NCAT Report 93-03

EVALUATION OF SMA USED IN MICHIGAN (1991)

By

Dr. E.R. Brown

April 1992

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National Center for Asphalt Technology
NCAT
AUBURN UNIVERSITY
277 Technology Parkway • Auburn, AL 36830

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DISCLAIMER

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INTRODUCTION

Stone Matrix Asphalt (SMA) is a new technology that has recently been imported from Europe to the United States. These SMA mixtures have been shown to be more resistant to permanent deformation than conventional Hot Mix Asphalt (HMA) and at the same time 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 VMA) along with high filler content, high asphalt content and some 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 last few years to provide greater rutting resistance. SMA does cost more initially but the additional cost is offset by improved performance. It’s too early to estimate the cost of SMA in the U.S. but the price should reduce as more and more SMA is placed and as contractors become familiar with handling this new mixture.

In the Summer of 1991, five states placed SMA sections. These five states were Michigan, Wisconsin, Missouri Georgia, and Indiana. Since there has been very little testing of SMA mixtures in the U.S. it was difficult to select the optimum asphalt content for the SMA mixture for the projects in these states and it was also 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. This study was performed using the same materials and job mix formula as that used in the Michigan project. The mixture components that were varied to evaluate sensitivity included amount of cellulose (Arbocel), asphalt content, percent passing the No. 4 Sieve, and percent passing the No. 200 Sieve. The properties used to evaluate the effect of these changes included tensile strength, Marshall stability, flow, Gyratory Properties (GSI, GEPI, and shear stress to produce 1 degree angle), resilient modulus, creep, and physical properties including voids, voids in mineral aggregate, and voids filled.

TEST PLAN

The overall test plan involved preparing 15 replicate samples for each of 17 mixture variations. These samples were compacted in the 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 120 psi, 1 degree angle and 120 revolutions). A dense graded HMA using the same aggregate as used in the SMA was prepared and tested for comparison purposes.

The JMFs for the dense graded mixture and SMA mixture are shown in Table 1. There were several variations of the SMA mixture that 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).

Fifteen samples were prepared at each mixture combination for evaluation. The samples were compacted in the Gyratory Testing Machine and the GSI, GEPI, and shear stress to produce one degree angle were determined. After compaction, three samples were tested to determine the Marshall stability and flow, three samples were tested for indirect tensile strength at 77°F, three samples were tested for resilient modulus at 40°F, 77°F, and 104°F; and three samples were tested to determine confined creep properties at 140°F and 120 psi loading pressure. The confinement pressure for creep testing was 20 psi.

Table 1. Job Mix Formulas for Dense-Graded and SMA Mixtures

Aggregate		
Sieve Size	**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

TEST RESULTS AND ANALYSIS

Voids in Total Mm (VTM)

All of the test results produced in this study are summarized in Table 2. The VTM in the SMA mixtures ranged from a low of 0.1 percent to a high of 5.5 percent. The optimum void content for dense graded mixtures is typically 4.0 percent and for SMA mixtures the void content is typicalIy 3.0 percent or slightly higher.

