Project: NCHRP 9-8						Blend Description:	Limerock Gradation #1			Percent passing #4:		40	Date:	
AC Sp. Gr. (Gb) = 1.029			Effective Sp. Gr. of Aggregate (Gse) = 2.486 Bulk Sp. Gr. of Agg. (Gsb) = 2.412									Unit wt. of CA in DRC (pcf): Unit wt. of CA in DRC (kg/m3)			90.4 1448.1	T 08-23-94	
Specimen Number	Asphalt Content (%)	Average Thickness (inches)	Weights			Mix Vol	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)x1 / (Gsb)	Bx1 / (Gb)	(1x62.4)	100 (1-I/J)	(100-K)	100 (O-N) / O			
4.4-1	4.4		1153.6	643.8	1162.0	518.2	2.226	2.347	88.2	9.5	138.9	4.9	11.8	58.7	47.1	39.9	1.179
4.4-2	4.4		1175.1	655.3	1183.1	527.8	2.226	2.340	88.2	9.5	138.9	4.9	11.8	58.7	47.1	39.9	1.179
4.4-3	4.4		1166.7	649.2	1173.3	524.1	2.226	2.340	88.2	9.5	138.9	4.9	11.8	58.6	47.1	39.9	1.179
AVG	4.4											4.9	11.8	58.7	47.1	39.9	1.179
4.8-1	4.8		1134.7	633.5	1138.9	505.4	2.245	2.328	88.6	10.5	140.1	3.6	11.4	68.7	46.8	39.9	1.174
4.8-2	4.8		1142.6	638.1	1148.9	510.8	2.237	2.328	88.3	10.4	139.6	3.9	11.7	66.6	47.0	39.9	1.179
4.8-3	4.8		1148.4	639.3	1152.5	513.2	2.238	2.328	88.3	10.4	139.6	3.9	11.7	66.8	47.0	39.9	1.178
AVG	4.8											3.8	11.6	67.4	47.0	39.9	1.177
5.3-1	5.3		1160.6	655.9	1163.0	507.1	2.289	2.312	89.9	11.8	142.8	1.0	10.1	90.1	46.1	39.9	1.155
5.3-2	5.3		1159.0	652.2	1161.6	509.4	2.275	2.312	89.3	11.7	142.0	1.6	10.7	85.1	46.4	39.9	1.163
5.3-3	5.3		1163.1	654.8	1165.2	510.4	2.279	2.312	89.5	11.7	142.2	1.4	10.5	86.4	46.3	39.9	1.161
AVG	5.3											1.3	10.4	87.2	46.3	39.9	1.159
5.8-1	5.8		1161.9	653.5	1163.8	510.3	2.277	2.297	88.9	12.8	142.1	0.9	11.1	92.1	46.6	39.9	1.169
5.8-2	5.8		1161.7	653.6	1163.2	509.6	2.280	2.297	89.0	12.8	142.2	0.8	11.0	93.1	46.6	39.9	1.167
5.8-3	5.8		1160.9	652.7	1162.4	509.7	2.278	2.297	89.0	12.8	142.1	0.8	11.0	92.4	46.6	39.9	1.169
AVG	5.8											0.8	11.0	92.5	46.6	39.9	1.168
6.3-1	6.3		1166.5	651.8	1167.8	516.0	2.261	2.282	87.8	13.8	141.1	0.9	12.2	92.3	47.3	39.9	1.186
6.3-2	6.3		1162.0	651.3	1163.2	511.9	2.270	2.282	88.2	13.9	141.6	0.5	11.8	95.5	47.1	39.9	1.180
6.3-3	6.3		1167.7	651.6	1169.0	517.4	2.257	2.282	87.7	13.8	140.8	1.1	12.3	91.1	47.4	39.9	1.188
AVG	6.3											0.9	12.1	93.0	47.3	39.9	1.184
Computed by: Scott R. Todd					Checked by												

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

Table B12: Mix Design Data for Florida Limestone Gradation Number 2

Job Number:	Project: NCHRP 9-8	Blend Description: Limerock Gradation #2 Percent passing #4: 30	Date:
AC Sp. Gr. (Gb) = 1.029	Effective Sp. Gr. of Aggregate (Gse) = 2.497 Bulk Sp. Gr. of Agg. (Gsb) = 2.424	Unit wt. of CA in DRC (pcf): 90.4 Unit wt. of CA in DRC (kg/m3) 1448.1	W 08-24-94

Specimen Number	Asphalt Content (%)	Average Thickness (inches)	Weights			Mix Vol	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)x1 / (Gsb)	Bx1 / (Gb)	(1x62.4)	100 (1-I/J)	(100-K)	100 (O-N) / O			
4.5-1	4.5		1152.3	643.5	1159.8	516.3	2.232	2.346	87.9	9.8	139.3	4.9	12.1	59.7	38.4	40.2	0.956
4.5-2	4.5		1156.9	646.4	1166.3	519.9	2.225	2.346	87.7	9.7	138.9	5.1	12.3	58.3	38.6	40.2	0.961
4.5-3	4.5		1148.1	642.1	1156.2	514.1	2.233	2.346	88.0	9.8	139.4	4.8	12.0	60.0	38.4	40.2	0.955
AVG	4.5											4.9	12.1	59.3	38.5	40.2	0.958
5.0-1	5.0		1156.7	647.8	1161.5	513.7	2.252	2.331	88.2	10.9	140.5	3.4	11.8	71.1	38.2	40.2	0.951
5.0-2	5.0		1157.7	649.9	1162.1	512.2	2.260	2.331	88.6	11.0	141.0	3.0	11.4	73.4	38.0	40.2	0.945
5.0-3	5.0		1152.3	641.8	1157.4	515.6	2.235	2.331	88.6	10.9	139.5	4.1	12.4	66.8	38.7	40.2	0.962
AVG	5.0											3.5	11.9	70.4	38.3	40.2	0.953
5.5-1	5.5		1162.5	648.3	1167.5	519.2	2.239	2.315	87.3	12.0	139.7	3.3	12.7	74.2	38.9	40.2	0.968
5.5-2	5.5		1171.8	656.0	1174.9	518.9	2.258	2.315	88.0	12.1	140.9	2.5	12.0	79.5	38.4	40.2	0.955
5.5-3	5.5		1158.9	646.9	1162.7	515.8	2.247	2.315	87.6	12.0	140.2	2.9	12.4	76.3	38.7	40.2	0.962
AVG	5.5											2.9	12.4	76.6	38.7	40.2	0.961
6.0-1	6.0		1163.4	646.8	1165.9	519.1	2.241	2.300	86.9	13.1	139.9	2.6	13.1	80.5	39.2	40.2	0.974
6.0-2	6.0		1165.2	650.5	1168.2	517.7	2.251	2.300	87.3	13.1	140.4	2.1	12.7	83.2	38.9	40.2	0.968
6.0-3	6.0		1171.2	656.0	1174.7	518.7	2.258	2.300	87.6	13.2	140.9	1.8	12.4	85.3	38.7	40.2	0.963
AVG	6.0											2.2	12.7	83.0	38.9	40.2	0.968
6.5-1	6.5		1181.7	657.9	1184.4	526.5	2.244	2.285	86.6	14.2	140.1	1.8	13.4	86.8	39.4	40.2	0.980
6.5-2	6.5		1170.3	649.2	1169.9	520.7	2.248	2.285	86.7	14.2	140.2	1.6	13.3	87.7	39.3	40.2	0.978
6.5-3	6.5		1167.1	652.0	1172.9	520.9	2.241	2.285	86.4	14.2	139.8	1.9	13.6	85.7	39.5	40.2	0.983
AVG	6.5											1.8	13.4	86.7	39.4	40.2	0.980

Computed by: Scott R. Todd   Checked b

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

Table B13: Mix Design Data for Florida Limestone Gradation Number 3

Job Number:	Project: NCHRP 9-8	Blend Description: Limerock Gradation #3	Percent passing #4: 25	Date:
AC Sp. Gr. (Gb) = 1.029	Effective Sp. Gr. of Aggregate (Gse) = 2.500 Bulk Sp. Gr. of Agg. (Gsb) = 2.413		Unit wt. of CA in DRC (pcf): 90.4 Unit wt. of CA in DRC (kg/m3) 1448.1	F 08-26-94

Specimen Number	Asphalt Content (%)	Average Thickness (inches)	Weights			Mix Vol	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)x1 / (Gsb)	Bx1 / (Gb)	(1x62.4)	100 (1-I/J)	(100-K)	100 (O-N) / O			
5.7-1	5.7		1200.5	656.9	1206.1	549.2	2.186	2.312	85.4	12.1	136.4	5.5	14.6	62.6	35.9	39.9	0.900
5.7-2	5.7		1220.4	664.4	1227.9	563.5	2.166	2.312	84.6	12.0	135.1	6.3	15.4	58.8	36.5	39.9	0.915
5.7-3	5.7		1211.1	658.3	1217.5	559.2	2.166	2.312	84.6	12.0	135.1	6.3	15.4	58.8	36.5	39.9	0.915
AVG	5.7											6.0	15.1	60.1	36.3	39.9	0.910
6.2-1	6.2		1165.9	640.7	1170.2	529.5	2.202	2.289	85.6	13.3	137.4	3.8	14.4	73.6	35.8	39.9	0.897
6.2-2	6.2		1165.4	642.0	1170.7	528.7	2.204	2.289	85.7	13.3	137.5	3.7	14.3	74.1	35.7	39.9	0.895
6.2-3	6.2		1161.9	639.9	1167.2	527.3	2.203	2.289	85.7	13.3	137.5	3.7	14.3	74.0	35.8	39.9	0.896
AVG	6.2											3.7	14.4	73.9	35.8	39.9	0.896
6.7-1	6.7		1205.7	660.6	1210.9	550.3	2.191	2.218	84.7	14.3	136.7	4.0	15.3	73.9	36.5	39.9	0.913
6.7-2	6.7		1222.3	667.5	1226.9	559.4	2.185	2.282	84.5	14.2	136.3	4.2	15.5	72.6	36.6	39.9	0.918
6.7-3	6.7		1202.4	660.1	1208.5	548.4	2.193	2.282	84.8	14.3	136.8	3.9	15.2	74.3	36.4	39.9	0.912
AVG	6.7											4.1	15.3	73.6	36.5	39.9	0.914
7.2-1	7.2		1168.1	641.7	1173.5	531.8	2.197	2.267	84.5	15.4	137.1	3.1	15.5	80.0	36.6	39.9	0.918
7.2-2	7.2		1167.8	639.3	1171.6	532.3	2.194	2.267	84.4	15.4	136.9	3.2	15.6	79.4	36.7	39.9	0.920
7.2-3	7.2		1169.9	640.4	1173.0	532.6	2.197	2.267	84.5	15.4	137.1	3.1	15.5	80.0	36.6	39.9	0.918
AVG	7.2											3.1	15.6	79.8	36.7	39.9	0.918
7.7-1	7.7		1158.9	633.1	1162.1	529.0	2.191	2.252	83.8	16.4	136.7	2.7	16.2	83.2	37.2	39.9	0.930
7.7-2	7.7		1154.6	632.5	1158.5	526.0	2.195	2.252	84.0	16.4	137.0	2.5	16.0	84.2	37.0	39.9	0.927
7.7-3	7.7		1168.8	639.7	1171.7	532.0	2.197	2.252	84.0	16.4	137.1	2.4	16.0	84.7	37.0	39.9	0.926
AVG	7.7											2.6	16.1	84.0	37.1	39.9	0.928

Computed by: Scott R. Todd Checked

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

Table B14: Mix Design Data for Florida Limestone Gradation Number 4

Job Number:	Project: NCHRP 9-8	Blend Description: Limerock Gradation #4	Percent passing #4: 20	Date:
AC Sp. Gr. (Gb) = 1.029	Effective Sp. Gr. of Aggregate (Gse) = 2.495 Bulk Sp. Gr. of Agg. (Gsb) = 2.414		Unit wt. of CA in DRC (pcf): 90.4 Unit wt. of CA in DRC (kg/m3) 1448.1	M 08-29-94

