

Evaluation of Stone Mastic Asphalt Used in Michigan in 1991

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Materials used in construction of Michigan's first stone mastic asphalt (SMA) pavement were received at the National Center for Asphalt Technology, Auburn University, for further evaluation. Mixtures were prepared to meet the job mix formula used in the Michigan project. Variations in the job mix formula were made to determine the sensitivity of the SMA mixtures to changes in mixture proportions. A dense-graded mixture using the same aggregates was produced to provide a reference for the SMA mixture. The prepared mixtures were compacted in a gyratory machine and gyratory properties were measured. Volumetric and creep properties were also determined. The test results indicate that SMA mixtures are more sensitive to gradation changes than are dense-graded mixtures. The gyratory and creep properties appear to have potential in evaluating SMA mixtures.

Stone mastic asphalt (SMA) is a new technology recently imported from Europe to the United States. The SMA mixtures have been shown to be more resistant to permanent deformation than is conventional hot-mix asphalt (HMA) and should be more durable than HMA because of the high asphalt content and thick film thickness. SMA typically consists of a high concentration of coarse aggregate [creating a relatively high voids in mineral aggregate (VMA)], high filler content, high asphalt content, and an additive, such as cellulose or mineral fiber, to prevent drainage of the asphalt cement.

SMA has been used in Europe for a number of years and has proven to be a cost-effective mixture for high traffic volumes. It was initially used to resist abrasion from studded tires but has been used in the past few years to provide greater rutting resistance. SMA costs more initially but the additional cost is offset by improved performance. It is too early to estimate the cost of SMA in the United States, but the price should decrease as more and more SMA is placed and contractors become familiar with handling this new mixture.

In summer 1991, five states—Georgia, Indiana, Michigan, Missouri, and Wisconsin—placed SMA sections. Because there has been very little testing of SMA mixtures in the United States, it was difficult to select the optimum asphalt content for the SMA mixtures for the projects and difficult to estimate performance.

The objective of this study was to evaluate the sensitivity of SMA mixture properties to changes in proportions of various mixture components. The study was performed using the same materials and job mix formula as that used in the first Michigan project using SMA. The mixture components, varied to evaluate sensitivity, included the amount of cellulose

(Arbocel), asphalt content, percentage passing the No. 4 sieve, and percent passing the No. 200 sieve. The properties used to evaluate the effect of these changes included gyratory properties [gyratory stability index (GSI) and shear stress to produce 1-degree angle], creep, and physical properties, including voids and voids in mineral aggregate.

TEST PLAN

The test plan involved preparing samples for each of 17 mixture variations [job mix formula (JMF)] four variations in percentage passing No. 4 sieve, in percentage passing No. 200 sieve, in asphalt content, and in fiber content. These samples were compacted in the U.S. Army Corps of Engineers gyratory testing machine set to produce a density equivalent to 50 blows with the Marshall hammer [based on a calibration curve, the gyratory machine was set at 827 kPa (120 psi), 1-degree angle, and 120 revolutions]. A dense-graded HMA using the same aggregate as in the SMA was prepared and tested for comparison purposes.

The JMFs for the dense graded mixture and SMA mixture are given in Table 1. Several individual variations of the SMA mixture were evaluated in this study to determine the sensitivity of mix properties to changes in mixture components. The amount of material passing the No. 4 sieve ranged from 26.0 to 46.0 percent (JMF = 36.0). The amount of material passing the No. 200 sieve ranged from 6.4 to 14.4 percent (JMF = 10.4). The asphalt content ranged from 5.5 to 7.5 percent (JMF = 6.5). The fiber content ranged from 0.0 to 0.4 percent of total mix (JMF = 0.3).

Samples were prepared at each mixture combination for evaluation. The samples were compacted in the gyratory testing machine and the GSI and shear stress to produce a 1-degree angle were determined. After compaction, three samples of each mixture were tested for volumetric properties and evaluated for confined creep properties at 140°F and 827 kPa (120 psi) loading pressure and 1 hr loading time. The confinement pressure for creep testing was 138 kPa (20 psi).

TEST RESULTS AND ANALYSIS

Voids in Total Mix

All the test results produced in this study are shown in Table 2. The voids in total mix (VTM) in the SMA mixtures ranged from 0.1 to 5.5 percent. The optimum void content for dense-graded mixtures is typically 4.0 percent and for SMA mixtures, 3.0 percent or slightly higher.

As shown in Figure 1, the VTM decreases with increasing asphalt content. SMA mixtures at all five asphalt contents evaluated had relatively low voids. It appears that the optimum asphalt content (to produce 3 percent voids) was likely between 5.5 and 6.0 percent. The original mix design selected an asphalt cement (AC) content of 6.5 percent, but this was reduced to 6.2 percent during construction. The JMF for as-

phalt content used for preparing samples for this study was 6.5 percent.

