Quality Management of HMA Construction Using Superpave Equipment: A Case Study

R. MICHAEL ANDERSON, ROBERT D. BOSLEY, AND PHILIP A. CREAMER

This report describes the results of a case study to evaluate the quality management of asphalt mixtures using equipment developed as part of the Strategic Highway Research Program (SHRP). The final product of SHRP was a collection of products known as Superpave™, **Su**perior **Per**forming Asphalt **Pave**ments. SHRP research involved the development of the Superpave system. While much asphalt mixtures work was performed in the laboratory, very little had been attempted in practice. This case study focused on the testing and field quality control of an intermediate course mixture on an interstate highway in Lexington, Kentucky. Specifically, a field sampling and testing plan was initialized to examine the sensitivity of the Superpave Gyratory Compactor (SGC) to changes in materials components. In addition to evaluating the SGC, Marshall specimens were produced and analyzed. In this manner, both compaction techniques were directly compared. Test results indicated that the SGC procedure is highly sensitive to changes in materials components, particularly asphalt content and dust content. In addition, the SGC procedure resulted in specimens with reduced variability within a set. The testing time was not significantly increased using the SGC procedure compared to the Marshall procedure.

Five years of research by the Strategic Highway Research Program (SHRP) culminated in a new set of test procedures and specifications for asphalt binders and mixtures. These tests were collectively incorporated into a system known as Superpave™, **Su**perior **Per**forming Asphalt **Pave**ments (*1*). Initial validation of this system was a series of special pavement studies identified as SPS–9(P) projects. These projects were intended to be designed and constructed using Superpave technology.

By the end of 1993, seven SPS–9(P) projects had been designed and constructed using Superpave. However, only Level 1 mix designs were performed for these projects. Level 1 mix design is the critical first step of all mix design and analysis procedures in Superpave. It involves determining an acceptable combination of asphalt binder and mineral aggregates to satisfy certain mixture criteria. The main equipment used for this evaluation is the Superpave Gyratory Compactor (SGC). Through the Level 1 mix design, mixture volumetric and densification properties can be determined for a given combination of materials.

Although the seven SPS–9(P) projects were designed using Level 1 techniques, not all of the projects used the SGC for field control. As part of a cooperative effort with the Federal Highway Administration (FHWA), the Kentucky Department of Highways (KDOH) requested assistance in testing two asphalt mixtures for a project on the common section of Interstate Highways (IH) 64 and 75 in Lexington. The proximity of the project to the Asphalt Institute Research Center presented an excellent opportunity for a cast study of the utility of Superpave for laboratory analysis and field control.

Asphalt Institute, P.O. Box 14052, Lexington, Ky. 40512–4052.

PROJECT BACKGROUND

This project involved the resurfacing of the common section of IH–64 and IH–75 in Lexington, Kentucky. This section of roadway is one of the most heavily traveled pavements in the state. All paving was accomplished at night and other off-peak periods. The design traffic was determined to be 34 million equivalent single axle loads (ESALs) for the 20-year design life of the overlay. The resurfacing consisted of 25,000 tonnes each of two mixtures: a 38-mm-thick intermediate course meeting KDOH gradation and mixture requirements and a 38-mm-thick wearing course. This case study focused only on the intermediate course.

Because this project was bid under KDOH specifications (*2*), the mixtures were tested and approved using standard KDOH tests. As a result, the intermediate course material components, gradation, and design asphalt binder content were approved based on KDOH specifications.

The testing plan included performing a Level 1 mix design for the intermediate course and evaluating the mixture properties. After the laboratory properties had been identified to be at the KDOH-recommended design asphalt binder content, field sampling and testing would begin. Specifically, field testing would focus on using the SGC for determining mixture properties. The speed of testing using the SGC and the sensitivity of the SGC to changes in material components, such as asphalt binder content, were the two primary concerns when incorporating Level 1 mix technology into field quality control practices.