Specimen Number	Asphalt Content (%)	Average Thickness (inches)	Weights			Mix Vol	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/V CA 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)x1 / (Gsb)	Bx1 / (Gb)	(1x62.4)	100 (1-I/J)	(100-K)	100 (O-N) / O			
7.0-1	7.0		1160.0	629.0	1166.4	537.4	2.159	2.269	83.2	14.7	134.7	4.9	16.8	71.1	33.5	40.0	0.838
7.0-2	7.0		1151.7	627.3	1156.7	529.4	2.175	2.269	83.8	14.8	135.8	4.1	16.2	74.5	33.0	40.0	0.825
7.0-3	7.0		1157.8	626.4	1163.6	537.2	2.155	2.269	83.0	14.7	134.5	5.0	17.0	70.5	33.6	40.0	0.840
AVG	7.0											4.7	16.7	72.0	33.3	40.0	0.834
7.5-1	7.5		1171.1	634.8	1174.7	539.9	2.169	2.254	83.1	15.8	135.4	3.8	16.9	77.7	33.5	40.0	0.839
7.5-2	7.5		1171.8	635.3	1175.4	540.1	2.170	2.254	83.1	15.8	135.4	3.7	16.9	77.8	33.5	40.0	0.838
7.5-3	7.5		1167.7	634.2	1171.1	536.9	2.175	2.254	83.3	15.9	135.7	3.5	16.7	78.9	33.3	40.0	0.834
AVG	7.5											3.7	16.8	78.1	33.4	40.0	0.837
8.0-1	8.0		1157.0	626.7	1161.9	535.2	2.162	2.240	82.4	16.8	134.9	3.5	17.6	80.2	34.1	40.0	0.853
8.0-2	8.0		1161.7	627.4	1165.7	538.3	2.158	2.240	82.2	16.8	134.7	3.7	17.8	79.4	34.2	40.0	0.856
8.0-3	8.0		1173.8	633.0	1179.0	546.0	2.150	2.240	81.9	16.7	134.1	4.0	18.1	77.7	34.5	40.0	0.862
AVG	8.0											3.7	17.8	79.1	34.2	40.0	0.857
8.5-1	8.5		1184.4	645.4	1187.5	542.1	2.185	2.225	82.8	18.0	136.3	1.8	17.2	89.5	33.7	40.0	0.845
8.5-2	8.5		1176.3	634.4	1179.4	545.0	2.158	2.225	81.8	17.8	134.7	3.0	18.2	83.5	34.6	40.0	0.865
8.5-3	8.5		1209.6	654.0	1213.7	559.7	2.161	2.225	81.9	17.9	134.9	2.9	18.1	84.1	34.5	40.0	0.863
AVG	8.5											2.6	17.8	85.7	34.3	40.0	0.857
9.0-1	9.0		1157.2	622.1	1160.8	538.7	2.148	2.211	81.0	18.8	134.0	2.8	19.0	85.1	35.2	40.0	0.881
9.0-2	9.0		1155.7	622.3	1157.7	535.4	2.159	2.211	81.4	18.9	134.7	2.4	18.6	87.3	34.9	40.0	0.874
9.0-3	9.0		1142.6	614.5	1145.3	530.8	2.153	2.211	81.1	18.8	134.3	2.6	18.9	86.0	35.1	40.0	0.878
AVG	9.0											2.6	18.8	86.1	35.1	40.0	0.878

Computed by: Scott R. Todd Checked

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

Table B15: Mix Design Data for Florida Limestone Gradation Number 5

Job Number:			Project: NCHRP 9-8							Blend Description: Limerock Gradation #5							Date:	
AC Sp. Gr. (Gb) = 1.029			Effective Sp. Gr. of Aggregate (Gse) = 2.416 Bulk Sp. Gr. of Agg. (Gsb) = 2.417														W 08-24-94	
Specimen Number	Asphalt Content (%)	Average Thickness (inches)	Weights			Mix Volumes		Specific Gravities		Volumes			Voids					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Volume Correlation Ratio	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	Measured (lb)	Correc-ted (lb)	Flow (.01 lb)
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)		D / (F-E)		(100-B)x1 / (Gsb)	Bx1 / (Gb)	(1x62.4)	100 (1-I/J)	(100-K)	100 (O-N) / O			
3.5-1	3.5	2.665	1036.2	0.0	0.0	0.0		1.894	2.307	75.6	6.4	118.2	17.9	24.4	26.6			
3.5-2	3.5	2.638	1031.2	0.0	0.0	0.0		1.904	2.307	76.0	6.5	118.8	17.5	24.0	27.1			
3.5-3	3.5	2.812	1033.2	0.0	0.0	0.0		1.790	2.307	71.4	6.1	111.7	22.4	28.6	21.4			
AVG	3.5												19.3	25.6	25.0			
4.0-1	4.0	2.704	1038.3	0.0	0.0	0.0		1.870	2.446	74.3	7.3	116.7	23.5	25.7	8.5			
4.0-2	4.0	2.625	1028.5	0.0	0.0	0.0		1.908	2.446	75.8	7.4	119.1	22.0	24.2	9.2			
4.0-3	4.0	2.662	1031.7	0.0	0.0	0.0		1.888	2.446	75.0	7.3	117.8	22.8	25.0	8.8			
4VG	4.0												22.8	25.0	8.8			
4.5-1	4.5	2.787	1045.6	0.0	0.0	0.0		1.827	2.428	72.6	7.1	114.0	24.7	27.4	9.8			
4.5-2	4.5	2.710	1027.0	0.0	0.0	0.0		1.846	2.428	73.3	7.2	115.2	24.0	26.7	10.1			
4.5-3	4.5	2.688	1035.5	0.0	0.0	0.0		1.876	2.428	74.5	7.3	117.1	22.7	25.5	10.8			
AVG	4.5												23.8	26.5	10.2			
5.0-1	5.0	2.678	1041.5	0.0	0.0	0.0		1.894	2.410	74.4	9.2	118.2	21.4	25.6	16.2			
5.0-2	5.0	2.696	1032.8	0.0	0.0	0.0		1.866	2.410	73.3	9.1	116.4	22.6	26.7	15.3			
5.0-3	5.0	3.298	1142.0	0.0	0.0	0.0		1.686	2.410	66.3	8.2	105.2	30.0	33.7	10.9			
AVG	5.0												24.7	28.6	14.2			
5.5-1	5.5	2.695	1024.5	0.0	0.0	0.0		1.851	2.393	72.4	9.9	115.5	22.6	27.6	18.0			
5.5-2	5.5	2.602	1034.0	0.0	0.0	0.0		1.935	2.393	75.7	10.3	120.8	19.1	24.3	21.4			
5.5-3	5.5	2.695	1053.6	0.0	0.0	0.0		1.904	2.393	74.4	10.2	118.8	20.4	25.6	20.0			
AVG	5.5												20.7	25.8	19.8			
Computed by: Scott R. Todd						Checked by:												

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

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

Table B16: Mix Design Data for Florida Limestone Gradation Number 6

Job Number:			Project: NCHRP 9-8							Blend Description: Limerock Gradation #6								Date:
AC Sp. Gr. (Gb) = 1.029			Effective Sp. Gr. of Aggregate (Gse) = 2.373 Bulk Sp. Gr. of Agg. (Gsb) = 2.373															W 08-24-94
Specimen Number	Asphalt Content (%)	Average Thickness (inches)	Weights			Mix Volumes		Specific Gravities		Volumes			Voids					
			In Air (gm)	In Water (gm)	SSD (gm)	Volume (cc)	Volume Correlation Ratio	Bulk (Gmb)	TMD (Gmm)	Aggregate Volume (cc)	AC by Volume (%)	Unit Weight (pcf)	Total (%)	VMA (%)	Filled (%)	Measured (lb)	Correc-ted (lb)	Flow (.01 lb)
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
						(F-E)		D / (F-E)		(100-B)x1 / (Gsb)	Bx1 / (Gb)	(1x62.4)	100 (1-I/J)	(100-K)	100 (O-N) O			
3.5-1	3.5	2.556	929.6	0.0	0.0	0.0		1.771	2.268	72.0	6.0	110.5	21.9	28.0	21.7			
3.5-2	3.5	2.543	934.0	0.0	0.0	0.0		1.789	2.268	72.7	6.1	111.6	21.1	27.3	22.5			
3.5-3	3.5	2.538	933.9	0.0	0.0	0.0		1.792	2.268	72.9	6.1	111.8	21.0	27.1	22.6			
AVG	3.5												21.3	27.4	22.3			
4.0-1	4.0	2.567	932.9	0.0	0.0	0.0		1.770	2.254	71.6	6.9	110.4	21.5	28.4	24.4			
4.0-2	4.0	2.547	929.0	0.0	0.0	0.0		1.776	2.254	71.9	6.9	110.8	21.2	28.1	24.7			
4.0-3	4.0	2.568	940.7	0.0	0.0	0.0		1.784	2.254	72.2	6.9	111.3	20.8	27.8	25.1			
4VG	4.0												21.2	28.1	24.7			
4.5-1	4.5	2.655	923.9	0.0	0.0	0.0		1.695	2.240	68.6	6.6	105.8	24.3	31.4	22.6			
4.5-2	4.5	2.566	939.9	0.0	0.0	0.0		1.784	2.240	72.2	6.9	111.3	20.4	27.8	26.8			
4.5-3	4.5	2.614	940.0	0.0	0.0	0.0		1.751	2.240	70.9	6.8	109.3	21.8	29.1	25.2			
AVG	4.5												22.2	29.5	24.9			
5.0-1	5.0	2.541	932.1	0.0	0.0	0.0		1.787	2.227	71.5	8.7	111.5	19.8	28.5	30.6			
5.0-2	5.0	2.585	938.6	0.0	0.0	0.0		1.768	2.227	70.8	8.6	110.3	20.6	29.2	29.5			
5.0-3	5.0	3.636	939.8	0.0	0.0	0.0		1.736	2.227	69.5	8.4	108.4	22.0	30.5	27.7			
AVG	5.0												20.8	29.4	29.3			
5.5-1	5.5	2.581	945.8	0.0	0.0	0.0		1.785	2.213	71.1	9.5	111.4	19.4	28.9	33.1			
5.5-2	5.5	2.544	957.3	0.0	0.0	0.0		1.833	2.213	73.0	9.8	114.4	17.2	27.0	36.4			
5.5-3	5.5	2.545	939.2	0.0	0.0	0.0		1.797	2.213	71.6	9.6	112.2	18.8	28.4	33.9			
AVG	5.5												18.4	28.1	34.5			
Computed by: Scott R. Todd						Checked by:												

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

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

Table B17: Mix Design Data for Florida Limestone Gradation Number 7

Job Number:	Project: NCHRP 9-8	Blend Description: Limerock Gradation #7	Percent passing #4: 25	Date:
AC Sp. Gr. (Gb) = 1.029	Effective Sp. Gr. of Aggregate (Gse) = 2.488 Bulk Sp. Gr. of Agg. (Gsb) = 2.413		Unit wt. of CA in DRC (pcf): 90.4 Unit wt. of CA in DRC (kg/m3) 1448.1	F 08-26-94

Specimen Number	Asphalt Content (%)	Average Thickness (inches)	Weights: In Air (gm)	Weights: In Water (gm)	Weights: SSD (gm)	Mix Vol: Volume (cc)	Specific Gravities: Bulk (Gmb)	Specific Gravities: TMD (Gmm)	Volumes: Aggregate Volume (cc)	Volumes: AC by Volume (%)	Unit Weight (pcf)	Voids: Total (%)	Voids: VMA (%)	Voids: Filled (%)	Voids: VCA (%)	Voids: VCA drc (%)	Voids: 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)x1 / (Gsb)	Bx1 / (Gb)	(1x62.4)	100 (1-I/J)	(100-K)	100 (O-N) / O			
5.5-1	5.5		1150.3	637.8	1157.4	519.6	2.214	2.308	86.7	11.8	138.1	4.1	13.3	69.3	35.0	39.9	0.876
5.5-2	5.5		1165.5	646.6	1171.4	524.8	2.221	2.308	87.0	11.9	138.6	3.8	13.0	71.0	34.8	39.9	0.871
5.5-3	5.5		1136.7	628.4	1141.2	512.8	2.217	2.308	86.8	11.8	138.3	4.0	13.2	70.0	34.9	39.9	0.874
AVG	5.5											3.9	13.2	70.1	34.9	39.9	0.874
6.0-1	6.0		1176.9	652.1	1182.8	530.7	2.218	2.293	86.4	12.9	138.4	3.3	13.6	75.9	35.2	39.9	0.882
6.0-2	6.0		1172.5	646.1	1177.6	531.4	2.206	2.293	86.0	12.9	137.7	3.8	14.0	73.1	35.5	39.9	0.890
6.0-3	6.0		1165.5	643.8	1171.3	527.5	2.209	2.293	86.1	12.9	137.9	3.6	13.9	73.8	35.4	39.9	0.888
AVG	6.0											3.6	13.9	74.3	35.4	39.9	0.886
6.5-1	6.5		1163.6	639.9	1168.2	528.3	2.203	2.278	85.3	13.9	137.4	3.3	14.7	77.4	36.0	39.9	0.901
6.5-2	6.5		1165.7	642.7	1170.9	528.2	2.207	2.278	85.5	13.9	137.7	3.1	14.5	78.5	35.9	39.9	0.898
6.5-3	6.5		1173.3	644.7	1177.1	532.4	2.204	2.278	85.4	13.9	137.5	3.3	14.6	77.7	36.0	39.9	0.900
AVG	6.5											3.2	14.6	77.9	35.9	39.9	0.900
7.0-1	7.0		1140.6	624.9	1145.3	520.4	2.192	2.263	84.5	14.9	136.8	3.1	15.5	79.7	36.6	39.9	0.918
7.0-2	7.0		1158.6	638.3	1163.2	524.9	2.207	2.263	85.1	15.0	137.7	2.5	14.9	83.5	36.4	39.9	0.907
7.0-3	7.0		1176.7	645.2	1180.2	535.0	2.199	2.263	84.8	15.0	137.2	2.8	15.2	81.6	36.4	39.9	0.912
AVG	7.0											2.8	15.2	81.6	36.4	39.9	0.912
7.5-1	7.5		1181.4	649.7	1185.4	535.7	2.205	2.248	84.5	16.1	137.6	1.9	15.5	87.7	36.6	39.9	0.917
7.5-2	7.5		1178.7	646.6	1181.6	535.0	2.203	2.248	84.5	16.1	137.5	2.0	15.5	87.2	36.7	39.9	0.918
7.5-3	7.5		1170.4	640.6	1173.9	533.3	2.195	2.248	84.1	16.0	136.9	2.4	15.9	85.0	36.9	39.9	0.924
AVG	7.5											2.1	15.6	86.6	36.7	39.9	0.920

