FINAL REPORT

COMPARISON OF SEVERAL ASPHALT DESIGN METHODS

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ABSTRACT

This laboratory study compared several methods of selecting the optimum asphalt content of surface mixes. Six surface mixes were tested using the 50-blow Marshall design, the 75-blow Marshall design, two brands of SHRP gyratory compactors, and the U.S. Army Corps of Engineers' gyratory testing machine (GTM) with the oil-filled and the air-filled rollers. The Georgia loaded wheel tester (GLWT) was also used in an attempt to define the maximum allowable asphalt content.

The GTM with the air-filled roller and the 75-blow Marshall design produced the largest differences in optimum asphalt content. The two SHRP gyratory compactors gave comparable contents. The lack of rutting with the GLWT at a high asphalt content prevented determining the maximum allowable asphalt content and fulfilling the primary purpose of the study. However, other findings were of interest.

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INTRODUCTION

Virginia has used the Marshall method of asphalt mix design for many years. The method subjects an asphalt-aggregate mixture to a specified compactive effort supplied by a dropping mass and uses the void structure of the compacted specimen to determine the proper asphalt content. The method has served users of asphalt hot mix well for several decades, but problems have developed recently because of increased traffic loads. As traffic becomes heavier, the Marshall method may not duplicate the kneading action of traffic, and achieving the ultimate purpose, the prediction of mix voids after considerable traffic, becomes more difficult.

Duplicating a heavy traffic loading with a dropping mass compaction method is difficult. Other compaction methods tend to produce specimens that have material properties more like those of in-place pavement. Harvey et al.[1] and VonQuintus[2] found differences in engineering properties of specimens compacted by several methods. Although the researchers for the Strategic Highway Research Program's (SHRP) A-003 project preferred the rolling wheel compactor to simulate field compaction, SHRP decided to use the SHRP gyratory compactor because of its relative simplicity.

The U.S. Army Corps of Engineers' gyratory testing machine (GTM) is a compaction device that can also measure the shear strength of the mix while it is being compacted. It can be operated in two modes: with an oil-filled roller or with an air-filled roller. Use of the oil-filled roller, which is essentially incompressible, results in a shear angle being very close to the angle set at the beginning of the test. Use of the air-filled roller, which is compressible, results in a shear angle being dependent on the supporting strength of the mix. Logically, using the air-filled roller should more closely duplicate the compaction caused by traffic because the procedure used for densification more closely replicates the summer pavement temperature. The vertical compaction pressure can be adjusted to match that of the tire pressure on the roadway for both modes of testing. In 1964, Kallas reported the use of the GTM with an oil-filled roller for mix design,[3] and several states have used it to analyze asphalt mixes.

Since different methods may give different results, it was desirable to see how several methods for determining design asphalt content compared. The methods compared were the Marshall design, use of SHRP's gyratory compactor, and use of the GTM. Mixes were selected that had varying degrees of field problems, including tenderness, permanent deformation, and failure to attain specified construction density.

PURPOSE AND SCOPE

The designed optimum asphalt content can vary from method to method depending on the compactive effort, type of compaction, and criteria used to select the optimum value. The aim of this study was to examine the design asphalt contents obtained by several design procedures and determine whether a particular procedure produced better designs.

Six mixes were selected that were reportedly associated with construction and service problems in the field.

METHODOLOGY

General

Since excessive asphalt cement makes a mix susceptible to rutting, a rutting test was used in an attempt to determine the maximum asphalt content that would yield satisfactory performance of the mix. The optimum asphalt content should be slightly less than the asphalt content that causes rutting. It was also desirable to compare the designs and determine whether any of the methods gave different optimum asphalt contents, possibly as a result of detecting mix weakness undetected by the other methods.

Three design procedures were used: the Marshall, the SHRP gyratory compactor, and the GTM. The 50-blow and 75-blow compactive efforts were used for the Marshall procedure. Two brands of compactors were used for the SHRP gyratory testing. Both the oil-filled and air-filled rollers were used with the GTM. Therefore, six series of mix designs were performed for each of the six mixes. The Georgia loaded-wheel tester (GLWT) was used at two asphalt contents near and above the original design asphalt contents in an attempt to determine the maximum tolerable asphalt content.

Test Methods

Marshall Method

The Marshall method of compaction (ASTM D1559)[4] and mix design by volumetric analysis was performed except that the mixing and compaction temperature were kept constant for all mixes at 143 to 147^{o}C. The voids data, such as voids in total mix (VTM), voids in mineral aggregate (VMA), and voids filled with asphalt (VFA), were used to select the design asphalt content. The criteria recommended by the Asphalt Institute and those specified by the Virginia Department of Transportation (VDOT) were both used to select the optimum asphalt content (see Table 1).

Table 1. Marshall design criteria for optimum asphalt content

	Asphalt Institute		VDOT	
	50-blow	**75-blow**	**50-blow**	**75-blow**
VTM, %	3-5	3-5	3-6	3-6
VMA for SM-2, %	>15 @ 4% VTM	>15 @ 4% VTM	>15	>15
VMA for SM-3, %	>14 @ 4% VTM	>14 @ 4% VTM	>14	>14
VFA, %	65-78	65-75	65-80	65-80

SHRP Gyratory Method

The SHRP gyratory compactor is used to perform volumetric design of asphalt mixes. It provides insight into the compactability of the mix for field construction and an indication of the densification that may be caused by traffic. The compactor is used for the three levels of mix design in SHRP Superpave. Level I contains only the volumetric design and is intended for low-traffic roadways. Levels II and III as originally planned by SHRP were to be used for higher trafficked highways and were to require performance tests to validate the initial mix design obtained with the compactor. Levels II and III are not yet available because of the lack of adequate prediction models. The SHRP gyratory results produced average compaction curves for each asphalt content, an example of which is shown in Figure 1.