Table 2. Test Results for SMA and Dense-Graded Mixtures

NATIONAL CENTER FOR ASPHALT TECHNOLOGY (NCAT)
HOT MIX ASPHALT PROPERTIES

Project:			**MICHIGAN SMA**														
Specimen Mix Type	Asphalt Content (%)	Unit Weight (pcf)	VOIDS			INDIRECT TENSILE		RESILIENT MODULUS			CONFINED CREEP		GYRATORY PROPERTIES			STABILITY & FLOW	
			Total (%)	VMA (%)	Filled (%)	Pult @ 77F (lb)	Strength @ 77F (psi)	Modulus @ 40F (ksi)	Modulus @ 77F (ksi)	Modulus @ 104F (ksi)	Perm. Strain (in/in)	Creep Modulus (psi)	GSI	GEPI	SHEAR STRESS (psi)	Corrected (lb)	Flow (.01 in)
SMA +1.0% A.C.	7.5	152.1	0.3	18.1	96.2	2382	142.5	2288	275	104	0.0108	11111	1.05	1.19	36.3	1768	24
SMA +0.50% A.C.	7.0	152.4	0.8	17.4	95.3	2438	145.6	2325	233	99	0.0101	1181	1.01	1.19	40.3	1814	21
SMA -0.5% A.C.	6.0	152.2	3.0	17.2	82.6	2278	136.3	2581	312	109	0.0079	15190	1.00	1.20	39.3	1617	14
SMA -1.0% A.C.	5.5	152.6	2.9	16.0	81.7	2425	142.6	2248	347	117	0.0058	20690	1.00	1.14	38.2	1550	16
SMA 0.0% FIBER	6.5	153.8	1.2	16.8	92.6	2542	151.9	2233	272	107	0.0126	9524	1.00	1.17	39.9	1668	22
SMA 0.2% FIBER	6.5	153.2	0.8	16.3	94.9	3337	200.5	2564	244	164	0.0078	15385	1.00	1.18	37.2	2000	17
SMA 0.3% FIBER	6.5	152.5	1.6	17.0	90.8	2428	138.3	2201	295	184	0.0081	14815	1.00	1.24	45.4	1690	16
SMA 0.4% FIBER	6.5	152.3	1.7	17.1	89.9	3388	200.6	1952	295	107	0.0113	10619	1.00	1.14	37.5	1791	20
SMA +10.0% SAND	6.5	154.3	0.4	16.0	97.8	2347	143.9	1265	515	138	0.0155	7742	1.34	1.21	12.2	2050	22
SMA +5.0% SAND	6.5	154.1	0.2	15.8	98.5	2542	154.0	1514	571	137	0.0112	10714	1.11	1.19	30.7	1850	20
SMA -10.0% SAND	6.5	146.4	5.5	20.3	73.0	1925	107.8	1075	406	120	0.0078	15385	1.00	1.15	41.0	1015	12
SMA -5.0% SAND	6.5	150.9	2.5	17.7	86.1	2293	132.3	1526	474	117	0.0066	18182	1.00	1.18	41.2	1566	14
SMA +4.0% FILLER	6.5	154.5	0.1	15.7	99.6	2573	158.1	1418	526	155	0.0117	10256	1.09	1.22	32.1	2050	21
SMA +2.0% FILLER	6.5	154.2	0.4	16.0	97.4	2520	152.7	1371	459	115	0.0081	14815	1.02	1.20	34.4	2107	19
SMA -4.0% FILLER	6.5	149.2	3.5	18.6	81.2	2250	129.0	2212	476	194	0.0186	6452	1.00	1.14	39.0	1602	19
SMA -2.0% FILLER	6.5	150.8	2.9	18.2	83.9	2383	139.1	2033	438	206	0.0064	18750	1.00	1.15	37.6	1607	16
HMA DENSE MIX	4.25	153.3	4.5	14.6	69.4	4048	247.0	3026	1044	528	0.0082	14634	1.05	1.13	37.6	3264	14

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 from this plot 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 AC content of 6.5 percent but this was reduced to 6.2 percent during construction.

Figure 2 shows that the fiber content had very little effect on VIM. Higher fiber content did appear to increase VIM slightly. 7his data seems to indicate that the optimum asphalt content can not be significantly increased by increasing the fiber content. The primary purpose of the fiber then is to stabilize the asphalt cement to prevent drainage and not to increase the AC content.

Figure 3 shows that the amount of sand (percent 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 3shows 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. This data shows that, on the 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 mix to the percentage passing the No. 200 Sieve is about the same as that for dense graded mixtures.