Figure 2 shows that the fiber content had very little effect on VTM. Higher fiber content appeared to increase VTM slightly. These data indicate that the optimum asphalt content cannot be significantly increased by increasing the fiber content. The primary purpose of the fiber then is to stabilize the

TABLE 1 Job Mix Formulas for Dense-Graded and SMA Mixtures

Sieve Size	Aggregate	
	SMA Percent Passing	Dense Graded Percent Passing
3/4 inch	100	100
1/2 inch	94	100
3/8 inch	72	81
No. 4	36	54
No. 8	24	41
No. 16	19	29
No. 30	16	22
No. 50	14	15
No. 100	12	9
No. 200	10.4	6.1

Mixture Components	SMA	Dense Graded
AC Content, %	6.5	4.2
Cellulose, %	0.3	0

TABLE 2 Test Results for Dense-Graded and SMA Mixtures, HMA Properties

Project: MICHIGAN SMA							
SPECIMEN MIX TYPE	ASPHALT CONTENT (%)	TOTAL VOIDS (%)	VMA (%)	PERM STRAIN (MM/MM)	CREEP MODULUS Kilopascals	GSI	SHEAR STRESS Kilopascals
SMA + 1.0% A.C.	7.5	0.3	18.1	0.0108	76610	1.05	250
SMA + 0.5% A.C.	7.0	0.8	17.4	0.0101	81919	1.01	278
SMA -0.5% A.C.	6.0	3.0	17.2	0.0079	104735	1.00	271
SMA -1.0% A.C.	5.5	2.9	16.0	0.0058	142658	1.00	263
SMA 0.0% FIBER	6.5	1.2	16.8	0.0126	65668	1.00	275
SMA 0.2% FIBER	6.5	0.8	16.3	0.0078	106080	1.00	256
SMA 0.3% FIBER	6.5	1.6	17.0	0.0081	102149	1.00	313
SMA 0.4% FIBER	6.5	1.7	17.1	0.0113	73218	1.00	259
SMA +10% SAND	6.5	0.4	16.0	0.0155	53381	1.34	84
SMA +5% SAND	6.5	0.2	15.8	0.0112	73873	1.11	212
SMA -10 SAND	6.5	5.5	20.3	0.0078	106080	1.00	283
SMA -5% SAND	6.5	2.5	17.7	0.0066	125365	1.00	284
SMA +4% FILLER	6.5	0.1	15.7	0.0117	70715	1.09	221
SMA +2% FILLER	6.5	0.4	16.0	0.0081	102149	1.02	237
SMA -4% FILLER	6.5	3.5	18.6	0.0186	44487	1.00	269
SMA -2% FILLER	6.5	2.9	18.2	0.0064	129281	1.00	259

asphalt cement to prevent drainage and not to increase the optimum AC content.

Figure 3 shows that the amount of sand (percentage passing the No. 4 sieve) in the mixture had a significant effect on the VTM. Lower sand content produces higher VTM. There has been much discussion about the need to produce SMA mixtures with high asphalt content. Figure 3 shows that a good way to increase the optimum asphalt content without producing low voids in the total mix is to decrease the amount passing the No. 4 sieve. These data show that, on average, a decrease of 2.5 percent passing the No. 4 sieve results in an increase in VTM of 1 percent. The sensitivity of VTM to a change in sand content is high, indicating that there must be close control on the percentage passing the No. 4 sieve during construction.

The VTM is affected by the amount of filler in the SMA mixture (Figure 4). A higher filler content produces lower voids. Another way to obtain higher optimum asphalt content

(if desired) is to lower the filler content, but lowering it too much will affect the consistency of the mastic and may result in drainage during haul, as well as other problems. The sensitivity of the VTM in the mix to the percentage passing the No. 200 sieve is about the same as that for dense-graded mixtures.

VMA

A satisfactory mixture with a high asphalt content can be produced only when the VMA is sufficiently high to provide space for the extra asphalt cement. The VMA is controlled with the aggregate gradation. Generally, the closer the aggregate is to one size, the higher the resulting VMA. Figure 5 shows that an increase in asphalt content produces a higher VMA. This indicates that the asphalt content is on the high side of optimum for the gradation being used and the increased asphalt content is forcing the aggregate particles apart