Criteria for percent of maximum theoretical density are specified for three locations on the compaction curve—$N_{initial}$, N_{design}, and $N_{maximum}$. These criteria are based on the amount of traffic and average high temperature. The criteria for this study were based on a traffic level of 3 to 10 million ESALs and an average high temperature less than 39°C. The corresponding compaction levels were $N_{initial}$ = 8 revolutions, N_{design} = 96 revolutions, and $N_{maximum}$ = 152

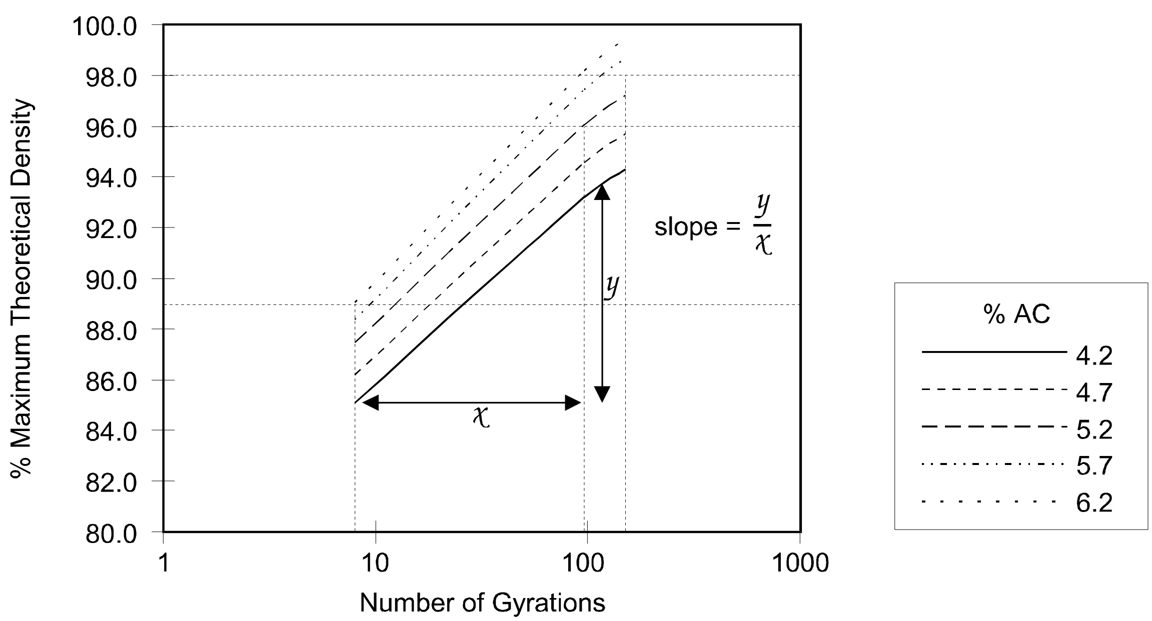

Figure 1. SHRP gyratory compaction curves

revolutions. The voids at $N_{initial}$ is supposed to indicate the tenderness of the mix during compaction, and the percent of maximum theoretical density should be less than 89. Voids at N_{design} should coincide with the design VTM, 4 percent, which represents the mix after construction and trafficking. The voids at $N_{maximum}$ is used as a rutting check. Mixes that compact below 2 percent under traffic commonly rut; therefore, the percent of maximum theoretical density should be less than 98. The minimum VMA requirement was 13.0, 14.0, and 15.0 percent for mixes with nominal aggregate sizes of 19.0, 12.5, and 9.5 mm, respectively. The allowable range of VFA was 65 to 75 percent.

Two brands of compactors, Pine and Troxler, were used to test the mixes. The purpose was to determine whether the brand affected the test results, i.e., the design asphalt content of the mix.

GTM

Oil-filled Roller

The American Society of Testing and Materials' (ASTM) Standard Test Method for Compaction and Shear Properties of Bituminous Mixtures by Means of the U.S. Corps of Engineers Gyratory Testing Machine [4] with several modifications was used to compact the specimens, which were 102 mm in diameter x 64 mm. A model 6B/4C compactor manufactured by Engineering Developments Company, Inc., was used for the tests. Instead of an angle of gyration of 0.017 rad, an angle of 0.013 rad was used with a vertical pressure of 827 kPa. Previous work had indicated that these settings closely approximated the density of pavement after traffic.[5] Also, instead of recording the shear strength and shear strain at 30 and 60 revolutions and then concluding the test, strength and strain values were recorded at regular intervals until the rate of densification decreased to 16 kg/m^3 per 100 revolutions. The compaction was stopped, roller pressure and height were recorded, and the specimen was removed from the machine.

The shear strength was determined by the following formula:

$$S_G = 7.22\, p/h$$

where S_G = gyratory shear strength, kPa
p = roller gage pressure, kPa
h = height of specimen, cm.