Voids Filled with Asphalt (VFA)

The VFA is inversely related to the VTM. Low VTM results when the VFA are high and high VTM results when the VFA are low. Figures 5-8 show that most of the SMA mixtures had relatively high VFA. For dense graded mixtures a VFA content above 80 percent is usually considered high. SMA mixtures having a VMA of approximately 17 would have a VFA of 82.4 at 3 percent air voids. Hence it is not unreasonable to expect up to 85 percent VFA for SMA mixtures.

The two variables that had the greatest effect on WA were sand content and filler content. Low filler content and low sand content increases the Wand thus decreases the VFA for a given asphalt content.

Unit Weight

As expected, the unit weight plots have opposite trends to that shown for VTM. Lower unit weights for a given mixture produce higher voids and vice versa. However factors other than unit weight such as asphalt content also affect the VTM. The unit weight is not affected much by asphalt content (Figure 9). There is very little change in unit weight over the range of AC contents evaluated. A higher fiber content produces a slight reduction in density (Figure 10). The fiber tends to bulk the aggregate resulting in a lower density. An increase in sand content

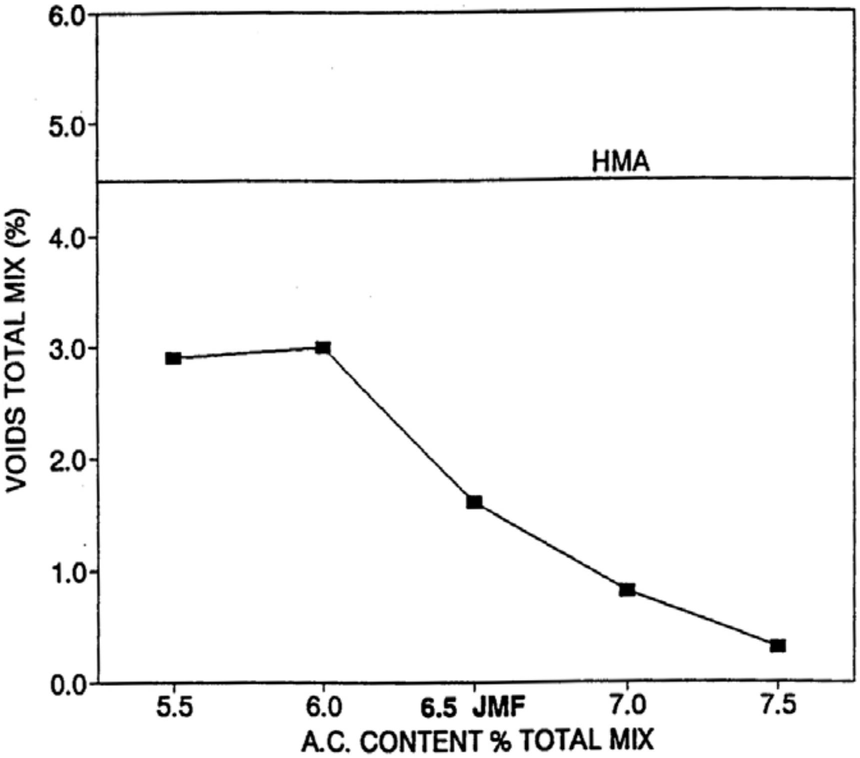

Figure 1: Voids Total Mix Vs. Asphalt Content for SMA and HMA.