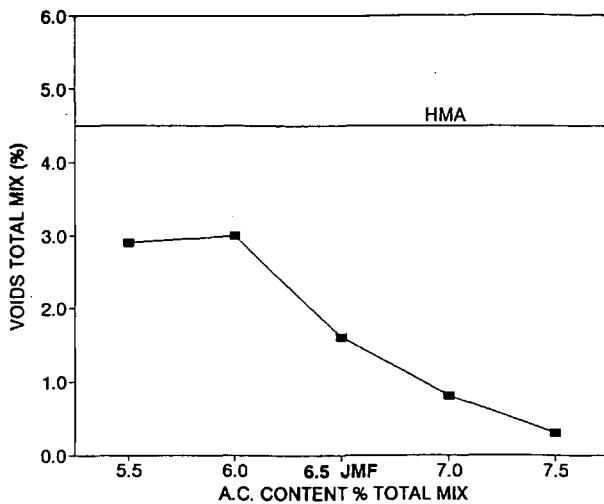


FIGURE 1 VTM versus asphalt content for SMA and HMA.

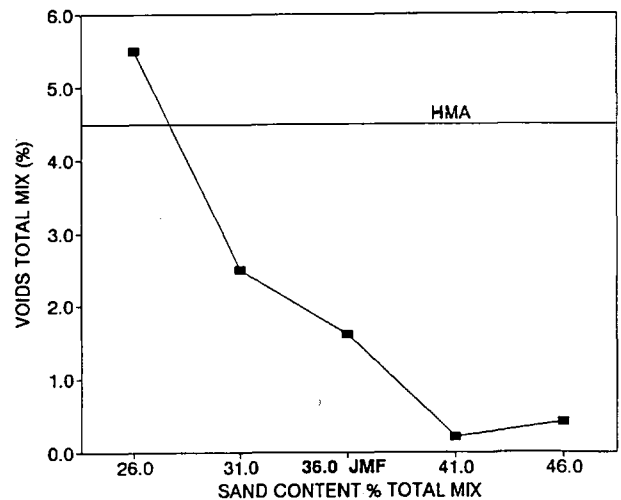


FIGURE 3 VTM versus percentage passing No. 4 sieve.

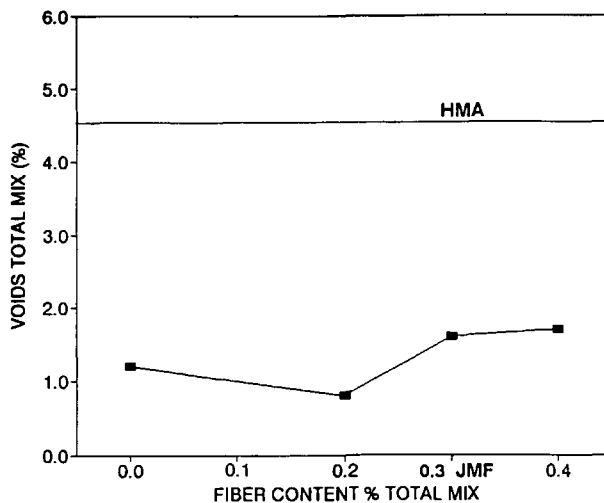


FIGURE 2 VTM versus fiber content for SMA.

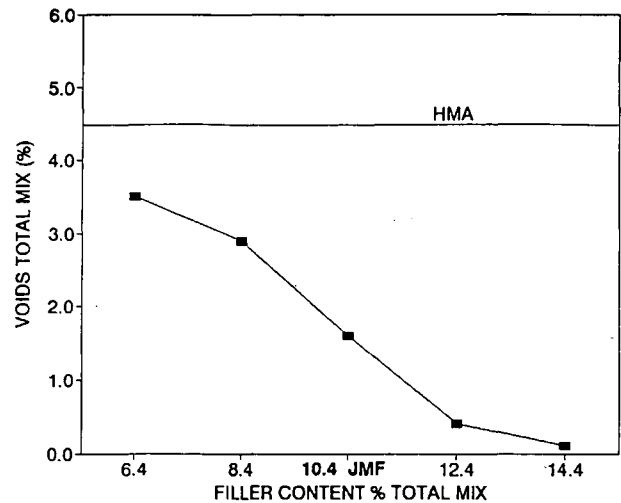


FIGURE 4 VTM versus percentage passing No. 200 sieve.

and thus increasing the VMA. This will result in a mix that is not stable under traffic and may result in permanent deformation. The design asphalt content was a little on the high side.

The fiber content has little effect on the VMA (Figure 6). This means that the optimum asphalt content cannot be significantly increased by increasing the fiber content. Some amount of fiber is needed, however, to hold the asphalt cement in place during production, hauling, and laydown. Without some method of stabilizing the asphalt cement, drainage will occur.