LABORATORY TESTING

A typical Level 1 mix design consists of four phases: selection and testing of component materials; selection of a design aggregate structure; selection of a design asphalt binder content; and evaluation of moisture sensitivity. Due to the circumstances of the project, not all testing phases were necessary.

Selection and Testing of Component Materials

In this phase of laboratory testing, the designer selects possible materials for use in the mix design. For this mixture, all materials were selected by the contractor, Central Kentucky Asphalt (CKA). The aggregates selected were locally available materials consisting of two sizes of crushed limestone coarse aggregate, a crushed limestone fine aggregate, and a natural river sand. The asphalt binder selected was required to meet KDOH specifications for a polymer modified asphalt, polymer modified asphalt cement (PMAC) ID (*3*). Instead of a PMAC–ID, a PG 76–28 asphalt binder would be accepted.

The contractor selected a supplier of the PMAC–ID asphalt binder, and it was sampled and tested. Test data indicated that the selected PMAC–ID asphalt binder did not meet any Superpave grade. The rolling thin film oven (RTFO) mass loss (−1.02 percent) was higher than the allowable maximum mass loss. Otherwise, the asphalt binder would be classified as a PG 70–22.

Aggregate testing normally involves individual testing of the different aggregates available for use in the mix design. Superpave uses four aggregate tests for quality: coarse aggregate angularity, thin and elongated particles, fine aggregate angularity, and sand equivalent. All four tests were performed on the selected *blend* of aggregates. The criteria are based on traffic and pavement layer position. In addition to the four Superpave tests, wet sieve gradation and specific gravity tests were also required for the aggregate blend. The combined gradation must meet Superpave-recommended gradation limits for a certain mixture type. In this case, the combined gradation was required to meet KDOH specifications for an intermediate course. The nominal maximum size of the mixture could be either 19 mm or 12.5 mm.

A combined gradation was selected consisting of 60 percent crushed limestone coarse aggregate and 40 percent fine aggregate (24 percent crushed limestone sand and 16 percent natural sand). The gradation met both the Superpave requirements for a 12.5-mm nominal mixture and a KDOH intermediate course mixture (*1*). Figure 1 illustrates the combined gradation with the KDOH and Superpave gradation limits.

The aggregate blend met all Superpave aggregate criteria except for fine aggregate angularity. The fine aggregate angularity of the blend was 42 percent, whereas Superpave would have required a minimum of 45 percent.

Selection of Design Aggregate Structure

Normally, this phase involves evaluating several combinations of aggregates to develop a design aggregate structure. However, the aggregate structure had been developed by the contractor and approved by KDOH. Therefore this phase of testing was unnecessary.

Selection of Design Asphalt Binder Content

In this phase of a Level 1 mix design, varying asphalt binder contents are combined with the design aggregate structure to determine the response of the mixture properties to changes in asphalt binder content. A design asphalt content is selected based on the ability of the mixture to meet Superpave criteria. The design asphalt content for this mixture was selected by KDOH as 4.5 percent asphalt binder (by weight of the mix). To establish the mixture properties, the design aggregate structure was evaluated by the SGC procedure using four asphalt contents: 4.0 percent, 4.5 percent, 5.0 percent, and 5.5 percent. In addition, the mixture properties were evaluated using the Marshall mix design method, but only at the 4.5 percent design asphalt content.

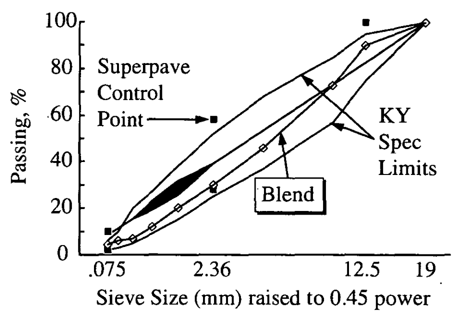

FIGURE 1 Intermediate coarse mixture gradation.