Computed by: Scott R. Todd Checked

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

Table B18: Mix Design Data for Florida Limestone Gradation Number 8

Job Number:	Project: NCHRP 9-8	Blend Description: Limerock Gradation #8	Percent passing #4: 25	Date:
AC Sp. Gr. (Gb) = 1.029	Effective Sp. Gr. of Aggregate (Gse) = 2.494 Bulk Sp. Gr. of Agg. (Gsb) = 2.413		Unit wt. of CA in DRC (pcf): 90.4 Unit wt. of CA in DRC (kg/m3) 1448.1	F 08-26-94

Specimen Number	Asphalt Content (%)	Average Thickness (inches)	Weights			Mix Vol	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)x1/(Gsb)	Bx1/(Gb)	(1x62.4)	100(1-I/J)	(100-K)	100 (O-N)/O			
5.5-1	5.5		1174.0	647.8	1179.6	531.8	2.208	2.313	86.5	11.8	137.8	4.6	13.5	66.4	35.2	39.9	0.881
5.5-2	5.5		1173.3	647.6	1181.3	533.7	2.198	2.313	86.1	11.8	137.2	5.0	13.9	64.4	35.4	39.9	0.887
5.5-3	5.5		1166.9	640.4	1172.4	532.0	2.193	2.313	85.9	11.7	136.9	5.2	14.1	63.3	35.6	39.9	0.891
AVG	5.5											4.9	13.8	64.7	35.4	39.9	0.886
6.0-1	6.0		1168.7	642.0	1174.9	532.9	2.193	2.298	85.4	12.8	136.8	4.6	14.6	68.7	35.9	39.9	0.900
6.0-2	6.0		1169.7	645.6	1175.2	529.6	2.209	2.298	86.0	12.9	137.8	3.9	14.0	72.1	35.5	39.9	0.888
6.0-3	6.0		1172.3	647.8	1177.0	529.2	2.215	2.298	86.3	12.9	138.2	3.6	13.7	73.7	35.3	39.9	0.884
AVG	6.0											4.0	14.1	71.5	35.6	39.9	0.891
6.5-1	6.5		1169.0	646.4	1174.3	527.9	2.214	2.283	85.8	14.0	138.2	3.0	14.2	78.8	35.6	39.9	0.893
6.5-2	6.5		1183.1	650.1	1187.3	537.2	2.202	2.283	85.3	13.9	137.4	3.5	14.7	75.9	36.0	39.9	0.902
6.5-3	6.5		1186.3	649.8	1189.2	539.4	2.199	2.283	85.2	13.9	137.2	3.7	14.8	75.2	36.1	39.9	0.904
AVG	6.5											3.4	14.5	76.6	35.9	39.9	0.899
7.0-1	7.0		1173.7	648.0	1176.4	528.4	2.221	2.268	85.6	15.1	138.6	2.1	14.4	85.7	35.8	39.9	0.896
7.0-2	7.0		1170.6	645.7	1173.3	527.6	2.219	2.268	85.5	15.1	138.4	2.2	14.5	85.0	35.9	39.9	0.898
7.0-3	7.0		1162.1	639.8	1165.1	525.3	2.212	2.268	85.3	15.0	138.0	2.5	14.7	83.3	36.1	39.9	0.903
AVG	7.0											2.2	14.5	84.7	35.9	39.9	0.899
7.5-1	7.5		1167.6	642.3	1170.4	528.1	2.211	2.253	84.8	16.1	138.0	1.9	15.2	87.8	36.4	39.9	0.912
7.5-2	7.5		1167.6	642.1	1170.2	528.1	2.211	2.253	84.8	16.1	138.0	1.9	15.2	87.8	36.4	39.9	0.912
7.5-3	7.5		1188.9	654.4	1190.9	536.5	2.216	2.253	84.9	16.2	138.3	1.6	15.1	89.1	36.3	39.9	0.909
AVG	7.5											1.8	15.2	88.2	36.4	39.9	0.911

Computed by: Scott R. Todd   Checked by:

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

Table B19: Mix Design Data for Florida Limestone Gradation Number 9

Job Number:			Project: NCHRP 9-8						Blend Description:	Limerock Gradation #9		Percent passing #4:		25				Date:
AC Sp. Gr. (Gb) = 1.029			Effective Sp. Gr. of Aggregate (Gse) = 2.443 Bulk Sp. Gr. of Agg. (Gsb) = 2.413									Unit wt. of CA in DRC (pcf): Unit wt. of CA in DRC (kg/m3)		90.4 1448.1				F 08-26-94
Specimen Number	Asphalt Content (%)	Average Thickness (inches)	Weights			Mix Vol	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)x1 / (Gsb)	Bx1 / (Gb)	(1x62.4)	100 (1-I/J)	(100-K)	100 (O-N) / O				
6.0-1	6.0		1140.2	622.5	1143.1	520.6	2.190	2.257	85.3	12.8	136.7	3.0	14.7	79.8	36.0	39.9	0.902	
6.0-2	6.0		1145.7	620.7	1151.9	531.2	2.157	2.257	84.0	12.6	134.6	4.4	16.0	72.2	37.0	39.9	0.926	
6.0-3	6.0		1159.8	627.2	1167.4	540.2	2.147	2.257	83.6	12.5	134.0	4.9	16.4	70.2	37.3	39.9	0.933	
AVG	6.0											4.1	15.7	74.1	36.8	39.9	0.921	
6.7-1	6.7		1167.9	639.3	1180.4	541.1	2.158	2.237	83.5	14.1	134.7	3.5	16.5	78.8	37.4	39.9	0.937	
6.7-2	6.7		1165.3	629.9	1171.1	541.2	2.153	2.237	83.3	14.0	134.4	3.7	16.7	77.6	37.6	39.9	0.941	
6.7-3	6.7		1173.5	636.3	1183.0	546.7	2.147	2.237	83.0	14.0	133.9	4.0	17.0	76.2	37.8	39.9	0.946	
AVG	6.7											3.8	16.8	77.5	37.6	39.9	0.941	
7.0-1	7.0		1172.7	634.9	1177.5	542.6	2.161	2.228	83.3	14.7	134.9	3.0	16.7	82.1	37.5	39.9	0.940	
7.0-2	7.0		1161.8	629.7	1167.7	538.0	2.159	2.228	83.2	14.7	134.8	3.1	16.8	81.7	37.6	39.9	0.941	
7.0-3	7.0		1142.0	620.0	1146.4	526.4	2.169	2.228	83.6	14.8	135.4	2.6	16.4	84.0	37.3	39.9	0.934	
AVG	7.0											2.9	16.6	82.6	37.5	39.9	0.938	
7.5-1	7.5		1139.7	617.9	1143.4	525.5	2.169	2.215	83.1	15.8	135.3	2.1	16.9	87.6	37.6	39.9	0.943	
7.5-2	7.5		1155.2	625.0	1159.2	534.2	2.162	2.215	82.9	15.8	134.9	2.4	17.1	86.1	37.8	39.9	0.947	
7.5-3	7.5		1166.5	628.1	1170.6	542.5	2.150	2.215	82.4	15.7	134.2	2.9	17.6	83.4	38.2	39.9	0.956	
AVG	7.5											2.5	17.2	85.7	37.9	39.9	0.949	
8.2-1	8.2		1176.0	638.9	1179.6	540.7	2.175	2.195	82.7	17.3	135.7	0.9	17.3	94.7	37.9	39.9	0.950	
8.2-2	8.2		1155.2	628.3	1157.7	529.4	2.182	2.195	83.0	17.4	136.2	0.6	17.0	96.5	37.7	39.9	0.945	
8.2-3	8.2		1182.3	640.7	1185.6	544.9	2.170	2.195	82.5	17.3	135.4	1.2	17.5	93.4	38.1	39.9	0.954	
AVG	8.2											0.9	17.2	94.9	37.9	39.9	0.950	

Computed by: Scott R. Todd   Checked by:

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

Table B20: Mix Design Data for Florida Limestone Dense Gradation

Job Number:			Project: NCHRP 9-8						Blend Description:		Limerock Dense Gradation		Percent passing #4:	49		Date:	
AC Sp. Gr. (Gb) = 1.029			Effective Sp. Gr. of Aggregate (Gse) = 2.480 Bulk Sp. Gr. of Agg. (Gsb) = 2.393													W 09-07-94	
Specimen Number	Asphalt Content (%)	Average Thickness (inches)	Weights			Mix Vol	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)x1 / (Gsb)	Bx1 / (Gb)	(1x62.4)	100 (1-I/J)	(100-K)	100 (O-N) / O			
5.0-1	5.0		1208.1	663.2	1211.8	548.6	2.202	2.317	87.4	10.7	137.4	5.0	12.6	60.6	55.4		
5.0-2	5.0		1197.8	657.5	1201.7	544.2	2.201	2.317	87.4	10.7	137.3	5.0	12.6	60.3	55.4		
5.0-3	5.0		1201.0	661.2	1206.5	545.3	2.202	2.317	87.4	10.7	137.4	4.9	12.6	60.7	55.4		
AVG	5.0											5.0	12.6	60.5	55.4	ERR	ERR
5.7-1	5.7		1200.2	661.5	1204.3	542.8	2.211	2.301	87.3	11.8	138.0	3.9	12.7	69.2	55.5		
5.7-2	5.7		1203.3	662.6	1207.4	544.8	2.209	2.301	87.2	11.8	137.8	4.0	12.8	68.6	55.5		
5.7-3	5.7		1199.8	659.2	1202.8	543.6	2.207	2.301	87.2	11.8	137.7	4.1	12.8	68.2	55.5		
AVG	5.7											4.0	12.8	68.7	55.5	ERR	ERR
6.0-1	6.0		1202.8	667.0	1204.2	537.2	2.239	2.286	88.0	13.1	139.7	2.1	12.0	82.9	55.1		
6.0-2	6.0		1199.6	664.4	1201.6	537.2	2.233	2.286	87.7	13.0	139.3	2.3	12.3	81.1	55.3		
6.0-3	6.0		1207.3	669.0	1208.9	539.9	2.236	2.286	87.8	13.0	139.5	2.2	12.2	82.1	55.2		
AVG	6.0											2.2	12.2	82.1	55.2	ERR	ERR
6.5-1	6.5		1211.6	670.8	1214.3	543.5	2.229	2.272	87.1	14.1	139.1	1.9	12.9	85.4	55.6		
6.5-2	6.5		1207.2	665.4	1210.5	545.1	2.215	2.272	86.5	14.0	138.2	2.5	13.5	81.3	55.9		
6.5-3	6.5		1208.3	669.8	1210.4	540.6	2.235	2.272	87.3	14.1	139.5	1.6	12.7	87.2	55.5		
AVG	6.5											2.0	13.0	84.6	55.6	ERR	ERR
7.2-1	7.2		1215.7	673.1	1217.4	544.3	2.234	2.257	86.8	15.2	139.4	1.0	13.2	92.1	55.7		
7.2-2	7.2		1220.3	677.7	1221.2	543.5	2.245	2.257	87.3	15.3	140.1	0.5	12.7	95.9	55.5		
7.2-3	7.2		1225.1	677.0	1226.9	549.9	2.228	2.257	86.6	15.2	139.0	1.3	13.4	90.4	55.8		
AVG	7.2											1.0	13.1	92.8	55.7	ERR	ERR
Computed by: Scott R. Todd					Checked by												

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

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

APPENDIX C -
Creep Test Results

Table C1: Creep Test Results From Granite Aggregate Gradation Number 1

Asphalt Content, %	Specimen Number	Creep Stiffness (MPa) @ 3600 seconds	Creep Stiffness (MPa) @ 4500 seconds
3.8	3.8-1	34.94	35.46
	3.8-2	41.61	42.22
	3.8-3	30.33	31.36
4.3	4.3-1	42.90	44.54
	4.3-2	38.16	38.98
	4.3-3	52.74	54.05
4.8	4.8-1	24.42	25.48
	4.8-2	20.70	22.08
	4.8-3	29.26	29.66
5.3	5.3-1	15.53	15.62
	5.3-2	18.48	18.68
	5.3-3	No Data	No Data
5.8	5.8-1	13.21	13.30
	5.8-2	10.39	10.47
	5.8-3	9.26	9.31

Table C2: Creep Test Results From Granite Aggregate Gradation Number 2

Asphalt Content, %	Specimen Number	Creep Stiffness (MPa) @ 3600 seconds	Creep Stiffness (MPa) @ 4500 seconds
5.3	5.3-1	24.66	25.02
	5.3-2	20.84	21.16
	5.3-3	15.46	15.61
5.8	5.8-1	19.52	19.84
	5.8-2	23.79	24.20
	5.8-3	19.32	19.62
6.3	6.3-1	13.56	13.67
	6.3-2	19.41	19.71
	6.3-3	13.87	13.96
6.8	6.8-1	14.84	15.01
	6.8-2	7.96	8.00
	6.8-3	13.25	13.38
7.3	7.3-1	9.12	9.16
	7.3-2	6.72	6.75
	7.3-3	5.43	5.71