The amount of material passing the No. 4 sieve (sand content) has a significant effect on VMA (Figure 7). A higher percentage of material passing the No. 4 sieve produced lower VMAs. With SMA mixtures, the voids between the coarse aggregate particles are not filled with sand-size material; therefore, using a higher percentage of sand tends to fill these voids similar to -200 material in a dense graded mixture. When the voids in the coarse aggregate are filled with fine

aggregate, stone-on-stone contact no longer exists and the mixture may become unstable. The amount of aggregate passing the No. 4 sieve must therefore be low enough that stone-on-stone contact exists. The filler content also affected the VMA (Figure 8). Higher filler contents resulted in low VMA in SMA just as it would in dense-graded mixtures. This points out the need to control the amount of material passing the No. 200 sieve and No. 4 sieve.

GSI

For dense-graded mixes, the GSI has been shown to be an indicator of mixes that tend to rut (*I*). When the GSI exceeds 1.1 to 1.2 for a dense-graded mix, the mixture has a high probability of rutting. The amount of asphalt cement and fiber content appears to have little effect on the GSI (Figures 9 and 10). The GSI values for the asphalt cement and fiber content evaluated are below 1.05. Even though the GSI values

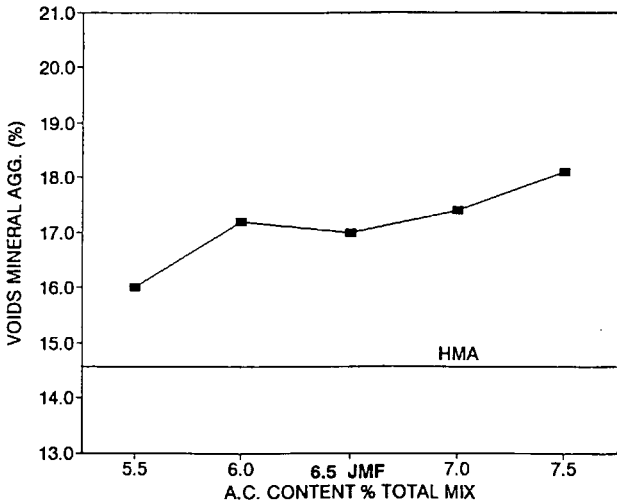


FIGURE 5 VMA versus asphalt content for SMA.

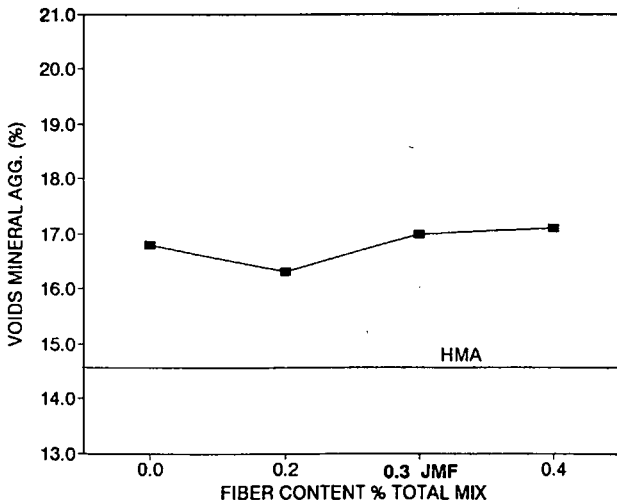


FIGURE 6 VMA versus fiber content for SMA.

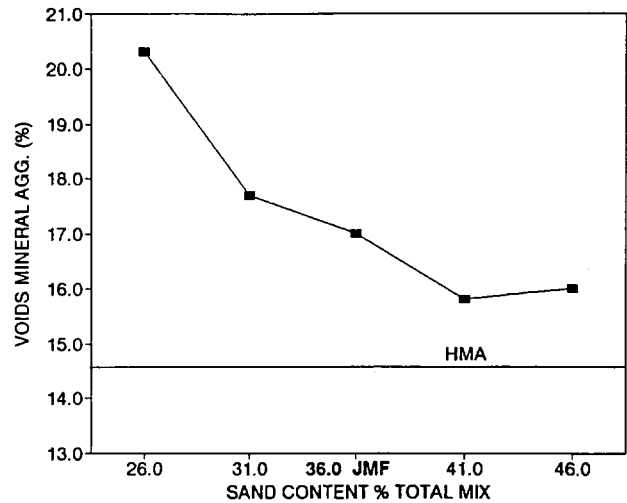


FIGURE 7 VMA versus percentage passing No. 4 sieve in SMA.