All specimens compacted using the SGC were prepared in the same manner. For each specimen, approximately 5,000 g of mixture was mixed at 160°C and placed in a shallow, flat pan. The mix was then placed in a forced draft oven operating at 135°C for 3.5 hr. After 3.5 hr, the mix was transferred to another forced draft oven operating at 160°C for 30 min. This last step was intended to bring the mix to the required compaction temperature, 143°C. The mix was then loaded into a mold and compacted using the SGC procedure (1.25° angle of gyration, 600 kPa vertical pressure, 30 gyrations/min). Compaction proceeded to the maximum number of gyrations ($N_{maximum}$) determined from the project climate and traffic. For this project, $N_{maximum}$ was 204 gyrations. After the compacted specimen was ejected from the mold, it was allowed to cool to room temperature. The bulk specific gravity (G_{mb}) of the mixture specimen was determined. This information, along with the compaction heights at each gyration, and the maximum theoretical specific gravity of the mixture (G_{mm}), was used to determine the compacted mixture density as a function of the number of gyrations. Three levels of compaction are observed in the level 1 mix design: an initial number of gyrations, $N_{initial}$ (9 gyrations); a design number of gyrations, N_{design} (126 gyrations); and a maximum number of gyrations, $N_{maximum}$ (204 gyrations). The mixture density at $N_{initial}$ and $N_{maximum}$ is used to determine the mixture densification properties. There are criteria for each of these values. The mixture density at N_{design} is the most important. This is the compaction level used to determine the mixture volumetric properties. Likewise, it is used to determine the design asphalt content. The mixture properties for the aggregate blend were determined by the SGC procedure and are indicated in Table 1.

Three Marshall specimens were prepared at 4.5 percent asphalt content. For each specimen, approximately 1,200 g of mixture was mixed at 160°C and placed in the compaction mold. The mold was then covered and placed in a forced draft oven operating at 143°C for 1.5 hr. This short-term aging is a KDOH requirement. After 1.5 hr, the mold was removed from the oven, and the mix was compacted. After the compacted specimen cooled to room temperature, it was ejected from the mold. The bulk specific gravity (G_{mb}) of the mixture specimen was determined. Mixture properties for the Marshall specimens are indicated in Table 2 along with the SGC data at 4.5 percent asphalt binder content. Superpave and KDOH criteria are also indicated in Table 2.

Evaluation of Moisture Sensitivity

In this phase, the design asphalt mixture (design aggregate structure at the design asphalt binder content) is tested using AASHTO T–283 to evaluate the moisture sensitivity of the mixture. Specimens are compacted to dimensions of 150 mm in diameter and 95 mm high using the SGC. These specimens have approximately 7 percent air voids at the completion of compaction. Two subsets of specimens are tested: a control subset and a conditional subset. The

TABLE 1 Superpave Gyratory Compactor Mixture Properties

	Asphalt Binder Content			
Property[a]	4.0%	4.5%	5.0%	5.5%
%Air Voids	4.8	3.5	2.2	1.4
%VMA	12.2	12.1	12.1	12.5
%VFA	60.7	71.5	81.5	88.6
Dust Proportion	1.4	1.2	1.1	1.0
%G_{mm} @ $N_{initial}$	84.8	85.9	86.9	87.6
%G_{mm} @ $N_{maximum}$	96.5	97.9	99.1	99.8

[a]Properties determined at N_{design} except where noted.

TABLE 2 SGC and Marshall Mixture Properties at 4.5 Percent Asphalt Content

	Compaction		Criteria	
Property	SGC[a]	Marshall-75	Superpave[a]	KDOH
%Asphalt Binder	4.5	4.5	n/a	n/a
%Air Voids	3.5	4.9	4.0	3.5 - 6.0
%VMA	12.1	13.5	14.0 min.	13.5 min.
%VFA	71.5	63.7	65 - 75	--
%G_{mm} at $N_{initial}$	85.9	--	89 max.	--
%G_{mm} at $N_{maximum}$	97.9	--	98 max.	--
Dust Proportion	1.2	--	0.6 - 1.2	--

[a]Property measured at N_{design}, 126 gyrations, except where noted.
"--" indicates data not applicable.

conditioned subset specimens are subjected to partial saturation, freezing, and hot water soaking before testing in indirect tension. The control subset is tested in indirect tension without conditioning. The ratio of the average tensile strength of the conditioned subset to the average tensile strength of the unconditioned subset is calculated as the mixture's tensile strength ratio (TSR).