The gyratory stability index was determined by the following formula:

$$\mathrm{GSI} = \theta_I/\theta_{end}$$

where GSI = gyratory stability index
θ_I = gyratory shear movement after approximately 30 revolutions, rad

θ_{end} = gyratory shear movement at the end of the test, rad.

Air-filled Roller

The material loading procedure was the same as that used for the oil-filled roller. After the sample was secured in the device, the air-roller pressure was increased to 620 kPa and an angle of gyration of 0.052 rad was applied. Initial work by Ruth et al. at the University of Florida used an angle of 0.052 rad for compaction and traffic densification.[6] A mix was tested initially using 12 turns of the lower roller angle control knob, which normally would have produced 0.052 rad, but the compaction effort was much too severe. The mix was nearly without voids. Subsequently, it was found that an angle of 0.052 rad required only 6 turns of the lower roller angle control knob when the angle calibration was performed with a cold mix. Therefore, 6 turns of the lower roller angle control knob were used to apply a 0.052-rad angle.

After the angle was applied, the roller pressure was reduced from 620 to 62 kPa and the gyrating mechanism was rotated for one complete turn and stopped. A zero point was recorded for the angle of gyration by turning on the recorder. Then, the gyrating mechanism was rotated one-half revolution and stopped, and the applied angle of gyration was noted and recorded. The rotation was continued for 18 revolutions, the angle of gyration was recorded, and the specimen and mold were removed for densification testing the next day.

For densification testing that simulates traffic, the mold and specimen were first placed in a 60^{o}C oven for 3 hr before loading into the GTM. A vertical pressure of 620 kPa and an angle of 0.052 rad were set. The vertical pressure was then decreased to 62 kPa, and the specimen densified for 300 revolutions or until the roller pressure dropped below 110 kPa. Roller pressure was recorded periodically, and the angle of gyration was recorded at the conclusion. The specimen was removed, cooled to room temperature, and measured for density. The shear strength and GSI were calculated by the formulas described previously for the oil-filled roller procedure.

Georgia Loaded Wheel Tests

GLWT were performed in accordance with the Georgia test method GTD-115 using a model LWT-II tester manufactured by Pavtec Engg Tech., Inc. Beam specimens, 75 mm x 125 mm x 300 mm, were compacted with a kneading action in a rolling wheel compaction machine using a polycarbonate compaction pad to 7.0 percent air voids. While maintained at 49^{o}C, the beams were loaded with the moving wheel (load = 534 N) for 8,000 cycles (16,000 passes). A rubber hose inflated to 827 kPa transferred the wheel load to the specimen. After the test was completed, the rutting was measured at three specified locations along the beam.

Mixes Tested

Six surface mixes that had been used in the field were tested with the six design methods. Some mixes were associated with problems during construction and service life such as low density and permanent deformation; therefore, an attempt was made to duplicate the mix that was produced and placed on the roadway. The field gradation and asphalt content production data were averaged for each mix to determine the gradation and asphalt content to be used in the laboratory testing. The aggregate was fractionated and recombined to produce the desired gradation. The gradations and asphalt contents used are listed in Table 2. The "A" designation in the mix descriptions, e.g., SM-3A, indicates that the mix contained AC-20 asphalt cement and was designed with a 50-blow Marshall compactive effort. The "B" designation indicates that the mix contained AC-20 asphalt cement but was designed with a 75-blow Marshall compactive effort. The "C" designation indicates that the mix contained AC-30 asphalt cement and was designed with a 75-blow Marshall compactive effort.

Table 2. Gradations and asphalt contents used in laboratory study

Mix No.	Percent Passing					
	1	**2**	**3**	**4**	**5**	**6**
Sieve, mm	**SM-3A**	**SM-2C**	**SM-2B**	**SM-3A**	**SM-2A**	**SM-2A**
25.0				100		
19.0	100	100	100	97	100	100
12.5	88	99	96	83	98	97
9.5		88	82		94	86
4.75	51	60	59	55	58	60
2.36						44
0.600	19	20	26	24	20	22
0.300	11					13
0.150						
0.075	5	5.4	5.5	5	5	5.7
Prod. % AC	5.2	5.1	5.7	4.5	---*	5.3
Design % AC	5.2	5.1	5.5	4.5	5.5	5.3

*Not available.

RESULTS

Marshall Design Tests

The results of the Marshall design tests are listed in Table 3. Since the requirements of the VTM of the Asphalt Institute and VDOT are different, the design asphalt contents at both levels (4.0 and 4.5 percent, respectively) are listed. As expected, the optimum asphalt content decreased 0.1 to 0.5 percent when going from a 50-blow to a 75-blow compactive effort. The design asphalt content also decreased 0.1 to 0.3 when going from a design air void level of 4.0 percent VTM to 4.5 percent VTM. All design criteria were satisfied except for the VFA of mix 2

Table 3. Design asphalt content and related values (percent) by Marshall method

	50-blow			75-blow		
Mix	**AC**	**VMA**	**VFA**	**AC**	**VMA**	**VFA**
4.0% design VTM						
1	5.9	16.1	76.4	5.5	15.4	74.0
2	5.9	18.3	78.6	5.6	17.6	77.8
3	5.6	16.5	75.7	5.3	15.8	75.4
4	4.8	14.9	74.2	4.6	14.6	72.7
5	5.1	15	73.8	4.6	13.9	70.7
6	5.3	16.3	75.1	4.9	15.4	73.7
4.5% design VTM						
1	5.6	16.1	71.7	5.4	15.4	72.1
2	5.7	18.4	75.3	5.4	17.6	74.6
3	5.4	16.6	72.4	5.1	15.9	71.9
4	4.6	15.3	69.1	4.5	14.7	70.0
5	4.9	15.1	70.0	4.5	14.0	70.0
6	5.1	16.3	71.7	4.7	15.5	66.6

at 4.0 percent VTM for the 50-blow design and the VMA of mix 5 for the 75-blow design at 4.0 percent VTM.