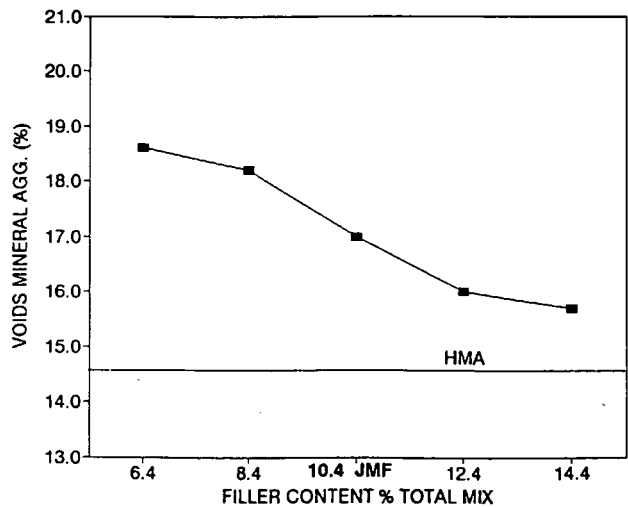


FIGURE 8 VMA versus percentage passing No. 200 sieve in SMA.

indicate that the SMA mixtures are stable at high asphalt contents (low voids), drainage of the asphalt cement will likely be a problem when the asphalt content is too high. High sand content or filler content produced mixes with high GSI values (Figures 11 and 12). The mixes with high sand and filler contents would be more likely to shove and rut than mixes with lower sand and filler contents. This indicates that the gradation must be controlled to maintain mixture properties that will provide good performance. The mix quality is very sensitive to changes in the percentage passing the No. 4 sieve and No. 200 sieve.

Gyratory Shear Stress To Produce 1-Degree Angle

Test results on dense graded mixtures have indicated that the shear stress to produce 1-degree angle is likely the best gyratory test GTM property for evaluating rutting resistance (2). A minimum value has not been selected for the property, but the referenced rutting study on HMA has clearly shown

that this test property is related to rutting. The shear stress to produce a 1-degree angle for SMA mixtures is generally higher than that for the HMA mixture, except for high sand contents and high filler contents (Figures 13 through 16). Asphalt content and fiber content appear to have little effect on the measured shear stress. The data indicate that SMA mixtures are less sensitive to a change in asphalt content than are HMA mixtures. High sand and filler contents significantly reduce the measured shear stress. These test results generally indicate that SMA mixtures are more resistant to rutting; however, at high sand and filler content the mixtures no longer meet the requirements for SMA mixtures and the test results indicate instability.

Creep

Results of the confined creep test showed that the SMA mixtures usually had more permanent deformation than did the HMA (Figures 17 through 20). The SMA creep results im-

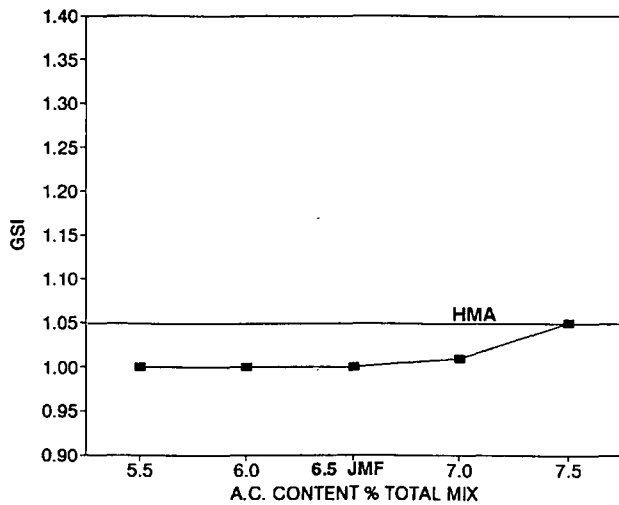


FIGURE 9 GSI versus asphalt content in SMA.

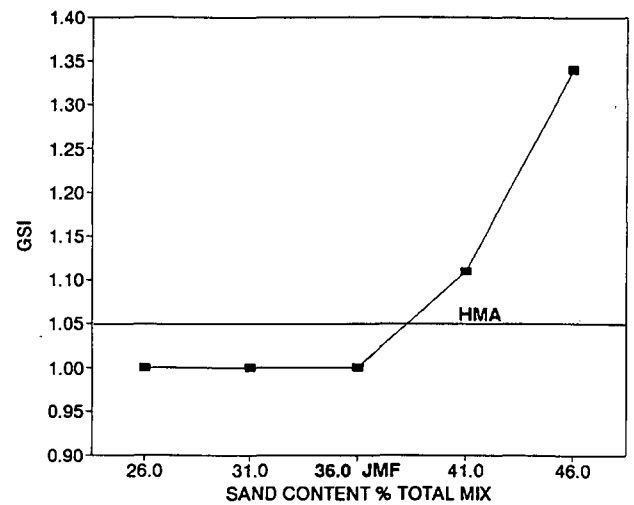


FIGURE 11 GSI versus percentage passing No. 4 sieve.