The TSR for the design asphalt mixture was 90 percent, with average tensile strengths of 778 kPa for the conditioned subset and 862 kPa for the unconditioned (control) subset. The Superpave Level 1 mix design requires a minimum TSR of 80 percent.

FIELD TESTING

The field sampling consisted of obtaining 10 samples from a 10,000-tonne lot of HMA. A stratified random sampling plan was used to divide the 10,000-tonne lot into ten 1,000-tonne sublots. From these 10 sublots, a randomly selected tonnage was determined for sampling.

Sampling began after CKA had produced approximately 10,000 tonnes of mixture. For sampling purposes, the first ton was designated at the beginning of the first night of sampling. The actual tonnage values were calculated based on the quantity of tonnage produced since the beginning of sampling.

All the samples were obtained from the haul trucks at CKA's plant. A sample consisted of approximately 20,000 g of mixture loaded into an insulated, 20-L container. After collecting the sample, the insulated container was loaded into an insulated carrier. Because the hot-mix plant was 15 min from the Asphalt Institute's laboratory, the insulated containers were needed to maintain the mix temperature during transportation.

Preparation of Samples

When the sample arrived at the laboratory, the temperature of the mix was determined. In most cases, the temperature was the same as the temperature determined from the haul trucks (≈165°C). The mix sample was placed onto a quartering table and quartered initially to obtain the proper amount of material (10,000 g) for compacting two SGC specimens for volumetric testing. Opposite quarters were individually placed in metal pans and then into an oven operating at 148°C, so the mixture could be heated to the required compaction temperature (143°C). The remaining mix was recombined and quartered a second time. Opposite quarters were selected and separated to determine the mixture's maximum theoretical specific gravity by ASTM D2041. The remaining two quarters were recombined and quartered a third time. Three of the quarters were individually placed into metal pans and then into the 148°C oven. These specimens were prepared for compaction by the Marshall procedure (ASTM 1559). The final quarter was allowed to cool and then used for extraction and gradation testing by ASTM D2172.

After quartering, the mixture was very near the 143°C compaction temperature. As such, the samples used for compaction were heated less than 5 min. The compaction of the field samples was identical to the compaction of the laboratory samples. SGC specimens were compacted to $N_{maximum}$ (204 gyrations). Marshall specimens were compacted using 75 blows.

Data Analysis

The purpose of the field sampling plan was to evaluate the utility of the SGC for field control. The plan was centered on the control of

two items: mixture components (asphalt content, aggregate gradation) and mixture volumetric and densification properties (percentage of air voids, etc.). Currently, at least one of these two controls are used for quality control throughout the United States.

Asphalt Binder Content

An extraction test was performed using ASTM D2172 once per sample. Trichloroethane was used as the solvent for the extractions. The extracted asphalt binder content is indicated in Figure 2 for each sample. As Figure 2 indicates, the asphalt binder content, as determined by solvent extraction, was generally higher than the design asphalt content. For one sample (Sample 1600), the asphalt content was 4.9 percent, exceeding the upper control limit.

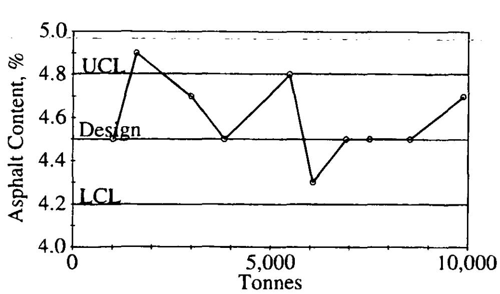

FIGURE 2 Extracted asphalt binder content for field samples.