The comparisons of the design asphalt contents used in the field and the production asphalt contents with the matching designs done for the study at the Virginia Transportation Research Council (VTRC) are listed in Table 4. There was not very good agreement between the two. The contractor's design asphalt content was not consistently higher or lower. The lack of agreement could indicate that the materials sampled for the laboratory study had changed since the original designs were done. In view of the disagreement, it was not thought wise to attempt to surmise from laboratory results why some of the mixes were associated with problems in the field. Therefore, the results were used only to compare the different methods.

Table 4. Comparison of design asphalt contents used in field and laboratory designs, %

Mix/No. blows	Contractor Lab Design @ 4.5% VTM	Average Production	VTRC Lab Design @ 4.5% VTM	VTRC Lab Design @ 4.0% VTM
1/50	5.2	5.2	5.6	5.9
2/75	5.1	5.1	5.4	5.6
3/75	5.5	5.7	5.1	5.3
4/50	4.5	4.5	4.6	4.8
5/50	5.5	----*	4.9	5.1
6/50	5.3	5.3	5.1	5.3

*Not available.

SHRP Gyratory Compactor Tests

The results of the tests performed with the two types of SHRP gyratory compactors are listed in Table 5. The design asphalt contents were selected at 4 percent VTM in accordance with Superpave, and the corresponding void contents at $N_{initial}$ and $N_{maximum}$ were checked to ascertain that the design criteria were met. Between the two compactors, the asphalt content of five of the six mixes agreed within 0.1 percent, and that of the remaining mix differed by only 0.2 percent. There was also good agreement for the other mix properties, VMA and VFA, at the design asphalt contents.

Table 5. Design asphalt contents by SHRP gyratory compactor tests

	%AC		%VMA		%VFA	
Mix	**Pine**	**Troxler**	**Pine**	**Troxler**	**Pine**	**Troxler**
1	5.4	5.5	14.8	15.1	74.0	73.6
2	5.4	5.5	17.3	17.3	74.2	76.9
3	5.0	5.1	14.6	14.8	72.6	72.7
4	4.3	4.4	14.0	14.3	70.7	71.0
5	4.6	4.8	13.6*	13.9*	70.5	72.2
6	5.0**	5.0**	15.1	15.1	73.5	73.5

*Failed minimum VMA requirement of 14.0.
**Failed maximum F/A ratio of 1.2.

Mix 5 failed the VMA requirements, and mix 6 failed the maximum fines-asphalt ratio criterion. Also, mixes 1, 2, 5, and 6 were either outside the Superpave gradation limits and/or went through the restricted zone. Therefore, even though an optimum asphalt content was obtained, it may appear unreasonable because the preselected gradation did not meet the Superpave criteria. To optimize performance, all Superpave criteria should be met.

GTM

Curves were developed for aggregate-only density, GSI, and shear strength. Aggregate-only density is the density of the aggregate mass in the specimen. A typical set of curves is shown in Figure 2. Asphalt content at maximum aggregate-only density, a GSI of 1.0, and a minimum shear strength of 310 kPa was determined from the graphs. The highest asphalt content meeting the GSI and shear strength criteria was selected as the design asphalt content for the GTM. GSI is supposed to indicate when the voids in the aggregate have been overfilled with asphalt. A national rutting study found some correlation between GSI and rutting when using the oil-filled roller.[7] As GSI increased, the rate of rutting increased. John MacRae, the developer of the testing equipment, has suggested a maximum value of 1.0. GSI was found most often to be the determining factor for asphalt content selection in the present study.