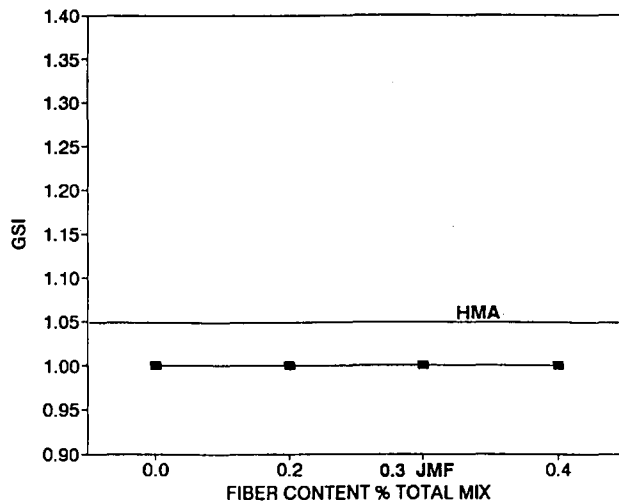


FIGURE 10 GSI versus fiber content in SMA.

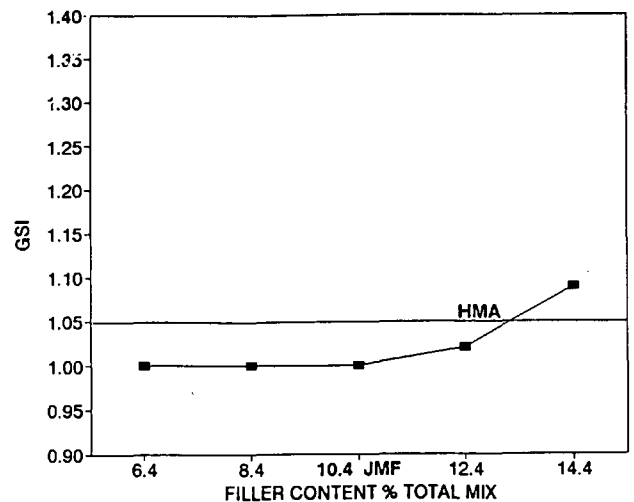


FIGURE 12 GSI versus percentage passing No. 200 sieve.

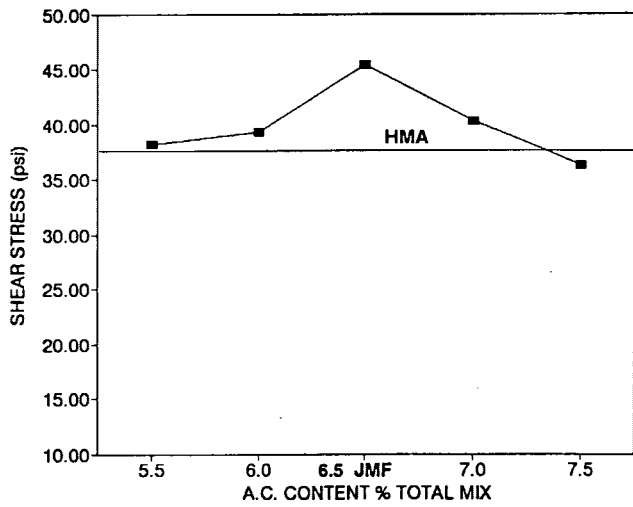


FIGURE 13 Gyratory shear stress to produce 1-degree angle of strain versus asphalt content in SMA.

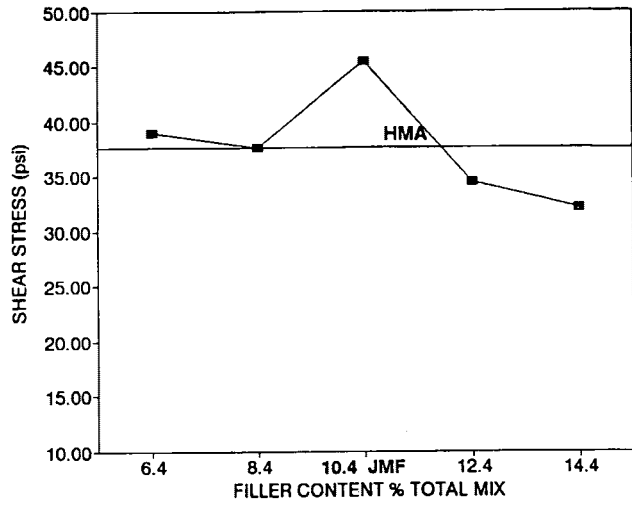


FIGURE 16 Gyratory shear stress to produce 1-degree angle of strain versus percentage passing No. 200 sieve in SMA.