Mixture Maximum Theoretical Specific Gravity

Although this is a mixture test used for determining a compacted specimen's volumetric and densification properties, it can also be used to estimate the asphalt binder content of the mix sample. To estimate the asphalt content from the G_{mm}, an effective specific gravity of the aggregate (G_{se}) must be assumed. For field control, the G_{se} was assumed to be the same value used for mix design. If the proportions of the aggregates vary significantly during production, and the specific gravities of the component aggregates differ by a large amount, the estimated G_{se} may be invalid. However, for this mixture, 84 percent of the aggregate was from the same quarry. The estimated G_{se} would change only if the relative proportion of crushed limestone (84 percent) to natural sand (16 percent) changed significantly. Figure 3 indicates the G_{mm} for each sample. Figure 4 is a comparison of the extracted asphalt content and the estimated asphalt content from the sample's G_{mm}.

As indicated in Figure 4, the estimated asphalt content from the G_{mm} is generally within 0.2 percent of the asphalt content determined from solvent extraction. Only Sample 1600 has significantly different test results. In general, the estimated asphalt content from the measured G_{mm} corroborates the asphalt content determined from solvent extraction.

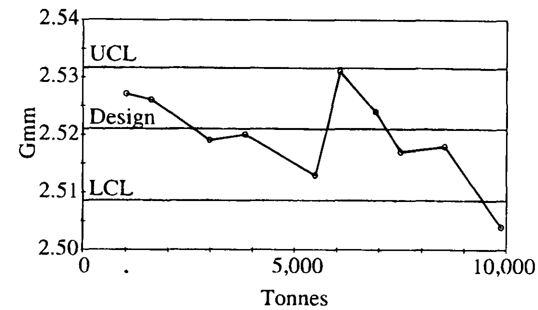

FIGURE 3 Maximum theoretical specific gravity (G_{mm}) of field samples.

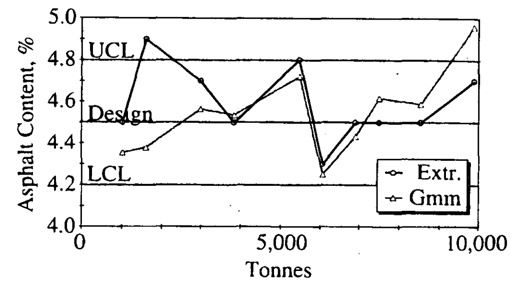

FIGURE 4 Comparison of asphalt content determined by solvent extraction and G_{mm}.

Aggregate Gradation

The gradation of the aggregate was determined by wet-sieve analysis (ASTM C117 and C136) after extraction. For analysis, four control sieves were used: 12.5-mm sieve; 9.5-mm sieve; 2.36-mm sieve; and 0.075-mm sieve. The 12.5- and 9.5-mm sieves were used to determine the nominal maximum size of the aggregate. The 2.36-mm sieve was used as a Superpave control point as an indication of the proportion of coarse and fine material. The 0.075-mm sieve was used as a Superpave control point as an indication of the dust in the mixture. Figure 5 indicates the extracted gradations for the three coarse sieves. Figure 6 indicates the amount of material finer than 0.075 mm in the extracted aggregate.

As is indicated in Figure 5, the aggregate gradation tended to get coarser as the sampling progressed. Interestingly, the percentage of material passing the 12.5-mm sieve decreased below 90 percent for all but two samples. The mixture as produced was not a 12.5-mm nominal mixture, but a 19-mm nominal mixture.

Figure 6 indicates gradation trends the opposite of Figure 5. The amount of material finer than the 0.075-millimeter sieve remained relatively constant, but 1 to 1½ percent finer than the design value.