Table C3: Creep Test Results From Granite Aggregate Gradation Number 3

Asphalt Content, %	Specimen Number	Creep Stiffness (MPa) @ 3600 seconds	Creep Stiffness (MPa) @ 4500 seconds
5.3	5.3-1	41.52	42.55
	5.3-2	38.96	39.62
	5.3-3	27.45	27.46
5.8	5.8-1	16.91	17.12
	5.8-2	No Data	No Data
	5.8-3	24.36	24.64
6.3	6.3-1	37.83	38.37
	6.3-2	No Data	No Data
	6.3-3	39.52	40.71
6.8	6.8-1	33.54	34.44
	6.8-2	16.19	16.37
	6.8-3	No Data	No Data
7.3	7.3-1	19.29	19.62
	7.3-2	21.37	21.73
	7.3-3	15.00	15.18

Table C4: Creep Test Results From Granite Aggregate Gradation Number 4

Asphalt Content, %	Specimen Number	Creep Stiffness (MPa) @ 3600 seconds	Creep Stiffness (MPa) @ 4500 seconds
6.0	6.0-1	73.08	73.47
	6.0-2	55.38	56.95
	6.0-3	No Data	No Data
6.5	6.5-1	No Data	No Data
	6.5-2	35.40	35.97
	6.5-3	No Data	No Data
7.0	7.0-1	56.91	57.94
	7.0-2	58.15	60.61
	7.0-3	7.75	7.81
7.5	7.5-1	15.53	15.68
	7.5-2	13.19	13.32
	7.5-3	21.03	21.33
8.0	8.0-1	4.33	4.33
	8.0-2	7.56	7.59
	8.0-3	23.17	23.48

Table C5: Creep Test Results From Granite Aggregate Gradation Number 7

Asphalt Content, %	Specimen Number	Creep Stiffness (MPa) @ 3600 seconds	Creep Stiffness (MPa) @ 4500 seconds
4.8	4.8-1	39.54	40.21
	4.8-2	40.89	41.48
	4.8-3	21.06	21.25
5.3	5.3-1	38.58	39.22
	5.3-2	27.55	27.58
	5.3-3	35.17	35.64
5.8	5.8-1	39.96	40.59
	5.8-2	28.37	28.79
	5.8-3	29.39	29.75
6.3	6.3-1	30.14	31.12
	6.3-2	26.91	27.14
	6.3-3	26.52	27.09
6.8	6.8-1	23.48	23.94
	6.8-2	35.16	35.72
	6.8-3	30.27	30.73

Table C6: Creep Test Results From Granite Aggregate Gradation Number 8

Asphalt Content, %	Specimen Number	Creep Stiffness (MPa) @ 3600 seconds	Creep Stiffness (MPa) @ 4500 seconds
5.0	5.0-1	42.53	43.46
	5.0-2	26.10	26.39
	5.0-3	34.36	34.95
5.5	5.5-1	41.67	42.72
	5.5-2	33.78	34.37
	5.5-3	28.67	29.17
6.1	6.1-1	32.42	33.24
	6.1-2	39.26	39.92
	6.1-3	41.38	42.70
6.8	6.8-1	12.73	12.90
	6.8-2	9.29	9.39
	6.8-3	30.27	30.73
7.3	7.3-1	16.77	16.97
	7.3-2	20.21	20.57
	7.3-3	17.68	17.93

Table C7: Creep Test Results From Granite Aggregate Gradation Number 9

Asphalt Content, %	Specimen Number	Creep Stiffness (MPa) @ 3600 seconds	Creep Stiffness (MPa) @ 4500 seconds
5.3	5.3-1	24.01	24.27
	5.3-2	54.62	56.06
	5.3-3	33.88	34.53
5.8	5.8-1	28.72	29.05
	5.8-2	24.04	24.34
	5.8-3	71.94	75.07
6.3	6.3-1	26.10	26.58
	6.3-2	19.80	20.05
	6.3-3	37.98	39.06
6.8	6.8-1	22.57	22.83
	6.8-2	26.10	26.80
	6.8-3	16.42	16.61
7.3	7.3-1	33.77	34.73
	7.3-2	10.71	10.83
	7.3-3	7.82	7.87

Table C8: Creep Test Results From Granite Aggregate Dense Gradation

Asphalt Content, %	Specimen Number	Creep Stiffness (MPa) @ 3600 seconds	Creep Stiffness (MPa) @ 4500 seconds
4.0	4.0-1	No Data	No Data
	4.0-2	58.02	60.61
	4.0-3	No Data	No Data
4.5	4.5-1	55.02	56.40
	4.5-2	68.04	71.75
	4.5-3	No Data	No Data
5.0	5.0-1	63.59	66.29
	5.0-2	59.35	61.65
	5.0-3	21.88	22.29
5.5	5.5-1	44.95	45.44
	5.5-2	30.63	30.92
	5.5-3	50.21	51.98
6.0	6.0-1	22.52	23.01
	6.0-2	37.05	38.10
	6.0-3	27.45	28.11

Table C9: Creep Test Results From Florida Limestone Aggregate Gradation Number 1

Asphalt Content, %	Specimen Number	Creep Stiffness (MPa) @ 3600 seconds	Creep Stiffness (MPa) @ 4500 seconds
4.4	4.4-1	29.87	30.56
	4.4-2	48.51	49.46
	4.4-3	15.77	15.90
4.8	4.8-1	25.67	25.98
	4.8-2	26.72	27.03
	4.8-3	18.48	18.74
5.3	5.3-1	19.04	19.26
	5.3-2	14.89	15.02
	5.3-3	11.99	12.09
5.8	5.8-1	8.58	8.64
	5.8-2	27.76	28.27
	5.8-3	10.15	10.20
6.3	6.3-1	8.50	8.55
	6.3-2	9.59	9.65
	6.3-3	11.06	11.17

Table C10: Creep Test Results From Florida Limestone Aggregate Gradation Number 2

Asphalt Content, %	Specimen Number	Creep Stiffness (MPa) @ 3600 seconds	Creep Stiffness (MPa) @ 4500 seconds
4.5	4.5-1	58.56	59.87
	4.5-2	31.47	31.93
	4.5-3	42.72	43.83
5.0	5.0-1	39.32	40.12
	5.0-2	42.42	43.42
	5.0-3	13.56	13.66
5.5	5.5-1	26.39	26.69
	5.5-2	35.91	36.59
	5.5-3	23.52	23.84
6.0	6.0-1	15.34	15.51
	6.0-2	16.91	16.95
	6.0-3	23.07	23.30
6.5	6.5-1	10.33	10.38
	6.5-2	22.38	22.41
	6.5-3	10.42	10.48

Table C11: Creep Test Results From Florida Limestone Aggregate Gradation Number 3

Asphalt Content, %	Specimen Number	Creep Stiffness (MPa) @ 3600 seconds	Creep Stiffness (MPa) @ 4500 seconds
5.7	5.7-1	22.85	25.34
	5.7-2	21.74	23.52
	5.7-3	15.34	16.68
6.2	6.2-1	No Data	No Data
	6.2-2	34.44	35.03
	6.2-3	25.66	25.91
6.7	6.7-1	18.67	19.48
	6.7-2	24.01	28.48
	6.7-3	24.71	29.54
7.2	7.2-1	16.32	18.82
	7.2-2	18.17	19.48
	7.2-3	12.20	12.26
7.7	7.7-1	13.25	14.03
	7.7-2	9.98	10.75
	7.7-3	13.13	13.23

Table C12: Creep Test Results From Florida Limestone Aggregate Gradation Number 4

Asphalt Content, %	Specimen Number	Creep Stiffness (MPa) @ 3600 seconds	Creep Stiffness (MPa) @ 4500 seconds
7.0	7.0-1	22.29	22.59
	7.0-2	38.67	43.46
	7.0-3	19.66	19.95
7.5	7.5-1	28.71	29.08
	7.5-2	30.60	31.38
	7.5-3	21.17	22.07
8.0	8.0-1	34.92	36.27
	8.0-2	35.43	36.87
	8.0-3	16.17	16.31
8.5	8.5-1	17.14	17.37
	8.5-2	16.31	16.76
	8.5-3	12.32	12.50
9.0	9.0-1	14.86	14.98
	9.0-2	26.02	26.54
	9.0-3	6.96	7.01

Table C13: Creep Test Results From Florida Limestone Aggregate Gradation Number 7

Asphalt Content, %	Specimen Number	Creep Stiffness (MPa) @ 3600 seconds	Creep Stiffness (MPa) @ 4500 seconds
5.5	5.5-1	26.63	26.97
	5.5-2	18.15	18.36
	5.5-3	30.19	30.56
6.0	6.0-1	19.76	19.99
	6.0-2	20.23	20.45
	6.0-3	36.11	36.82
6.5	6.5-1	30.87	31.39
	6.5-2	32.97	33.56
	6.5-3	18.54	18.78
7.0	7.0-1	16.39	16.61
	7.0-2	27.66	28.07
	7.0-3	12.23	12.31
7.5	7.5-1	12.56	12.65
	7.5-2	12.67	12.72
	7.5-3	17.59	17.81

Table C14: Creep Test Results From Florida Limestone Aggregate Gradation Number 8

Asphalt Content, %	Specimen Number	Creep Stiffness (MPa) @ 3600 seconds	Creep Stiffness (MPa) @ 4500 seconds
5.5	5.5-1	31.70	32.19
	5.5-2	43.13	44.21
	5.5-3	30.96	31.36
6.0	6.0-1	30.70	31.09
	6.0-2	27.90	28.30
	6.0-3	42.18	43.58
6.5	6.5-1	36.60	37.52
	6.5-2	29.07	29.65
	6.5-3	14.30	14.45
7.0	7.0-1	18.00	18.19
	7.0-2	7.79	7.81
	7.0-3	14.90	15.05
7.5	7.5-1	No Data	No Data
	7.5-2	10.85	10.92
	7.5-3	5.01	4.77

Table C15: Creep Test Results From Florida Limestone Aggregate Gradation Number 9

Asphalt Content, %	Specimen Number	Creep Stiffness (MPa) @ 3600 seconds	Creep Stiffness (MPa) @ 4500 seconds
6.0	6.0-1	42.31	43.24
	6.0-2	38.19	39.02
	6.0-3	28.79	29.17
6.7	6.7-1	23.62	23.90
	6.7-2	25.29	25.63
	6.7-3	32.92	34.19
7.0	7.0-1	32.84	33.33
	7.0-2	26.64	27.56
	7.0-3	29.93	30.80
7.5	7.5-1	34.05	34.79
	7.5-2	41.63	42.55
	7.5-3	29.17	29.65
8.2	8.2-1	20.20	20.60
	8.2-2	12.36	12.55
	8.2-3	No Data	No Data

Table C16: Creep Test Results From Florida Limestone Aggregate Dense Gradation

Asphalt Content, %	Specimen Number	Creep Stiffness (MPa) @ 3600 seconds	Creep Stiffness (MPa) @ 4500 seconds
5.0	5.0-1	74.26	76.60
	5.0-2	47.10	47.15
	5.0-3	47.23	48.08
5.5	5.5-1	47.59	48.00
	5.5-2	28.52	28.92
	5.5-3	63.89	64.89
6.0	6.0-1	58.47	60.31
	6.0-2	69.00	70.17
	6.0-3	72.00	73.34
6.5	6.5-1	52.77	54.51
	6.5-2	No Data	No Data
	6.5-3	53.87	54.30
7.0	7.0-1	39.64	40.81
	7.0-2	32.09	32.69
	7.0-3	31.20	31.53

APPENDIX D -
Draindown Test Results

Table D1: Draindown Test Results for the Five SMA Mixture Designs

		Percent Draindown				
Temperature, °C	Specimen Number	Granite	Florida Limestone	Gravel	Limestone	Traprock
135	1	0.02	0.12	0.09	0.02	0.02
	2	0.03	0.09	0.03	0	0.01
149	1	0.02	0.12	0.03	0.03	0.08
	2	0.02	0.09	0.26	0.03	0.03
163	1	0.02	0.12	0.17	0.03	0.03
	2	0.01	0.08	0.15	0.01	0.05

Table D2: Draindown Test Results for the Nine Granite Mixtures

		Percent Draindown								
Temperature, °C	Specimen Number	Grad 1	Grad 2	Grad 3	Grad 4	Grad 5	Grad 6	Grad 7	Grad 8	Grad 9
135	1	0.02	0.04	0.08	0.04	-	-	0.22	0.04	0.16
	2	0.04	0.06	0.20	0.46	-	-	0.09	0.08	0.08
149	1	0.05	0.15	0.03	0.09	10.75	2.80	0.11	0.22	0.24
	2	0.03	0.08	0.06	0.33	10.98	4.05	0.04	0.18	0.21
163	1	0.07	0.10	0.05	0.45	-	-	0.12	0.03	0.06
	2	0.09	0.09	0.11	0.41	-	-	0.33	0.13	0.11