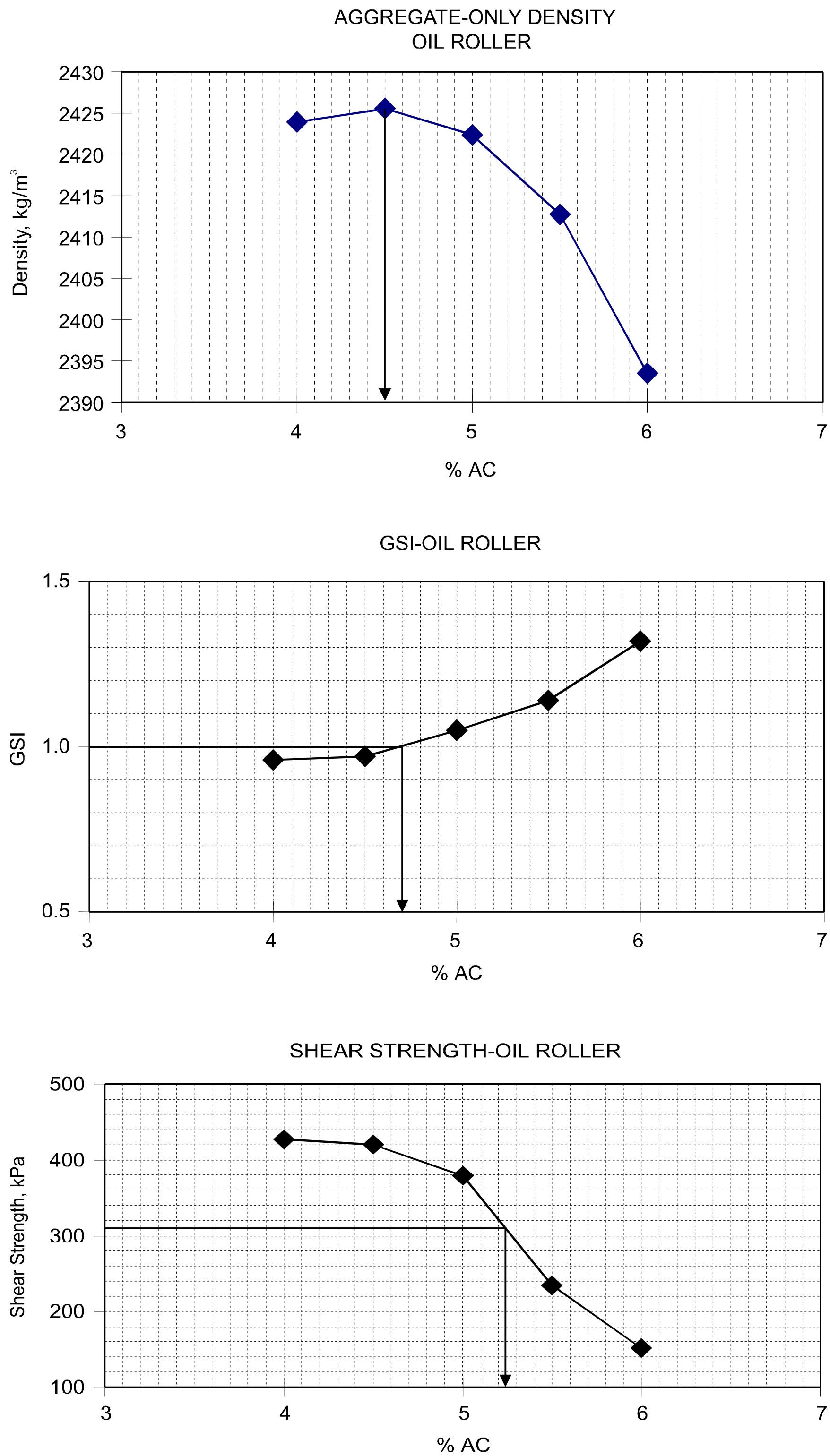

Figure 2. Typical GTM results

Ruth et al. at the University of Florida have done considerable experimentation using the air-filled roller.[6,8] They found an excellent correlation between the gyratory shear strength and asphalt content and mixture volumetric properties such as VMA and VTM.[6] They suggested that the gyratory shear strength may be all that is needed for mixture evaluation. When the shear strength drops below a specified minimum acceptable value, the mixture is too weak to resist permanent deformation. They used a minimum value of 372 kPa at 200 revolutions to predict the suitability of mixtures with respect to permanent deformation resistance.

Examination of the shear strength values for the mixes at the asphalt contents listed in the Appendix reveals that most of the mixes tested were below 372 kPa, even at low asphalt contents. Therefore, there is a question raised about whether this value is the correct minimum strength to accept or reject mixes. There is not a standard calibration procedure that can be used to standardize and equalize the testing devices; therefore, there could be a constant difference between values obtained with the devices. After examination of the data, an arbitrary value of 310 kPa seemed more appropriate as an acceptable minimum shear strength.

GLWT

GLWT were performed on each of the six mixes at two asphalt contents in an attempt to define the maximum asphalt content at which the mix became unstable. More tests would have been preferred to define the curve better; however, sufficient quantities of materials were not available. The results are shown in Figure 3. The researcher planned to perform the tests at the optimum asphalt content and 1 percent above the optimum. The tests were performed concurrently with the Marshall tests; therefore, it was assumed that the laboratory design