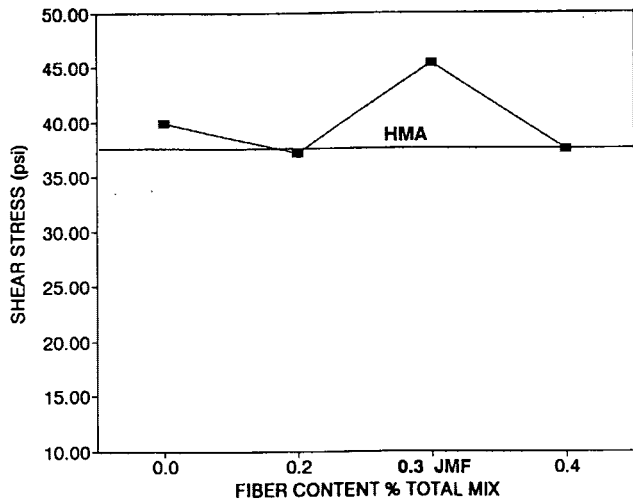


FIGURE 14 Gyratory shear stress to produce 1-degree angle of strain versus fiber content in SMA.

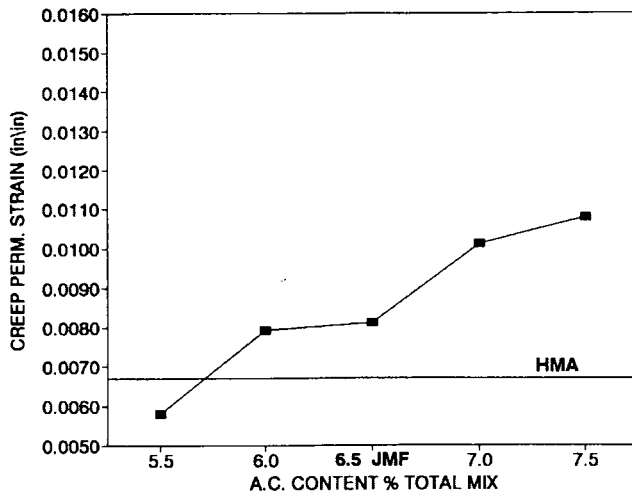


FIGURE 17 Permanent strain versus percentage asphalt content.

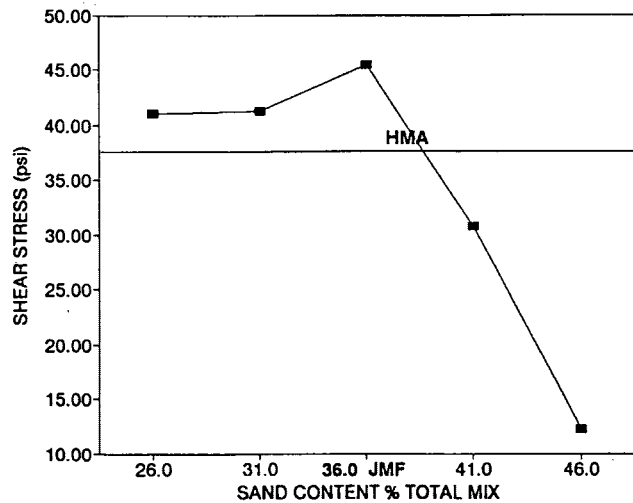


FIGURE 15 Gyratory shear stress to produce 1-degree angle of strain versus percentage passing No. 4 sieve in SMA.

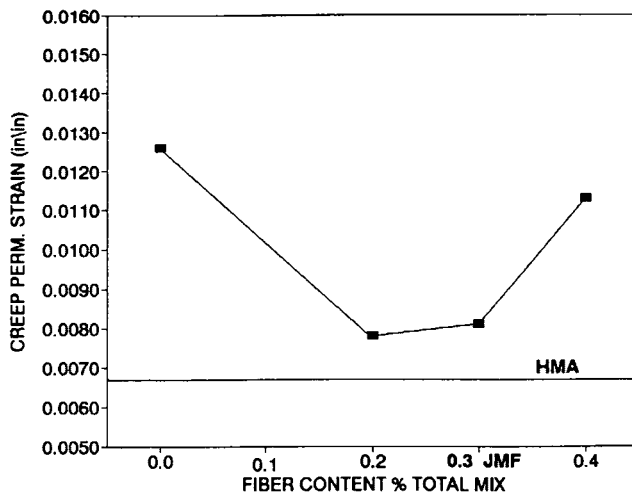


FIGURE 18 Permanent strain versus percentage fiber.