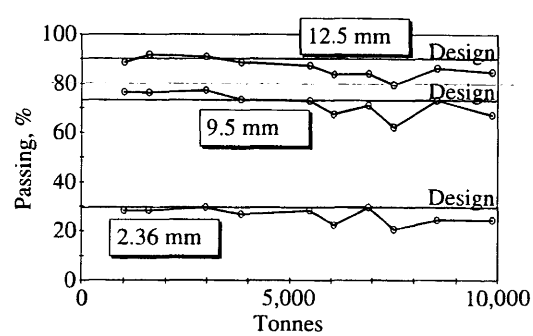

FIGURE 5 Extracted aggregate gradation—coarse sieves.

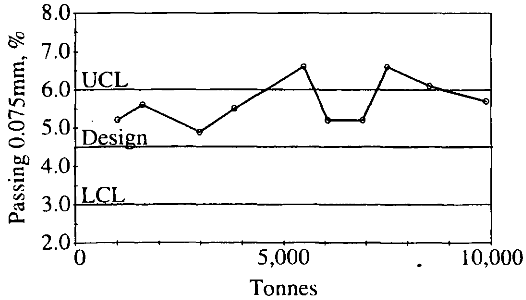

FIGURE 6 Extracted aggregate gradation—material finer than 0.075 mm.

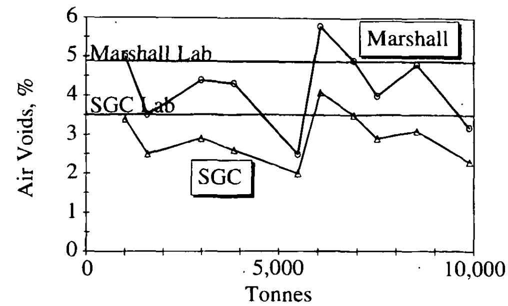

FIGURE 8 Percentage of air voids in compacted mixture specimens.

To determine if segregation was a problem, a plot was generated of asphalt content as a function of the percentage of material passing the 2.36-mm sieve (*4*). Figure 7 illustrates those data.

The relatively low R^2 and slope of the best fit line indicate that only minor segregation is occurring in the process. The minor segregation of the mixture could be occurring anywhere downstream from the mixing chamber through the sampling from the haul trucks. As a result of this diagnostic check, it was assumed that the test samples were properly collected and could be used for further analysis.

Mixture Volumetric and Densification Properties

Mixture volumetric and densification properties were determined using the SGC and the Marshall procedures. From SGC specimen height measurements taken during compaction, the mixtures G_{mb} and G_{mm}, the densification of the mixture, and likewise the volumetric properties of the mixture were determined. The percentage of air voids in the compacted specimens at N_{design} was the most important piece of information. For field control of HMA using mixture volumetrics, it is necessary to have a compaction procedure that will allow changes in critical mixture components, such as the percentage of asphalt binder, to be reflected in the volumetric and densification properties of the mixture. Figure 8 indicates the percentage of air voids in the mixture for the SGC specimens, at N_{design}, and the 75-blow Marshall specimens.

As indicated in Figure 8, the percentage of air voids was lower than the design for 8 of the 10 samples. Values for the percentage of VMA and the percentage of VFA closely followed the trends established by the percentage of air voids for both the SGC and Marshall specimens. The percentage of VMA was generally lower, and the percentage of VFA was higher than the design values for the 10 samples.

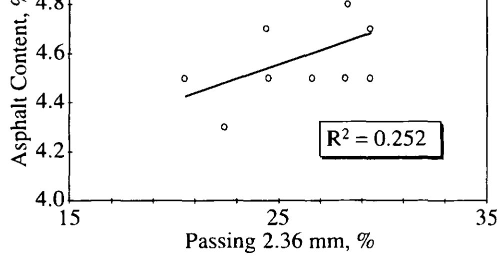

FIGURE 7 Mixture diagnostics—segregation.

Sensitivity of Compaction Procedure to Mixture Component Changes

As stated earlier, it is imperative for field control that a compaction procedure is sensitive to changes in critical mixture components. Of the mixture components, the asphalt content and percentage of material finer than 0.075 mm are considered by some to be the most critical (*5*). Research completed during SHRP (*6*) indicated that the SGC appeared to be most sensitive to changes in these two components. However, little field control testing had been performed at the time of that research.