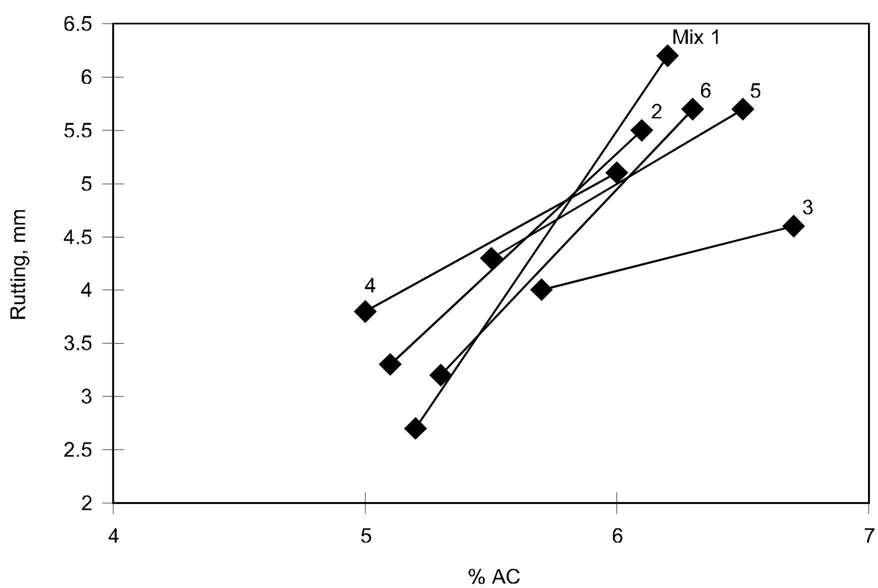

Figure 3. Rut tests

optimums would be close to that of the original design job mixes. The assumed design asphalt contents for mixes 1 and 2 were significantly lower than the VTRC design asphalt contents. Therefore, the asphalt contents used in the GLWT might not have been high enough to yield significant rutting for the particular mixes.

Since the GLWT loading and temperature conditions were applicable to heavy duty traffic, the asphalt content should be examined in relation to the 75-blow Marshall design optimum asphalt content. Table 6 lists the highest asphalt content at which GLWT were performed in relation to the 75-blow design value and the related rut depths. Rutting in excess of the maximum allowable value of 8 mm did not occur even though some mixes were tested at asphalt contents approximately 1.5 to 2 percent above the optimum value. This leaves some doubt about the ability of this particular tester to determine the sensitivity of mixes to changes in asphalt content. Also, the researcher hoped that the maximum amount of tolerable asphalt could be estimated from the tests, but since the maximum allowable value was not exceeded, this was not possible. After the tests were completed, a model APA II tester manufactured by ASTEC Industries, Inc., was purchased, and testing of some field mixes seemed to indicate that weak mixes produced rutting with this tester. It was not feasible to retest the mixes investigated in this study because of insufficient materials.

Table 6. GLWT at high asphalt contents

Mix	% AC Above 75-Blow Optimum	Rutting, mm
1	0.7	6.2
2	0.5	5.5
3	1.4	4.6
4	1.4	5.1
5	1.9	5.7
6	1.4	5.7

The slope of the curves is some indication of the sensitivity of the mixes to changes in asphalt content. The slope of the curve for mix 1 was much steeper than for mix 3. A 1 percent change in asphalt content for mixes 1 and 3 produced an increase in rutting of 3.5 and 0.6 mm, respectively. A sensitive mix such as mix 1 could be associated with problems if production variability is excessive or if the mix is already borderline with respect to stability.

DISCUSSION

Table 7 lists the optimum asphalt contents determined by the different methods used in this study. The compactive effort of the SHRP gyratory tests and GTM should be similar to that of the 75-blow Marshall test; therefore, comparing the optimum asphalt contents determined by these methods is justified.

Table 7. Comparison of design asphalt content obtained by different design methods

Mix No.	50-blow Marshall @4.0%	50-blow Marshall @4.5%	75-blow Marshall @4.0%	75-blow Marshall @4.5%	Pine SGC	Troxler SGC	GTM Air Roller	GTM Oil Roller
1	5.9	5.6	5.5	5.4	5.4	5.5	5.7	5.4
2	5.9	5.7	5.6	5.4	5.4	5.5	5.0	5.1
3	5.6	5.4	5.3	5.1	5.0	5.1	5.6	5.4
4	4.8	4.6	4.6	4.5	4.3	4.4	4.6	4.7
5	5.1	4.9	4.6	4.5	4.6	4.8	4.5	4.5
6	5.3	5.1	4.9	4.7	5.0	5.0	<4.3	5.0

Table 8 shows the differences between the gyratory tests and the 75-blow Marshall. The results of the GTM with the oil-filled roller most closely match the 75-blow Marshall results except for mix 2. The GTM with the air-filled roller produced the largest differences. The range of differences from the 75-blow Marshall was -0.6 to +0.3. In one case, the GTM produced a design asphalt content 0.7 percent less than that of the SHRP gyratory compactors.

Table 8. Difference of optimum asphalt content between gyratory tests and 75-blow Marshall at 4% VTM (Gyratory % AC - Marshall % AC)

Mix	Pine SGC	Troxler SGC	GTM Air Roller	GTM Oil Roller
1	-0.1	0.0	+0.2	-0.1
2	-0.2	-0.1	-0.6	-0.5
3	-0.3	-0.2	+0.3	+0.1
4	-0.3	-0.2	0.0	+0.1
5	0.0	+0.2	-0.1	-0.1
6	+0.1	+0.1	-0.6	+0.1
Average/Range	-0.1/-0.3 to +0.1	0.0/-0.2 to +0.2	-0.1/-0.6 to +0.3	-0.1/-0.5 to +0.1

The optimum asphalt content determined by the GTM is based on shear strain and strength data measured during the compaction process. The optimum asphalt content for the SHRP gyratory design tests is based on volumetrics; therefore, it should not be surprising that the results are different. Generally, the GTM detects a weakening of the mix indicated by shear strain (angle of gyration) and/or strength changes. The GTM with the air-filled roller detected that the strain (GSI) approached unacceptable values at low asphalt contents, resulting in lower design asphalt contents than the 75-blow Marshall. Conversely, for two mixes (1 and 3) the GTM with the air-filled roller allowed a slightly higher asphalt content than the other methods. Even though the voids appeared to be overfilled according to the other methods using volumetric criteria, the GTM predicted that slightly more asphalt could be added before excessive strain or strength loss occurred.