Table D3: Draindown Test Results for the Nine Florida Limestone Mixtures

		Percent Draindown								
Temperature, °C	Specimen Number	Grad 1	Grad 2	Grad 3	Grad 4	Grad 5	Grad 6	Grad 7	Grad 8	Grad 9
135	1	0.04	0.02	0.08	0.02	-	-	0.02	0.14	0.01
	2	0	0.03	0.14	0.03	-	-	0.02	0.11	0.01
149	1	0.06	0.03	0.08	0.04	7.45	1.69	0.03	0.40	0.03
	2	0.08	0.02	0.06	0.04	7.15	0.99	0.02	0.29	0.03
163	1	0.01	0.02	0.20	0.02	-	-	0.08	0.61	0.02
	2	0.07	0.01	0.30	0.04	-	-	0.04	0.28	0.04

APPENDIX E -
Coarse Aggregate, Fine Aggregate, and Mineral Filler Test Results

Table E1: Granite Coarse Aggregate Test Results

Property	Sample Number			
	1	2	3	4
Bulk Specific Gravity	2.664	-	-	-
Apparent Specific Gravity	2.713	-	-	-
Absorption, %	0.7	-	-	-

Table E2: Florida Limestone Coarse Aggregate Test Results

Property	Sample Number			
	1	2	3	4
Bulk Specific Gravity	2.378	2.369	-	-
Apparent Specific Gravity	2.607	2.597	-	-
Absorption, %	2.7	3.7	-	-

Table E3: Gravel Coarse Aggregate Test Results

Property	Sample Number			
	1	2	3	4
Bulk Specific Gravity	2.580	2.572	2.556	2.543
Apparent Specific Gravity	2.648	2.642	2.635	2.647
Absorption, %	0.9	1.3	1.6	1.0

Table E4: Limestone Coarse Aggregate Test Results

Property	Sample Number			
	1	2	3	4
Bulk Specific Gravity	2.743	2.706	2.729	2.722
Apparent Specific Gravity	2.769	2.732	2.764	2.757
Absorption, %	0.34	0.35	0.46	0.46

Table E5: Traprock Coarse Aggregate Test Results

Property	Sample Number			
	1	2	3	4
Bulk Specific Gravity	2.949	2.945	2.913	2.921
Apparent Specific Gravity	3.022	3.021	3.026	3.023
Absorption, %	0.82	0.86	1.3	1.2

Table E6: Granite Fine Aggregate Test Results

Property	Sample Number			
	1	2	3	4
Bulk Specific Gravity	2.687	2.702	-	-
Apparent Specific Gravity	2.697	2.725	-	-
Absorption, %	0.13	0.31	-	-

Table E7: Florida Limestone Fine Aggregate Test Results

Property	Sample Number			
	1	2	3	4
Bulk Specific Gravity	2.358	2.357	-	-
Apparent Specific Gravity	2.648	2.675	-	-
Absorption, %	4.6	5.0	-	-

Table E8: Gravel Fine Aggregate Test Results

Property	Sample Number			
	1	2	3	4
Bulk Specific Gravity	2.450	2.422	-	-
Apparent Specific Gravity	2.622	2.633	-	-
Absorption, %	2.67	3.32	-	-

Table E9: Limestone Fine Aggregate Test Results

Property	Sample Number			
	1	2	3	4
Bulk Specific Gravity	2.703	2.665	-	-
Apparent Specific Gravity	2.771	2.768	-	-
Absorption, %	0.92	1.40	-	-

Table E10: Traprock Fine Aggregate Test Results

Property	Sample Number			
	1	2	3	4
Bulk Specific Gravity	2.912	2.894	-	-
Apparent Specific Gravity	3.013	2.994	-	-
Absorption, %	1.15	1.15	-	-

Table E11: Baghouse Fines Test Results

Property	Sample Number		
	1	2	3
Apparent Specific Gravity	2.702	2.720	-
Passing 0.02-mm Sieve, %	40.72	4.055	40.35

Table E12: Limestone Dust Test Results

Property	Sample Number		
	1	2	3
Apparent Specific Gravity	2.923	2.877	-
Passing 0.02-mm Sieve, %	62.7	61.2	61.4

Table E13: Limestone Dust Gradation Using Hydrometer Analysis

Sieve Size (mm)	Percent Passing		
	Sample 1	Sample 2	Sample 3
2.36	-	-	-
1.18	-	-	-
0.60	-	-	-
0.30	-	-	-
0.15	-	-	-
0.075	-	-	-
0.045	58.3	55.0	57.7
0.020	46.9	45.9	46.7

Table E14: Limestone Dust Gradation Using a Wet Sieve Analysis

Sieve Size (mm)	Percent Passing	
	Sample 1	Sample 2
2.36	100.0	100.0
1.18	99.6	99.8
0.60	98.6	98.9
0.30	96.0	96.5
0.15	90.0	90.9
0.075	79.4	81.3
0.045	-	-
0.020	-	-

Table E15: Limestone Dust Gradation Using the Particle Size Analyzer

Sieve Size (mm)	Percent Passing		
	Sample 1	Sample 2	Sample 3
2.36	100.0	100.0	100.0
1.18	100.0	100.0	100.0
0.60	100.0	100.0	100.0
0.30	100.0	100.0	99.6
0.15	95.8	94.7	94.7
0.075	86.0	84.4	84.4
0.045	76.9	75.3	75.4
0.020	62.7	61.2	61.4

Table E16: Baghouse Fines Gradation Using a Wet Sieve Analysis

Sieve Size (mm)	Percent Passing		
	Sample 1	Sample 2	Sample 3
2.36	100.0	100.0	100.0
1.18	100.0	99.9	99.8
0.60	99.9	99.7	99.7
0.30	99.4	98.7	98.9
0.15	97.8	95.1	96.0
0.075	92.0	87.1	88.5
0.045	-	-	-
0.020	-	-	-

Table E17: Baghouse Fines Gradation Using Hydrometer Analysis

Sieve Size (mm)	Percent Passing		
	Sample 1	Sample 2	Sample 3
2.36	-	-	-
1.18	-	-	-
0.60	-	-	-
0.30	-	-	-
0.15	-	-	-
0.075	-	-	-
0.045	-	65.3	65.8
0.020	54.7	46.9	48.8

Table E18: Baghouse Fines Gradation Using the Particle Size Analyzer

Sieve Size (mm)	Percent Passing		
	Sample 1	Sample 2	Sample 3
2.36	100.0	100.0	100.0
1.18	100.0	100.0	100.0
0.60	99.7	99.8	99.6
0.30	97.2	97.5	97.0
0.15	92.3	92.4	91.9
0.075	80.3	80.2	79.8
0.045	66.4	66.3	66.0
0.020	40.7	40.6	40.4

APPENDIX F -
Specimen Gradations After VCA Determinations

Table F1: Granite Specimen Gradations After VCA Determination Using the 50-Blow Marshall Method

	Percent Passing		
Sieve Size (mm)	Specimen 1	Specimen 2	Specimen 3
19.0	100.0	100.0	100.0
12.5	90.9	87.7	90.7
9.5	54.8	57.7	56.4
4.75	14.1	15.0	13.6
2.36	6.9	7.5	6.7
1.18	5.0	5.4	4.7
0.60	3.7	4.1	3.5
0.30	2.7	3.0	2.5
0.15	1.8	2.0	1.6
0.075	1.2	1.4	1.1

Table F2: Granite Specimen Gradations After VCA Determination Using the Dry-Rodded Method

	Percent Passing		
Sieve Size (mm)	Specimen 1	Specimen 2	Specimen 3
19.0	100.0		
12.5	87.2		
9.5	44.7	N	N
4.75	2.5	O	O
2.36	0.7	D	D
1.18	0.6	A	A
0.60	0.5	T	T
0.30	0.5	A	A
0.15	0.4		
0.075	0.3		

Table F3: Granite Specimen Gradations After VCA Determination Using the Vibrating Table Method

	Percent Passing		
Sieve Size (mm)	Specimen 1	Specimen 2	Specimen 3
19.0	100.0		
12.5	88.6		
9.5	42.9	N	N
4.75	1.4	O	O
2.36	0.4	D	D
1.18	0.4	A	A
0.60	0.4	T	T
0.30	0.3	A	A
0.15	0.3		
0.075	0.2		

Table F4: Granite Specimen Gradations After VCA Determination Using the SHRP Gyratory Method

	Percent Passing		
Sieve Size (mm)	Specimen 1	Specimen 2	Specimen 3
19.0	100.0	100.0	100.0
12.5	86.9	88.9	88.0
9.5	51.8	52.1	53.3
4.75	10.8	12.2	10.5
2.36	4.9	5.5	4.8
1.18	3.3	3.7	3.3
0.60	2.3	2.7	2.3
0.30	1.5	1.7	1.5
0.15	0.9	0.9	0.8
0.075	0.4	0.4	0.3

Table F5: Granite Specimen Gradations After VCA Determination Using the Kango Hammer Method

	Percent Passing		
Sieve Size (mm)	Specimen 1	Specimen 2	Specimen 3
19.0	100.0	100.0	100.0
12.5	85.9	86.7	91.9
9.5	38.5	40.2	45.8
4.75	2.1	2.2	3.3
2.36	1.0	0.9	1.2
1.18	0.9	0.8	1.0
0.60	0.8	0.7	1.0
0.30	0.8	0.6	0.9
0.15	0.7	0.5	0.8
0.075	0.6	0.4	0.7

Table F6: Granite Specimen Gradations After VCA Determination Using the 50-Blow Marshall Method

	Percent Passing		
Sieve Size (mm)	Specimen 1	Specimen 2	Specimen 3
19.0	100.0	100.0	100.0
12.5	92.9	91.1	90.0
9.5	55.9	58.2	59.1
4.75	20.6	22.8	24.2
2.36	10.0	10.7	11.5
1.18	6.7	7.1	8.0
0.60	5.0	5.3	6.1
0.30	4.0	4.2	5.0
0.15	3.3	3.4	4.3
0.075	2.7	2.9	3.7

Table F7: Florida Limestone Specimen Gradations After VCA Determination Using the Dry-Rodded Method

	Percent Passing		
Sieve Size (mm)	**Specimen 1**	**Specimen 2**	**Specimen 3**
19.0	100.0		
12.5	86.2		
9.5	30.3	N	N
4.75	2.5	O	O
2.36	0.8	D	D
1.18	0.7	A	A
0.60	0.7	T	T
0.30	0.7	A	A
0.15	0.6		
0.075	0.4		

Table F8: Florida Limestone Specimen Gradations After VCA Determination Using the Vibrating Table Method

	Percent Passing		
Sieve Size (mm)	Specimen 1	Specimen 2	Specimen 3
19.0	100.0	100.0	100.0
12.5	88.4	87.9	90.0
9.5	40.9	41.7	44.2
4.75	1.2	2.5	3.5
2.36	0.9	1.0	1.1
1.18	0.8	0.9	1.0
0.60	0.8	0.9	1.0
0.30	0.8	0.9	0.9
0.15	0.7	0.8	0.8
0.075	0.6	0.6	0.7

Table F9: Florida Limestone Specimen Gradations After VCA Determination Using the SHRP Gyratory Method

	Percent Passing		
Sieve Size (mm)	Specimen 1	Specimen 2	Specimen 3
19.0	100.0	100.0	100.0
12.5	89.6	89.1	88.2
9.5	48.8	50.4	47.2
4.75	17.2	15.3	13.8
2.36	7.9	7.8	6.2
1.18	5.6	5.8	4.6
0.60	4.3	4.6	3.7
0.30	3.6	3.8	3.2
0.15	3.1	3.3	2.8
0.075	2.7	2.9	2.5

Table F10: Florida Limestone Specimen Gradations After VCA Determination Using the Kango Hammer Method

	Percent Passing		
Sieve Size (mm)	Specimen 1	Specimen 2	Specimen 3
19.0	100.0	100.0	100.0
12.5	86.8	89.5	93.7
9.5	44.6	46.0	47.7
4.75	1.5	1.3	1.1
2.36	0.8	0.9	0.8
1.18	0.7	0.8	0.7
0.60	0.6	0.7	0.7
0.30	0.6	0.6	0.6
0.15	0.5	0.5	0.5
0.075	0.4	0.4	0.4

Table F11: Gravel Specimen Gradations After VCA Determination Using the 50-Blow Marshall Method

	Percent Passing		
Sieve Size (mm)	Specimen 1	Specimen 2	Specimen 3
19.0	100.0	100.0	100.0
12.5	88.9	92.3	91.1
9.5	58.7	60.0	56.3
4.75	14.1	13.0	13.2
2.36	5.3	5.4	5.1
1.18	3.2	3.1	2.9
0.60	2.0	1.9	1.8
0.30	1.2	1.2	1.1
0.15	0.6	0.6	0.6
0.075	0.2	0.2	0.2

Table F12: Gravel Specimen Gradations After VCA Determination Using the Dry-Rodded Method

	Percent Passing		
Sieve Size (mm)	Specimen 1	Specimen 2	Specimen 3
19.0	100.0	100.0	100.0
12.5	89.0	88.4	85.7
9.5	44.2	46.7	47.6
4.75	3.0	2.6	3.1
2.36	0.5	0.5	0.5
1.18	0.4	0.4	0.4
0.60	0.4	0.4	0.4
0.30	0.3	0.4	0.3
0.15	0.3	0.3	0.3
0.075	0.2	0.2	0.2