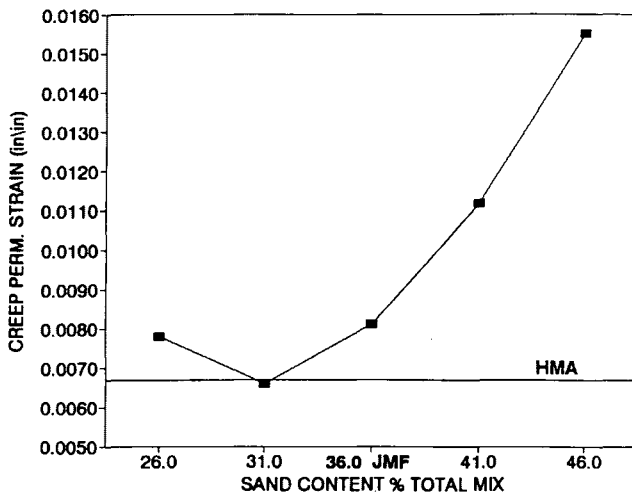


FIGURE 19 Permanent strain versus percentage passing No. 4 sieve.

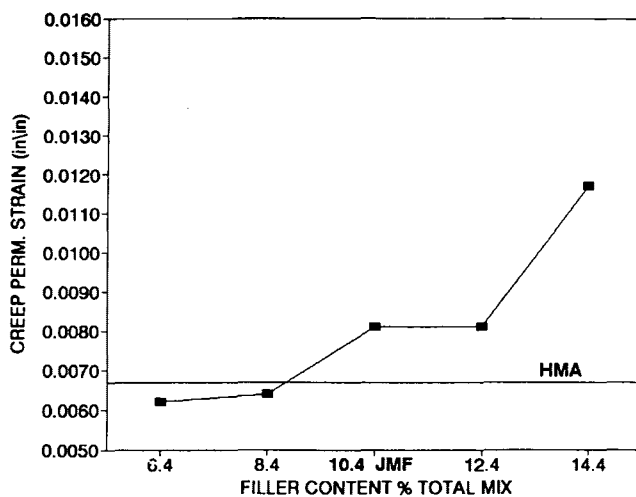


FIGURE 20 Permanent strain versus percentage passing No. 200 sieve.

prove with lower asphalt content, higher fiber content (up to a point), lower sand content, and lower filler content. Most of the SMA mixtures evaluated in this study had low void contents (below 3 percent). The data indicate that a properly designed SMA mixture would have approximately equal performance in the creep test as the standard HMA mixture. If the percent passing the No. 4 sieve had been approximately 30 percent or lower and if the voids in the mixture had been 3.0 percent or higher, it appears that the SMA mixture would provide good creep performance. The creep test shows some potential for being a good test for evaluating the quality of SMA mixtures.

CONCLUSIONS AND RECOMMENDATIONS

This was a limited study using one aggregate, one asphalt cement, and one additive to produce SMA mixtures and a dense-graded mixture. The results of this study are useful in identifying trends and problem areas and for providing preliminary guidance. Care must be used in making general statements about SMA.

- The HMA performed better in many laboratory tests than did some of the mixtures having variations to the SMA job mix formula. This indicates that control of the SMA within proper limits is necessary for best performance. Tests more related to performance are needed to better evaluate SMA mixtures. The creep and gyratory tests appear to be good tests for evaluating the relative performance of SMA mixtures.

- The addition of fiber had little effect on the VMA and the optimum asphalt content. However the fiber or another additive is necessary to prevent drainage of the asphalt cement.

- The best way to increase the optimum asphalt content is to lower the percentage passing the No. 4 sieve. Lowering filler content will also increase the optimum asphalt content but decreasing filler content may result in asphalt cement drainage problems.

- The performance of SMA mixtures in the laboratory is significantly affected by the aggregate gradation, which indicates that very close control of the aggregate gradation during construction is required. The laboratory properties are not greatly affected by asphalt content.

- The gyratory shear stress to produce a 1-degree angle is one test that the SMA mixture generally performed better than did the HMA mixture. The SMA mixture also did reasonably well in the confined creep test. These two tests are indicators of rutting resistance and will be useful in evaluating quality of SMA.

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REFERENCES

1. Brown, E. R., and S. A. Cross. A Study of In-Place Rutting of Asphalt Pavements, *Proc., Association of Asphalt Paving Technologies*, Vol. 5, 1989, pp. 1-31.
2. Brown, E. R., and S. A. Cross. *A National Study of Rutting in Asphalt Pavements*. Draft. National Center for Asphalt Technology, Auburn University, Alabama, 1992.

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