The design asphalt contents using the SHRP gyratory compactors were slightly less than or equal to the design asphalt contents from the 75-blow Marshall with the exception of mixes 5 and 6. Through limited experimentation and experience, VDOT has found that 50-blow mixes containing high amounts of stiff binder can function well under heavy traffic. They currently use 50-blow D (PG-70 binder) and E (PG-76 binder) mixes in heavy traffic if they are proof tested with a rut tester. It is possible that the Superpave compactive effort is too severe, resulting in low asphalt contents. Studies are examining this issue.

Translation and rotation (change of slope) of the gyratory compaction curve (see Figure 1) were found to be related to the aggregate structure when Superpave was developed.[9] Also, the compaction curve has been used to analyze aggregate structure in another research study.[10] The slope was computed and examined to determine if it was related to other resistance measurements such as shear strength and angle of gyration (strain) from the GTM tests. The values were normalized and compared, but there was no meaningful correlation.

The gyratory compactors in general are supposed to more closely duplicate the type of compaction achieved by asphalt rollers during construction and vehicular traffic during service life. In an NCHRP study, the Texas gyratory shear compactor closely simulated the properties and characteristics of field compacted mixes.[2] The mechanical Marshall hammer provided the poorest simulation. Therefore, it is not surprising that the Marshall hammer and the gyratory compactors gave different design asphalt contents for some of the mixes used in this study. The gyratory compactor would be more likely to orient slabby-elongated particles in a manner that produces lower VMA and requires less asphalt cement.

CONCLUSIONS

1. When comparing the gyratory compactors and the 75-blow Marshall, the GTM with the air-filled roller and the 75-blow Marshall design produced the largest differences in optimum asphalt content. These differences are dependent on the shear characteristics of the mixes, which were measured with the GTM.

2. The two SHRP gyratory compactors produced comparable design asphalt contents. The result was very encouraging.

3. The design asphalt contents produced by the SHRP gyratory compactors were 0.3 less to 0.2 more than those produced by the 75-blow Marshall designs at 4.0 percent air voids. However, not all of the Superpave criteria were met.

4. As expected, the 75-blow designs produced asphalt contents 0.1 to 0.5 percent less than the 50-blow designs. Also, the designs at 4.5 percent air voids produced asphalt contents 0.1 to 0.3 percent less than designs at 4.0 percent air voids.

5. Even though high asphalt contents were used, the maximum allowable rutting for GLWT was not exceeded. Therefore, the maximum asphalt content that could be used before rutting would be a problem could not be determined.

RECOMMENDATION

As time permits, record test data for Superpave tests and perform matching tests with the GTM with the air-filled roller for routine testing of mixes that perform well and mixes that perform poorly. Correlating the data with performance will determine whether the GTM can be a helpful mixture analysis tool.

REFERENCES

1. Harvey, J., C. Monismith, and J. Sousa. 1994. An investigation of field and laboratory-compacted asphalt-rubber, SMA, recycled and conventional asphalt-concrete mixes using SHRP project A-003A equipment. In *Proceedings of the Association of Asphalt Paving Technologists,* Vol. 63.

2. VonQuintus, H.L., J.A. Scherocman, C.S. Hughes, and T.W. Kennedy. 1991. *NCHRP report: Asphalt-aggregate mixture analysis system*. Transportation Research Board, Washington, D.C.

3. Kallas, B.F. 1964. Gyratory mix design. In *Proceedings of the Association of Asphalt Paving Technologists,* Vol. 33.

4. American Society of Testing and Materials. 1995. *Annual book of ASTM standards.* Volume 04.03. Philadelphia.

5. Maupin, G.W., Jr. Determination of compactive effort to duplicate pavement voids for Corps of Engineers gyratory testing machine. *Hot mix asphalt design, testing, evaluation, and performance, Transportation Research Record No. 1492.* Transportation Research Board, Washington, D.C.

6. Ruth, B.E., X. Shen and L.-H. Wang. 1992. Gyratory evaluation of aggregate blends to determine their effect on shear resistance and sensitivity to asphalt content. *Effects of aggregates and mineral fillers on asphalt mixture performance, ASTM STP 1147.* American Society for Testing and Materials, Philadelphia.

7. Brown, E.R. and S.A. Cross. 1992. *A national study of rutting in hot mix asphalt (HMA) pavements*. National Center for Asphalt Technology, Auburn University, Alabama.

8. Sigurjonsson, S., and B.E. Ruth. 1990. Use of gyratory testing machine to evaluate shear resistance of asphalt paving mixture. *Chip seals, friction courses, and asphalt pavement rutting, Transportation Research Record No. 1259.* Transportation Research Board. Washington, D.C.

9. Solaimanian, M., T.W. Kennedy, and R.B. McGennis. 1997. Use of waste toner in asphalt concrete, *Research Report 39330-1F*, Center of Transportation Research, University of Texas at Austin.

10. Cominsky, R. 1994. Level one mix design: Materials selection, compaction, and conditioning, *SHRP-A-408*. Strategic Highway Research Program, National Research Council, Washington, D.C.