As part of the Level 1 mix design, trial specimens are produced during the Design Aggregate Structure phase for various aggregate blends. The purpose of this phase is to evaluate the aggregate structures on an equal air voids basis. Because a single trial asphalt content is used for the trial specimens, estimates must be made of the design asphalt content—that is the asphalt content at which the compacted SGC specimens would have 4 percent air voids at N_{design}. The equation used for this estimate relates asphalt content to air voids by a 0.4 factor. A 1 percent change in air voids results in an estimated 0.4 percent change in asphalt content (*1*).

Using the equation relating a change in air voids to a change in asphalt content, it was possible to determine an estimated asphalt content from the SGC specimen air voids. Figure 9 illustrates the SGC specimen air voids and the extracted asphalt content for the field samples.

The scales of the two ordinate axes were fixed so that a 1.0 percent change in air voids for one axis resulted in a change of 0.4 percent on the asphalt content axis. The design line was also fixed so that the design asphalt content was the same line as the design air voids.

If the equation relating air voids and asphalt content was correct, the two curves would be coincident. This hypothesis requires the assumption that the air voids are unaffected by any factors other than asphalt content. As stated earlier, research has indicated that the material finer than the 0.075-mm sieve has a significant effect on air voids as well. However, Figure 6 indicates that while the amount of dust was higher than the design, it was consistently high. Because the −0.075 mm material was relatively consistent, it was initially treated as a constant in the relationship between air voids and asphalt content, as illustrated in Figures 9 and 10.

Figure 9 indicates that the two curves for percentage of SGC air voids and extracted asphalt content are similar. Five data

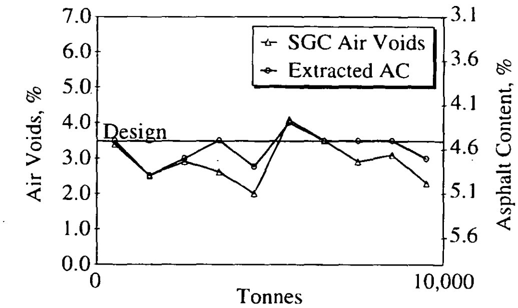

FIGURE 9 SGC air voids and extracted asphalt content.

points need explanation: Samples 3829, 5478, 7512, 8534, and 9883.

The data from Samples 7512 and 8534 indicate that the asphalt content is at the design value, but the percentage of air voids are slightly lower than design value (approximately 0.5 percent). These are two of the samples with the highest amount of material finer than 0.075 mm. However, Figures 5 and 6 also indicate that both samples were generally coarser than the design gradation on the coarse sieves. The combination of the two effects resulted in SGC specimens with air voids slightly less than the design value.

The data from Samples 3829, 5478, and 9883, as seen in Figure 9, indicate that the SGC air voids are not as strongly related to the asphalt content. In particular, the air voids were lower (more than 0.5 percent lower) than could be explained by asphalt content. Figures 5 and 6 again offer an explanation for Sample 5478. While the gradation for the coarse sieves was near design values, the amount of −0.075-mm material was much higher than the average. In this case, the higher dust content resulted in lower air voids.

Sample 3829 has a gradation near the design gradation for the coarse sieves, an asphalt content at the design value, and a dust content near the average for the 10 samples. The lower air voids cannot be explained by either asphalt content or gradation. The likely possibility is sampling or testing error.

Sample 9883 has a coarse gradation for the coarse sieves, a dust content higher than the average, and an asphalt content that is slightly high. It is likely that the combination of asphalt content and gradation are the cause of the lower air voids.