Table F13: Gravel Specimen Gradations After VCA Determination Using the Vibrating Table Method

	Percent Passing		
Sieve Size (mm)	Specimen 1	Specimen 2	Specimen 3
19.0	100.0	100.0	100.0
12.5	89.7	86.5	90.8
9.5	44.4	41.8	43.2
4.75	2.2	2.4	2.3
2.36	0.5	0.4	0.5
1.18	0.4	0.4	0.5
0.60	0.4	0.4	0.5
0.30	0.4	0.4	0.4
0.15	0.4	0.3	0.4
0.075	0.3	0.3	0.3

Table F14: Gravel Specimen Gradations After VCA Determination Using the SHRP Gyratory Method

	Percent Passing		
Sieve Size (mm)	Specimen 1	Specimen 2	Specimen 3
19.0	100.0	100.0	100.0
12.5	89.8	89.2	88.6
9.5	49.3	50.1	48.3
4.75	5.6	6.0	4.8
2.36	1.8	1.9	1.6
1.18	1.2	1.2	1.0
0.60	0.8	0.7	0.7
0.30	0.5	0.5	0.4
0.15	0.3	0.3	0.3
0.075	0.1	0.1	0.1

Table F15: Gravel Specimen Gradations After VCA Determination Using the Kango Hammer Method

	Percent Passing		
Sieve Size (mm)	Specimen 1	Specimen 2	Specimen 3
19.0	100.0	100.0	100.0
12.5	88.3	89.9	87.1
9.5	38.9	46.2	43.3
4.75	2.2	2.7	2.5
2.36	0.4	0.4	0.4
1.18	0.4	0.4	0.3
0.60	0.3	0.3	0.3
0.30	0.2	0.3	0.2
0.15	0.2	0.2	0.1
0.075	0.1	0.2	0.1

Table F16: Limestone Specimen Gradations After VCA Determination Using the 50-Blow Marshall Method

	Percent Passing		
Sieve Size (mm)	Specimen 1	Specimen 2	Specimen 3
19.0	100.0	100.0	100.0
12.5	92.0	91.7	91.4
9.5	66.7	65.5	68.2
4.75	24.4	22.7	26.4
2.36	12.5	11.5	13.4
1.18	7.2	6.4	7.3
0.60	4.5	3.9	4.3
0.30	3.0	2.5	2.7
0.15	2.2	1.8	1.9
0.075	1.7	1.4	1.5

Table F17: Limestone Specimen Gradations After VCA Determination Using the Dry-Rodded Method

	Percent Passing		
Sieve Size (mm)	Specimen 1	Specimen 2	Specimen 3
19.0	100.0	100.0	100.0
12.5	89.8	73.8	88.0
9.5	45.0	30.7	43.4
4.75	1.5	0.9	1.5
2.36	0.5	0.5	0.5
1.18	0.4	0.4	0.4
0.60	0.3	0.4	0.3
0.30	0.3	0.4	0.3
0.15	0.3	0.4	0.3
0.075	0.3	0.4	0.2

Table F18: Limestone Specimen Gradations After VCA Determination Using the Vibrating Table Method

	Percent Passing		
Sieve Size (mm)	Specimen 1	Specimen 2	Specimen 3
19.0	100.0	100.0	100.0
12.5	87.2	87.2	83.4
9.5	41.0	42.9	40.9
4.75	1.4	1.6	1.3
2.36	0.4	0.5	0.4
1.18	0.3	0.4	0.4
0.60	0.3	0.3	0.3
0.30	0.3	0.3	0.3
0.15	0.3	0.3	0.2
0.075	0.2	0.2	0.2

Table F19: Limestone Specimen Gradations After VCA Determination Using the SHRP Gyratory Method

	Percent Passing		
Sieve Size (mm)	Specimen 1	Specimen 2	Specimen 3
19.0	100.0	100.0	100.0
12.5	88.9	88.5	88.5
9.5	53.1	53.0	52.3
4.75	11.0	11.3	10.1
2.36	5.9	6.0	5.3
1.18	3.6	3.6	3.2
0.60	2.3	2.4	2.1
0.30	1.5	1.6	1.5
0.15	1.1	1.2	1.1
0.075	0.9	1.0	0.9

Table F20: Limestone Specimen Gradations After VCA Determination Using the Kango Hammer Method

	Percent Passing		
Sieve Size (mm)	Specimen 1	Specimen 2	Specimen 3
19.0	100.0	100.0	100.0
12.5	87.7	85.9	86.5
9.5	46.4	42.4	42.4
4.75	1.7	1.7	1.4
2.36	0.6	0.7	0.7
1.18	0.5	0.6	0.5
0.60	0.4	0.5	0.4
0.30	0.3	0.5	0.4
0.15	0.3	0.4	0.3
0.075	0.2	0.4	0.3

Table F21: Traprock Specimen Gradations After VCA Determination Using the 50-Blow Marshall Method

	Percent Passing		
Sieve Size (mm)	Specimen 1	Specimen 2	Specimen 3
19.0	100.0	100.0	
12.5	87.9	89.3	
9.5	50.2	52.0	N
4.75	13.9	11.8	O
2.36	4.7	4.3	D
1.18	2.6	2.5	A
0.60	1.8	1.7	T
0.30	1.4	1.2	A
0.15	1.0	0.9	
0.075	0.7	0.6	

Table F22: Traprock Specimen Gradations After VCA Determination Using the Dry-Rodded Method

	Percent Passing		
Sieve Size (mm)	Specimen 1	Specimen 2	Specimen 3
19.0	100.0	100.0	100.0
12.5	88.5	87.4	86.5
9.5	44.0	42.3	44.0
4.75	1.5	1.7	1.5
2.36	0.3	0.4	0.3
1.18	0.3	0.3	0.3
0.60	0.2	0.3	0.3
0.30	0.2	0.3	0.3
0.15	0.2	0.2	0.2
0.075	0.2	0.2	0.2

Table F23: Traprock Specimen Gradations After VCA Determination Using the Vibrating Table Method

	Percent Passing		
Sieve Size (mm)	Specimen 1	Specimen 2	Specimen 3
19.0	100.0	100.0	100.0
12.5	86.1	87.7	86.2
9.5	44.1	40.8	41.7
4.75	1.5	1.6	1.3
2.36	0.4	0.4	0.3
1.18	0.4	0.4	0.3
0.60	0.4	0.4	0.3
0.30	0.4	0.4	0.3
0.15	0.4	0.4	0.3
0.075	0.4	0.4	0.3

Table F24: Traprock Specimen Gradations After VCA Determination Using the SHRP Gyratory Method

	Percent Passing		
Sieve Size (mm)	Specimen 1	Specimen 2	Specimen 3
19.0	100.0	100.0	100.0
12.5	87.4	86.9	86.1
9.5	46.7	46.7	49.3
4.75	5.8	5.3	6.9
2.36	2.2	1.8	2.3
1.18	1.4	1.1	1.4
0.60	1.0	0.9	1.0
0.30	0.8	0.7	0.8
0.15	0.7	0.6	0.7
0.075	0.5	0.4	0.6

Table F25: Traprock Specimen Gradations After VCA Determination Using the Kango Hammer Method

	Percent Passing		
Sieve Size (mm)	Specimen 1	Specimen 2	Specimen 3
19.0	100.0	100.0	100.0
12.5	88.3	86.3	85.1
9.5	42.6	37.7	41.4
4.75	6.8	2.0	2.0
2.36	0.6	0.3	0.4
1.18	0.5	0.2	0.4
0.60	0.5	0.2	0.3
0.30	0.4	0.2	0.3
0.15	0.4	0.2	0.3
0.075	0.4	0.1	0.3

APPENDIX G -
Original Asphalt Cement, Fine Mortar, and Total Mortar Test Results

Table G1
Fine Mortar Brookfield Viscosity Data
(Test Temperature: 175°C)

Fine Mortar	Brookfield Viscosity (cP)			
	Measure-ment 1	Measure-ment 2	Measure-ment 3	Average
AC-20,LD	850	925	870	882
AC-20,FA	9440	9450	9630	9507
AC-20,F1,LD	*****	*****	*****	*****
AC-20,F1,FA	*****	*****	*****	*****
AC-20M1,LD	4035	4030	4085	4050
AC-20M1,FA	*****	*****	*****	*****
AC-20M1,F2,LD	*****	*****	*****	*****
AC-20M1,F2,FA	*****	*****	*****	*****
AC-20,F2,LD	7190	6230	6100	6507
AC-20,F2,FA	*****	*****	*****	*****
AC-20M1,F1,LD	*****	*****	*****	*****
AC-20M1,F1,FA	*****	*****	*****	*****
AC-20M2,FA	13420	13040	13360	13273
AC-20M3,FA	16260	15000	13900	15053
AC-20,F3,FA	*****	*****	*****	*****
AC-20	75	75	75	75
AC-20M1	287	287	287	287
AC-20M2	137	137	125	133
AC-20M3	150	150	150	150

*****Material too stiff for equipment to measure viscosity.

Table G2. Fine Mortar G*, Complex Modulus (kPa) Data for the Original Binder Material (Test Temperature: 64°C)											
Fine Mortar	Measurement No.										Average Value
	1	2	3	4	5	6	7	8	9	10	
AC-20,LD	5.340	5.400	5.470	5.510	5.520	5.530	5.520	5.480	5.450	5.370	5.459
AC-20,FA	6.830	6.740	6.710	6.720	6.700	6.690	6.700	6.740	6.760	6.820	6.741
AC-20,F1,LD	8.890	8.880	8.860	8.850	8.820	8.770	8.780	8.720	8.670	8.650	8.789
AC-20,F1,FA	1.270	1.270	1.270	1.270	1.270	1.270	1.270	1.260	1.260	1.260	1.267
AC-20M1,LD	1.110	1.110	1.120	1.120	1.120	1.120	1.120	1.130	1.120	1.130	1.120
AC-20M1,FA	1.320	1.320	1.310	1.310	1.300	1.300	1.290	1.280	1.280	1.280	1.299
AC-20M1,F2,LD	1.160	1.160	1.150	1.150	1.140	1.130	1.130	1.120	1.120	1.120	1.138
AC-20M1,F2,FA	1.560	1.560	1.550	1.550	1.550	1.550	1.560	1.550	1.550	1.560	1.554
AC-20,F2,LD	6.050	6.110	6.140	6.130	6.060	6.010	5.930	5.830	5.790	5.770	5.982
AC-20,F2,FA	8.810	8.790	8.770	8.810	8.820	8.840	8.880	8.920	9.970	9.040	8.965
AC-20M1,F1,LD	1.710	1.710	1.710	1.700	1.700	1.700	1.700	1.700	1.700	1.700	1.703
AC-20M1,F1,FA	2.340	2.340	2.320	2.330	2.320	2.320	2.310	2.310	2.310	2.300	2.320
AC-20M2,FA	9.660	9.690	9.780	9.800	9.870	9.890	9.890	9.920	9.870	9.840	9.821
AC-20M3,FA	1.220	1.220	1.220	1.250	1.230	1.230	1.230	1.240	1.240	1.240	1.232
AC-20,F3,FA	8.010	8.020	8.000	8.010	8.080	8.130	8.170	8.240	8.290	8.380	8.133
AC-20	1.040	1.030	1.030	1.040	1.040	1.030	1.030	1.030	1.030	1.030	1.033
AC-20M1	2.210	2.220	2.220	2.220	2.230	2.220	2.220	2.220	2.220	2.220	2.220
AC-20M2	1.280	1.280	1.280	1.280	1.280	1.280	1.290	1.290	1.290	1.290	1.284
AC-20M3	2.360	2.360	2.360	2.360	2.360	2.360	2.360	2.360	2.370	2.370	2.362

Table G3. Fine Mortar δ, Phase Angle (degrees) Data for the Original Binder Material (Test Temperature: 64°C)											
Fine Mortar	Measurement No.										Average Value
	1	2	3	4	5	6	7	8	9	10	
AC-20,LD	87.0	87.3	87.2	87.1	87.4	87.3	87.1	87.2	87.2	87.1	87.2
AC-20,FA	87.0	86.9	87.0	86.9	86.7	87.1	86.9	86.8	86.7	86.8	86.9
AC-20,F1,LD	80.8	80.6	80.7	80.6	80.5	80.6	80.7	80.6	80.6	80.7	80.6
AC-20,F1,FA	82.3	82.3	82.3	82.6	82.3	82.4	82.6	82.4	82.6	82.6	82.4
AC-20M1,LD	65.5	65.4	65.3	65.6	65.4	65.3	65.6	65.4	65.2	65.6	65.4
AC-20M1,FA	66.0	66.0	66.0	66.0	66.0	66.0	66.0	66.0	66.0	66.0	66.0
AC-20M1,F2,LD	66.0	65.9	66.0	66.0	65.9	66.0	65.9	65.8	66.1	66.0	66.0
AC-20M1,F2,FA	64.8	64.7	64.9	64.9	64.7	64.7	64.8	64.7	64.9	64.8	64.8
AC-20,F2,LD	86.6	86.4	86.7	86.4	86.6	86.7	86.4	86.4	86.6	86.4	86.5
AC-20,F2,FA	85.7	85.7	85.9	85.6	85.5	85.9	85.7	85.6	85.7	85.7	85.7
AC-20M1,F1,LD	62.2	62.3	62.4	62.4	62.4	62.4	62.4	62.4	62.4	62.4	62.4
AC-20M1,F1,FA	61.7	61.9	61.7	61.7	61.7	62.0	61.8	61.6	62.0	61.8	61.8
AC-20M2,FA	83.6	83.7	83.7	83.8	83.8	83.7	83.7	83.9	83.7	83.8	83.7
AC-20M3,FA	81.5	81.2	81.4	81.2	81.2	81.5	81.5	81.2	81.4	81.3	81.3
AC-20,F3,FA	86.3	86.1	86.0	86.0	86.0	86.0	86.2	86.1	85.7	86.2	86.1
AC-20	87.8	88.0	88.0	87.9	87.8	87.8	88.0	87.8	87.9	87.8	87.9
AC-20M1	67.1	67.1	67.5	67.3	67.0	67.2	67.2	67.2	67.3	67.3	67.2
AC-20M2	84.6	84.5	84.5	84.4	84.4	84.3	84.4	84.5	84.4	84.5	84.5
AC-20M3	83.2	83.3	83.3	83.4	83.4	83.4	83.4	83.4	83.4	83.5	83.4