APPENDIX

Results of GTM Tests Using Oil-Filled and Air-Filled Rollers

		Aggregate Density						Shear Strength	
	% AC	Pcf	kg/m^3	VTM	VMA	VFA	GSI	psi	KPa
Mix 1–Lee Hy Oil-filled									
	4.2	143.3	2294	5.6	14	59.7	0.96	60	413
	4.7	142.9	2288	4.7	14.2	67	0.95	56	386
	5.2	143.4	2296	3.1	13.9	78	0.98	54	372
	5.7	143.5	2297	1.8	13.9	87	1	46	317
	6.2	143.2	2293	0.7	14	94.9	1.04	42	289
Mix 1–Lee Hy Air-filled									
	4.2	144.9	2320	4.6	13	64.9	0.89	52	358
	4.7	145.3	2326	3.1	12.8	76.1	0.97	50	345
	5.2	145.1	2323	1.9	12.9	85	0.95	48	331
	5.7	144.9	2320	0.8	13	94	No data	45	310
	6.2	143.8	2302	0.3	13.7	97.8	No data	38	262
Mix 2–Superior Oil-filled									
	4.1	148.9	2384	6.8	16.8	59.4	0.93	50	345
	4.6	149.4	2392	5.3	16.5	68	0.97	49	338
	5.1	149.8	2398	3.7	16.3	77.3	0.97	52	358
	5.6	150.7	2413	1.8	15.8	88.5	0.99	49	338
	6.1	150.2	2405	0.8	16.1	94.9	1.04	44	303
Mix 2–Superior Air-filled									
	4.1	144	2305	9.9	19.5	49.4	0.82	52	358
	4.6	145.7	2333	7.6	18.6	59	0.95	50	345
	5.1	145	2321	6.8	19	64.1	1.02	50	345
	5.6	146.7	2349	4.4	18	75.5	1.16	46	317
	6.1	145.9	2336	3.7	18.5	80.2	1.49	43	296
Mix 3–Sawyer Oil-filled									
	4.7	142.3	2278	3.8	14.4	73.8	0.96	63	434
	5.2	142.3	2278	2.5	14.4	82.5	0.97	63	434
	5.7	141.8	2270	1.6	14.6	89.1	1.04	35	241
	6.2	141.5	2265	0.5	14.8	96.5	1.13	40	276
	6.7	140.7	2253	0	15.3	100	1.42	21	145

Mix 3–Sawyer Air-filled									
	4.7	137.9	2208	6.7	17	60.6	0.88	53	365
	5.2	138.6	2219	5.1	16.6	69.5	0.93	51	351
	5.7	137.8	2206	4.4	17.1	74.1	1.12	44	303
	6.2	138.8	2222	2.5	16.5	84.9	1.3	41	282
	6.7	138.6	2219	1.4	16.6	91.8	1.64	33	227
Mix 4–MEGA Oil-filled									
	4	151.4	2424	4.4	13.5	67.6	0.96	62	427
	4.5	151.5	2426	3	13.5	77.5	0.97	61	420
	5	151.3	2422	1.8	13.6	86.4	1.05	55	379
	5.5	150.7	2413	0.9	13.9	93.5	1.14	34	234
	6	149.5	2393	0.4	14.6	97.3	1.32	22	152
Mix 4–MEGA Air-filled									
	4	153.2	2453	3.2	12.5	74.1	0.88	50	345
	4.5	153.5	2458	1.8	12.4	85.6	0.95	48	331
	5	152.8	2446	0.9	12.8	93	1.14	44	303
	5.5	150.9	2416	0.8	13.8	94.5	1.49	40	276
	6	149.6	2395	0.3	14.5	97.9	1.72	33	227
Mix 5–Templeton Oil-filled									
	4.5	147.4	2360	2.8	12.5	77.6	1	58	400
	5	147	2353	1.8	12.8	85.6	1.17	52	358
	5.5	146.1	2339	1.1	13.3	91.8	1.26	39	269
	6	145.3	2326	0.4	13.8	97.3	1.34	23	158
	6.5	143.8	2302	0.1	14.6	99.3	1.37	18	124
Mix 5–Templeton Air-filled									
	4.5	148.8	2382	1.7	11.7	85.3	1.02	49	338
	5	147.8	2366	1.1	12.3	91	1.26	47	324
	5.5	146.3	2342	0.9	13.2	93.5	1.8	41	282
	6	145.3	2326	0.3	13.8	98.2	2.37	34	234
	6.5	143.8	2302	0	14.7	100	2.52	36	248
Mix 6–Williamson Oil-filled									
	4.3	146.9	2352	5.4	15.2	64.5	0.96	60	413
	4.8	147.6	2363	3.7	14.8	75.3	0.97	61	420
	5.3	147.6	2363	2.4	14.8	84	1.03	54	372
	5.8	147.4	2360	1.3	15	91.6	1.13	50	345
	6.3	146.6	2347	0.5	15.4	97	1.22	22	152
Mix 6–Williamson Air-filled									
	4.3	150.3	2406	3.2	13.3	75.9	1.09	50	345
	4.8	150.3	2406	1.9	13.3	85.6	1.1	48	331
	5.3	149.7	2397	1	13.6	92.7	1.22	44	303
	5.8	148.2	2373	0.8	14.5	94.7	1.68	40	276
	6.3	146.8	2350	0.3	15.3	97.8	1.9	37	255