The same graph was generated for the Marshall compacted specimens and is shown in Figure 10. As indicated in the figure 10, the Marshall air voids are also related to the asphalt content. Figure 10

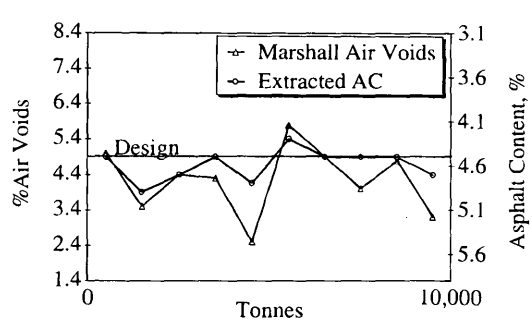

FIGURE 10 Marshall air voids and extracted asphalt content.

also indicates that the greatest variances are in Samples 5478, 7512, and 9883. Samples 5478 and 7512 had high dust contents (Figure 6). Sample 9883 had a combination of coarse gradation, and dust and asphalt contents higher than the design values.

Both Figures 9 and 10 indicate that the SGC and Marshall procedures are sensitive to changes in asphalt content and, to an extent, gradation.

The variability of the test results used for each sample was also investigated and compared with laboratory values. For the field samples, the average difference in air voids of the two SGC specimens was 0.3 percent, and it was 0.6 percent for the three Marshall specimens. For the laboratory design samples (Table 1), the average difference in air voids of the three SGC specimens was 0.1 percent, and it was 0.6 percent for the three Marshall specimens. The SGC procedure appears to produce specimens with less variability. It is unclear whether this reduced variability is solely the result of the compaction procedure. It may also be the result of the larger specimen sizes used in the SGC process; a small error in mass measurements affects G_{mb} less for a large specimen compared with that of a small specimen.

SUMMARY

This project was a case study of quality management of HMA using Superpave technology. Specifically, the purpose of the study was to evaluate the utility of the Superpave Gyratory Compactor for field control. To this end, a laboratory determination of the mixture volumetric properties using the SGC was performed. Field sampling and testing centered on the control of two items: mixture components (asphalt content, aggregate gradation) and mixture volumetric and densification properties. In addition, Marshall volumetric properties were determined from laboratory and field samples to allow a comparison of the two compaction procedures.

The field data indicate that the SGC appears to be acceptable for use as a field control tool. The SGC procedure is very sensitive to changes in asphalt content. Because the amount of material finer than the 0.075-mm sieve was relatively constant over the sampling interval, the sensitivity of the SGC to this factor could not be thoroughly evaluated. The Marshall procedure also appears to be sensitive to changes in asphalt content. However, there is slightly more variability in the test data for the Marshall specimens than the SGC specimens. It is possible that the reduced SGC specimen variability is related to the enlarged specimen size rather than the compaction procedure.

In conclusion, it appears that the SGC procedure is at least as good a field control tool as the Marshall procedure. The SGC provides specimens with reduced variability, which permits more confidence in test results and the potential for better control. Testing time should not be significantly increased when using the SGC procedure.

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REFERENCES

1. Cominsky, R. J., G. A. Huber, T. W. Kennedy, and R. M. Anderson. *The Superpave Mix Design Manual for New Construction and Overlays.* Report SHRP-A-407. Strategic Highway Research Program, Washington, D.C., 1994.
2. Marshall Design Method Criteria, Special Provision 43. Kentucky Transportation Cabinet, Department of Highways, Ky., 1993.
3. Special Note for Polymer-Modified Asphalt Cement (PMAC). Kentucky Transportation Cabinet, Department of Highways, Ky., 1994.
4. Brock, J. D. *Asphalt Cement Content Diagnostic Approach for Hot Mix Asphalt (HMA) Facilities.* Report QIP-109. National Asphalt Pavement Association, 1986.
5. D'Angelo, J. A., and T. Ferragut. Summary of Simulation Studies from Demonstration Project No. 74: Field Management of Asphalt Mixes. *Journal of the Association of Asphalt Paving Technologists,* Volume 60, 1991.
6. Cominsky, R. J., R. B. Leahy, and E. T. Harrigan. *Level One Mix Design: Materials Selection, Compaction, and Conditioning.* Report SHRP-A-408. Strategic Highway Research Program, Washington, D.C., 1994.

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