Table G4. Fine Mortar G*, Complex Modulus (kPa) Data for the RTFOT/TFOT Aged Binder (Test Temperature: 64°C)											
Fine Mortar	Measurement No.										Average Value
	1	2	3	4	5	6	7	8	9	10	
AC-20,LD	9.340	9.460	9.530	9.600	9.680	9.650	9.570	9.510	9.400	9.310	9.505
AC-20,FA	1.210	1.210	1.210	1.210	1.210	1.210	1.220	1.230	1.240	1.240	1.219
AC-20,F1,LD	1.380	1.370	1.370	1.370	1.370	1.370	1.370	1.360	1.360	1.360	1.368
AC-20,F1,FA	2.300	2.320	2.330	2.350	2.370	2.390	2.390	2.410	2.400	2.410	2.367
AC-20M1,LD	1.710	1.720	1.710	1.710	1.710	1.710	1.710	1.710	1.720	1.710	1.712
AC-20M1,FA	2.380	2.380	2.370	2.380	2.370	2.370	2.360	2.360	2.360	2.360	2.369
AC-20M1,F2,LD	1.380	1.380	1.380	1.380	1.380	1.380	1.390	1.390	1.390	1.390	1.384
AC-20M1,F2,FA	3.090	3.090	3.070	3.060	3.070	3.050	3.070	3.050	3.040	3.050	3.064
AC-20,F2,LD	1.050	1.060	1.080	1.090	1.090	1.100	1.090	1.080	1.080	1.060	1.078
AC-20,F2,FA	1.640	1.650	1.660	1.670	1.680	1.680	1.680	1.690	1.680	1.680	1.671
AC-20M1,F1,LD	2.660	2.650	2.650	2.640	2.640	2.640	2.650	2.640	2.640	2.640	2.645
AC-20M1,F1,FA	3.530	3.530	3.520	3.510	3.520	3.500	3.510	3.520	3.490	3.520	3.515
AC-20M2,FA	1.680	1.680	1.680	1.690	1.680	1.690	1.680	1.690	1.680	1.680	1.683
AC-20M3,FA	2.520	2.510	2.520	2.520	2.530	2.540	2.540	2.540	2.560	2.560	2.534
AC-20,F3,FA	1.690	1.690	1.690	1.690	1.690	1.690	1.690	1.690	1.680	1.680	1.688
AC-20	2.290	2.290	2.290	2.290	2.290	2.290	2.290	2.290	2.290	2.290	2.290
AC-20M1	4.660	4.640	4.620	4.620	4.610	4.620	4.640	4.670	4.710	4.760	4.655
AC-20M2	2.470	2.480	2.470	2.470	2.480	2.470	2.480	2.480	2.480	2.480	2.476
AC-20M3	5.150	5.150	5.140	5.140	5.140	5.140	5.130	5.140	5.140	5.150	5.142

Table G5. Fine Mortar δ, Phase Angle Data (degrees) for the RTFOT/TFOT Aged Binder (Test Temperature: 64°C)											
Fine Mortar	Measurement No.										Average Value
	1	2	3	4	5	6	7	8	9	10	
AC-20,LD	85.1	85.0	84.9	85.2	85.1	85.0	85.0	85.1	84.8	85.5	85.1
AC-20,FA	84.4	84.2	84.1	84.2	84.2	84.2	84.4	84.2	84.0	84.3	84.2
AC-20,F1,LD	80.6	80.5	80.5	80.5	80.5	80.5	80.5	80.5	80.6	80.6	80.5
AC-20,F1,FA	79.6	79.8	79.6	79.6	79.6	79.6	79.7	79.4	79.5	79.7	79.6
AC-20M1,LD	63.0	63.0	62.9	62.8	63.0	62.9	62.9	62.7	62.8	63.1	62.9
AC-20M1,FA	62.9	62.8	62.8	62.7	62.8	62.8	62.8	62.8	62.8	62.8	62.8
AC-20M1,F2,LD	63.3	63.1	63.2	63.1	63.2	63.1	63.2	63.1	63.3	63.1	63.2
AC-20M1,F2,FA	61.3	61.4	61.3	61.4	61.2	61.5	61.4	61.3	61.4	61.5	61.4
AC-20,F2,LD	84.5	84.5	84.5	84.5	84.6	84.6	84.6	84.5	84.3	84.6	84.5
AC-20,F2,FA	83.4	83.5	83.4	83.7	83.5	83.3	83.5	83.4	83.3	83.5	83.5
AC-20M1,F1,LD	59.9	60.0	60.0	59.9	59.7	60.0	60.0	60.0	60.2	59.8	60.0
AC-20M1,F1,FA	59.7	59.5	59.6	59.5	59.5	59.7	59.6	59.5	59.5	59.7	59.6
AC-20M2,FA	81.2	81.1	81.1	81.2	81.1	81.2	81.1	81.2	81.2	81.2	81.2
AC-20M3,FA	79.1	78.9	78.8	78.9	79.1	79.0	78.8	79.0	78.9	78.9	78.9
AC-20,F3,FA	84.1	84.0	84.0	84.0	84.0	84.0	84.0	84.0	84.0	84.0	84.0
AC-20	85.5	85.4	85.5	85.4	85.3	85.3	85.5	85.4	85.4	85.4	85.4
AC-20M1	64.1	64.1	64.1	64.1	64.0	64.1	64.0	64.1	64.0	64.1	64.1
AC-20M2	82.5	82.4	82.3	82.5	82.4	82.3	82.4	82.4	82.4	82.5	82.4
AC-20M3	78.1	78.1	78.1	78.2	78.1	78.0	78.3	78.0	78.3	78.1	78.1

Table G6. Fine Mortar G*, Complex Modulus (MPa) Data for the PAV Aged Binder (Test Temperature: 25°C)											
Fine Mortar	Measurement No.										Average Value
	1	2	3	4	5	6	7	8	9	10	
AC-20,LD	1.440	1.450	1.440	1.430	1.430	1.430	1.430	1.420	1.420	1.410	1.430
AC-20,FA	1.560	1.550	1.550	1.550	1.550	1.560	1.540	1.540	1.540	1.540	1.548
AC-20,F1,LD	1.230	1.230	1.230	1.220	1.230	1.230	1.220	1.220	1.210	1.210	1.223
AC-20,F1,FA	1.720	1.710	1.710	1.700	1.690	1.690	1.680	1.680	1.680	1.670	1.693
AC-20M1,LD	1.040	1.040	1.030	1.030	1.030	1.030	1.030	1.030	1.020	1.030	1.031
AC-20M1,FA	8.910	8.880	8.850	8.840	8.810	8.780	8.760	8.710	8.690	8.680	8.791
AC-20M1,F2,LD	1.190	1.180	1.180	1.170	1.180	1.170	1.160	1.170	1.160	1.180	1.174
AC-20M1,F2,FA	1.230	1.220	1.220	1.210	1.210	1.210	1.210	1.200	1.200	1.190	1.210
AC-20	3.420	3.420	3.410	3.420	3.420	3.420	3.410	3.420	3.410	3.410	3.416
AC-20M1	2.710	2.700	2.700	2.710	2.710	2.710	2.710	2.700	2.700	2.700	2.705
AC-20M2	2.790	2.800	2.790	2.800	2.810	2.800	2.810	2.800	2.800	2.800	2.800
AC-20M3	5.210	5.200	5.210	5.200	5.200	5.210	5.200	5.220	5.190	5.210	5.205

Table G7. Fine Mortar δ, Phase Angle Data (degrees) for the PAV Aged Binder (Test Temperature: 25°C)											
Fine Mortar	Measurement No.										Average Value
	1	2	3	4	5	6	7	8	9	10	
AC-20,LD	55.9	55.7	55.7	55.8	55.9	55.8	55.5	56.0	55.8	55.9	55.8
AC-20,FA	55.7	56.0	56.2	55.8	55.9	56.0	55.7	55.9	55.8	56.0	55.9
AC-20,F1,LD	58.0	58.0	57.8	58.0	58.0	57.8	58.1	58.0	57.7	58.1	58.0
AC-20,F1,FA	55.6	55.7	55.7	55.6	55.8	55.8	55.8	56.0	55.8	56.0	55.8
AC-20M1,LD	51.6	51.9	51.9	51.8	51.9	51.7	52.2	51.9	51.7	52.2	51.9
AC-20M1,FA	54.0	54.2	54.1	54.2	54.2	54.3	54.3	54.2	54.4	54.4	54.2
AC-20M1,F2,LD	50.3	50.5	50.6	50.3	50.7	50.4	50.5	50.7	50.5	50.6	50.5
AC-20M1,F2,FA	52.6	52.6	52.8	52.8	53.0	52.9	52.8	52.9	53.1	53.0	52.9
AC-20	54.1	54.1	54.1	54.1	54.1	54.1	54.1	54.1	54.1	54.1	54.1
AC-20M1	48.7	48.7	48.7	48.6	48.5	48.8	48.6	48.8	48.8	48.6	48.7
AC-20M2	54.8	54.6	54.7	54.7	54.6	54.9	54.8	54.6	54.8	54.6	54.7
AC-20M3	47.2	47.3	47.3	47.4	47.4	47.2	47.4	47.3	47.2	47.5	47.3

Table G8
Fine Mortar Bending Beam Rheometer Data
(Test Temperature: -12°C)

Total Mortar	S, Creep Stiffness (MPa)			m, Logarithmic Creep Rate		
	Test 1	Test 2	Average	Test 1	Test 2	Average
AC-20, LD	821	826	824	0.315	0.331	0.323
AC-20, FA	1136	1167	1152	0.330	0.339	0.335
AC-20, F1,LD	789	738	764	0.332	0.365	0.349
AC-20, F1,FA	1145	901	1023	0.276	0.306	0.291
AC-20M1, LD	489	503	496	0.340	0.350	0.345
AC-20M1, FA	632	632	632	0.329	0.320	0.325
AC-20M1, F2,LD	609	619	614	0.310	0.312	0.311
AC-20M1, F2,FA	605	602	604	0.302	0.302	0.302
AC-20	198	210	204	0.350	0.360	0.355
AC-20M1	103	97	100	0.354	0.357	0.356
AC-20M2	158	158	158	0.380	0.382	0.381
AC-20M3	211	219	215	0.322	0.324	0.323

Table G9
Fine Mortar Direct Tension Test Data
(Test Temperature: -12°C)

Total Mortar	Ultimate Tensile Strength (Stress at Failure) (MPa)				
	Test 1	Test 2	Test 3	Test 4	Average
AC-20,LD	7.0325	5.6178	6.0984	6.4659	6.3037
AC-20,FA	4.5994	7.6808	5.5311	4.7622	5.6434
AC-20,F1,LD	5.3077	5.3946	4.5786	3.9425	4.8059
AC-20,F1,FA	0.7292	1.9228	1.4244	1.6781	1.4386
AC-20M1,LD	5.3853	6.3488	5.4923	5.7738	5.7501
AC-20M1,FA	3.5269	8.0274	7.8797	3.5023	5.7341
AC-20M1,F2,LD	2.0535	3.2798	2.8159	1.6535	2.4507
AC-20M1,F2,FA	3.4005	3.3507	2.1933	5.5103	3.6137
AC-20	1.6025	2.5675	2.1962	0.8589	1.8063
AC-20M1	2.6189	2.1478	2.6606	2.6462	2.5184
AC-20M2	1.6985	1.5125	1.5690	1.1788	1.4897
AC-20M3	1.4995	1.9989	2.0461	1.3162	1.7152

Table G10
Fine Mortar Direct Tension Test Data
(Test Temperature: -12°C)

Total Mortar	Tensile Strain at Failure (%)				
	Test 1	Test 2	Test 3	Test 4	Average
AC-20,LD	0.4029	0.4063	0.3776	0.3197	0.4516
AC-20,FA	0.2744	0.6027	0.3856	0.2546	0.3793
AC-20,F1,LD	0.4075	0.3614	0.2910	0.2596	0.3299
AC-20,F1,FA	0.0280	0.0398	0.0002	0.0199	0.0220
AC-20M1,LD	3.7174	2.5187	2.5559	3.6786	3.1177
AC-20M1,FA	0.2647	1.5070	1.8346	0.3282	0.9836
AC-20M1,F2,LD	0.1393	0.3293	0.1541	0.0673	0.1725
AC-20M1,F2,FA	0.2905	0.2164	0.1343	0.3476	0.2472
AC-20	0.5860	1.0532	0.8253	0.2081	0.6682
AC-20M1	3.2459	1.7383	2.6621	2.7161	2.5906
AC-20M2	0.7201	0.4027	0.5698	0.4281	0.5302
AC-20M3	0.4934	0.6731	0.6971	1.0456	0.7273

Table G11
Total Mortar Bending Beam Rheometer Data
(Test Temperature: -12°C)

Total Mortar	S, Creep Stiffness (MPa)			m, Logarithmic Creep Rate		
	Test 1	Test 2	Average	Test 1	Test 2	Average
AC-20, LD	998	830	914	0.390	0.380	0.385
AC-20, FA	1322	1469	1396	0.280	0.290	0.285
AC-20, F1,LD	831	759	795	0.360	0.370	0.365
AC-20, F1,FA	1220	1107	1164	0.340	0.320	0.330
AC-20, F2,LD	883	732	808	0.400	0.410	0.405
AC-20M1, LD	532	505	519	0.410	0.410	0.410
AC-20M1, FA	781	715	748	0.340	0.340	0.340
AC-20M1, F1,LD	511	492	502	0.380	0.380	0.380
AC-20M1, F1,FA	883	946	915	0.340	0.340	0.340
AC-20M1, F2,LD	484	480	482	0.390	0.390	0.390

Table G12
Total Mortar Resilient Modulus Data
(Test Temperature: 5°C)

Total Mortar	Resilient Modulus (ksi)			
	Test 1	Test 2	Test 3	Average
AC-20, LD	100.6	93.9	111.4	102.0
AC-20, FA	202.2	201.8	169.3	191.1
AC-20, F1,LD	100.3	106.9	101.0	102.7
AC-20, F1,FA	115.2	131.2	202.8	149.7
AC-20, F2,LD	121.5	128.0	139.4	129.6
AC-20M1, LD	92.9	84.0	79.5	85.5
AC-20M1, FA	102.9	93.0	91.2	95.7
AC-20M1, F1,LD	86.4	101.1	94.6	94.0
AC-20M1, F1,FA	98.6	111.2	118.7	109.5
AC-20M1, F2,LD	65.5	69.2	64.3	66.3

Table G13
Total Mortar Indirect Tensile Strength Data
(Test Temperature: 5°C)

Total Mortar	Indirect Tensile Strength (psi)			
	Test 1	Test 2	Test 3	Average
AC-20, LD	108.1	125.5	130.8	121.5
AC-20, FA	165.8	153.8	139.9	153.2
AC-20, F1,LD	131.9	120.8	102.8	118.5
AC-20, F1,FA	145.7	142.6	148.8	145.7
AC-20, F2,LD	128.2	126.5	119.7	124.8
AC-20M1, LD	90.0	92.5	92.3	91.6
AC-20M1, FA	133.1	127.8	123.2	128.0
AC-20M1, F1,LD	97.6	97.3	91.9	95.6
AC-20M1, F1,FA	99.5	103.7	102.6	101.9
AC-20M1, F2,LD	76.5	77.5	76.1	76.7

Table G14
Total Mortar Indirect Tensile Strain at Failure Data
(Test Temperature: 5°C)

Total Mortar	Indirect Tensile Strain at Failure			
	Test 1	Test 2	Test 3	Average
AC-20, LD	0.0315	0.0315	0.0306	0.0312
AC-20, FA	0.0297	0.0297	0.0270	0.0288
AC-20, F1,LD	0.0306	0.0247	0.0225	0.0259
AC-20, F1,FA	0.0279	0.0306	0.0261	0.0282
AC-20, F2,LD	0.0288	0.0279	0.0279	0.0282
AC-20M1, LD	0.0279	0.0261	0.0261	0.0267
AC-20M1, FA	0.0256	0.0274	0.0265	0.0265
AC-20M1, F1,LD	0.0280	0.0274	0.0288	0.0281
AC-20M1, F1,FA	0.0268	0.0255	0.0168	0.0230
AC-20M1, F2,LD	0.0270	0.0270	0.0270	0.0270

Table G15
Total Mortar Brookfield Viscosity Data
(Test Temperature: 175°C)

Total Mortar	Brookfield Viscosity (cP)			
	Measurement 1	Measurement 2	Measurement 3	Average
AC-20, LD	4325	4325	5275	4642
AC-20, FA	*****	*****	*****	*****
AC-20, F1,LD	4800	4612	4887	4766
AC-20, F1,FA	*****	*****	*****	*****
AC-20, F2,LD	3662	3887	8325	3791
AC-20M1, LD	8400	8438	9100	8646
AC-20M1, FA	*****	*****	*****	*****
AC-20M1, F1,LD	11830	12010	12270	12037
AC-20M1, F1,FA	*****	*****	*****	*****
AC-20M1, F2,LD	11750	11725	11337	11604

*****Material too stiff for equipment to measure viscosity.

APPENDIX H -
Moisture Susceptibility Test Results

Table H1 - Moisture susceptibility results for the granite SMA mix design.

Property	Conditioned Samples			Unconditioned Samples		
Sample Number	1	2	3	1	2	3
Air Voids, %	6.7	5.1	4.9	5.4	6.1	6.2
Saturation, %	64.2	74.3	68.5	-	-	-
Breaking Strength, kPa	509	507	758	932	918	869

Table H2 - Moisture susceptibility results for the Florida limestone SMA mix design.

Property	Conditioned Samples			Unconditioned Samples		
Sample Number	1	2	3	1	2	3
Air Voids, %	5.9	5.5	5.2	5.6	5.2	5.7
Saturation, %	62.4	72.0	68.8	-	-	-
Breaking Strength, kPa	531	425	539	771	863	738

Table H3 - Moisture susceptibility results for the granite dense-graded mix.

Property	Conditioned Samples			Unconditioned Samples		
Sample Number	1	2	3	1	2	3
Air Voids, %	6.3	6.4	3.8	6.4	6.6	6.2
Saturation, %	74.3	74.8	68.8	-	-	-
Breaking Strength, kPa	531	461	436	997	1062	1062

Table H4 - Moisture susceptibility results for the Florida limestone dense-graded mix.

Property	Conditioned Samples			Unconditioned Samples		
Sample Number	1	2	3	1	2	3
Air Voids, %	7.1	8.3	8.3	7.9	8.0	8.0
Saturation, %	78.8	76.1	77.7	-	-	-
Breaking Strength, kPa	585	577	628	1016	1109	1022

Table H5 - Moisture susceptibility results for the gravel dense-graded mix.

Property	Conditioned Samples			Unconditioned Samples		
Sample Number	1	2	3	1	2	3
Air Voids, %	8.3	6.0	6.0	6.0	6.4	6.5
Saturation, %	58.4	56.2	59.2	-	-	-
Breaking Strength, kPa	380	479	611	1036	1023	1029

Table H6 - Moisture susceptibility results for the limestone dense-graded mix.

Property	Conditioned Samples			Unconditioned Samples		
Sample Number	1	2	3	1	2	3
Air Voids, %	7.4	8.0	8.1	7.8	7.9	8.1
Saturation, %	61.3	67.3	66.3	-	-	-
Breaking Strength, kPa	1038	889	949	1325	1285	1244

Table H7 - Moisture susceptibility results for the traprock dense-graded mix.

Property	Conditioned Samples			Unconditioned Samples		
Sample Number	1	2	3	1	2	3
Air Voids, %	7.0	8.0	6.7	7.6	7.6	6.7
Saturation, %	65.8	60.7	58.1	-	-	-
Breaking Strength, kPa	655	639	720	988	1094	1078

Table H8 - Moisture susceptibility results for the granite gradation number 1 mix design.

Property	Conditioned Samples			Unconditioned Samples		
Sample Number	1	2	3	1	2	3
Air Voids, %	6.3	5.9	6.5	6.3	5.7	6.8
Saturation, %	55.0	55.7	62.0	-	-	-
Breaking Strength, kPa	532	500	495	1181	1196	933

Table H9 - Moisture susceptibility results for the granite gradation number 2 mix design.

Property	Conditioned Samples			Unconditioned Samples		
Sample Number	1	2	3	1	2	3
Air Voids, %	5.4	5.3	5.2	5.1	6.0	5.1
Saturation, %	56.1	55.3	61.8	-	-	-
Breaking Strength, kPa	500	606	466	688	674	805

Table H10 - Moisture susceptibility results for the granite gradation number 3 mix design.

Property	Conditioned Samples			Unconditioned Samples		
Sample Number	1	2	3	1	2	3
Air Voids, %	6.0	6.6	6.0	6.3	5.9	6.0
Saturation, %	63.6	74.4	59.6	-	-	-
Breaking Strength, kPa	420	439	472	722	782	726

Table H11 - Moisture susceptibility results for the granite gradation number 4 mix design.

Property	Conditioned Samples			Unconditioned Samples		
Sample Number	1	2	3	1	2	3
Air Voids, %	5.4	7.2	-	6.1	6.6	-
Saturation, %	63.3	72.0	-	-	-	-
Breaking Strength, kPa	513	346	-	789	763	-

Table H12 - Moisture susceptibility results for the granite gradation number 7 mix design.

Property	Conditioned Samples			Unconditioned Samples		
Sample Number	1	2	3	1	2	3
Air Voids, %	5.3	6.0	5.3	5.5	5.5	5.4
Saturation, %	72.1	71.1	60.1	-	-	-
Breaking Strength, kPa	407	391	553	850	844	864

Table H13 - Moisture susceptibility results for the granite gradation number 8 mix design.

Property	Conditioned Samples			Unconditioned Samples		
Sample Number	1	2	3	1	2	3
Air Voids, %	5.3	5.0	5.6	5.1	5.0	5.6
Saturation, %	68.4	55.9	58.6	-	-	-
Breaking Strength, kPa	446	463	472	696	725	659

Table H14 - Moisture susceptibility results for the granite gradation number 9 mix design.

Property	Conditioned Samples			Unconditioned Samples		
Sample Number	1	2	3	1	2	3
Air Voids, %	5.4	5.5	6.2	5.6	5.7	5.7
Saturation, %	57.6	61.1	58.5	-	-	-
Breaking Strength, kPa	465	497	442	900	880	794

Table H15 - Moisture susceptibility results for the Florida limestone gradation number 1 mix design.

Property	Conditioned Samples			Unconditioned Samples		
Sample Number	1	2	3	1	2	3
Air Voids, %	6.3	5.0	5.9	5.5	6.2	5.2
Saturation, %	72.0	*	78.0	-	-	-
Breaking Strength, kPa	562	*	620	989	926	1149

* - Specimen was damaged during conditioning.

Table H16 - Moisture susceptibility results for the Florida limestone gradation number 2 mix design.

Property	Conditioned Samples			Unconditioned Samples		
Sample Number	1	2	3	1	2	3
Air Voids, %	5.0	6.9	6.9	6.0	6.8	6.0
Saturation, %	*	71.4	76.2	-	-	-
Breaking Strength, kPa	*	406	448	976	824	923

* - Specimen was damaged during conditioning.

Table H17 - Moisture susceptibility results for the Florida limestone gradation number 3 mix design.

Property	Conditioned Samples			Unconditioned Samples		
Sample Number	1	2	3	1	2	3
Air Voids, %	5.4	6.8	7.0	6.2	6.3	6.4
Saturation, %	73.6	59.8	70.1	-	-	-
Breaking Strength, kPa	393	392	446	793	740	631

Table H18 - Moisture susceptibility results for the Florida limestone gradation number 4 mix design.

Property	Conditioned Samples			Unconditioned Samples		
Sample Number	1	2	3	1	2	3
Air Voids, %	6.8	5.5	6.9	6.3	6.4	6.6
Saturation, %	60.6	57.4	67.0	-	-	-
Breaking Strength, kPa	347	290	439	600	758	725

Table H19 - Moisture susceptibility results for the Florida limestone gradation number 7 mix design.

Property	Conditioned Samples			Unconditioned Samples		
Sample Number	1	2	3	1	2	3
Air Voids, %	6.2	5.0	5.9	5.5	5.9	5.9
Saturation, %	*	75.6	76.7	-	-	-
Breaking Strength, kPa	*	437	395	612	572	630

* - Specimen was damaged during conditioning.

Table H20 - Moisture susceptibility results for the Florida limestone gradation number 8 mix design.

Property	Conditioned Samples			Unconditioned Samples		
Sample Number	1	2	3	1	2	3
Air Voids, %	5.9	5.9	5.9	5.3	6.3	6.0
Saturation, %	56.5	73.9	66.8	-	-	-
Breaking Strength, kPa	397	484	494	684	729	709

Table H21 - Moisture susceptibility results for the Florida limestone gradation number 9 mix design.

Property	Conditioned Samples			Unconditioned Samples		
Sample Number	1	2	3	1	2	3
Air Voids, %	5.9	5.8	5.7	6.6	5.1	5.2
Saturation, %	66.0	68.8	56.5	-	-	-
Breaking Strength, kPa	431	390	453	483	825	935