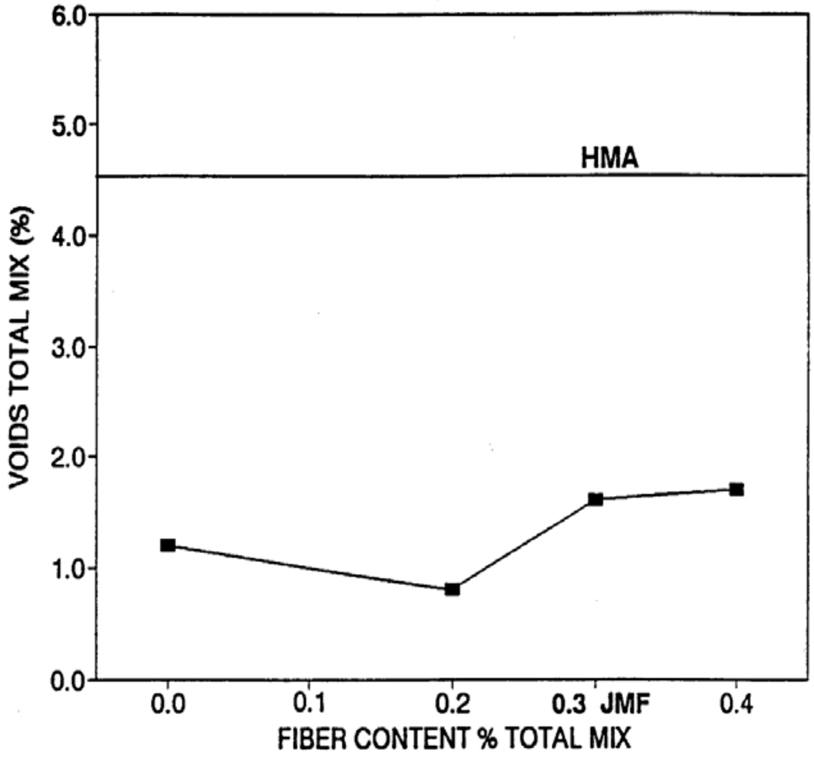

Figure 2: Voids Total Mix Vs. Fiber Content for SMA.

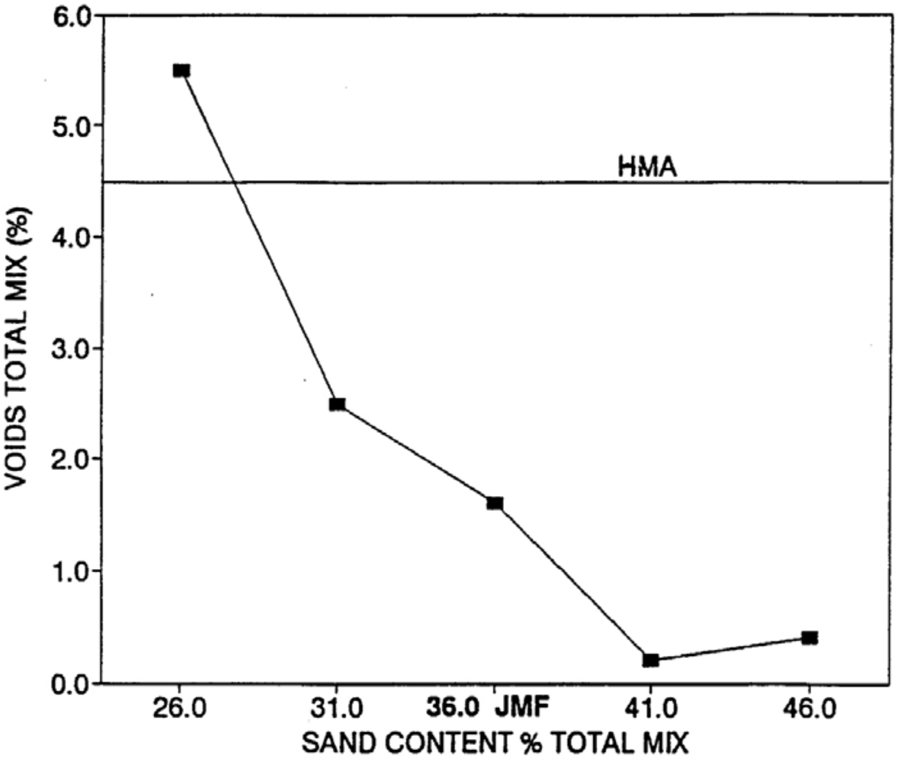

Figure 3: Voids Total Mix Vs. Sand Content for SMA.

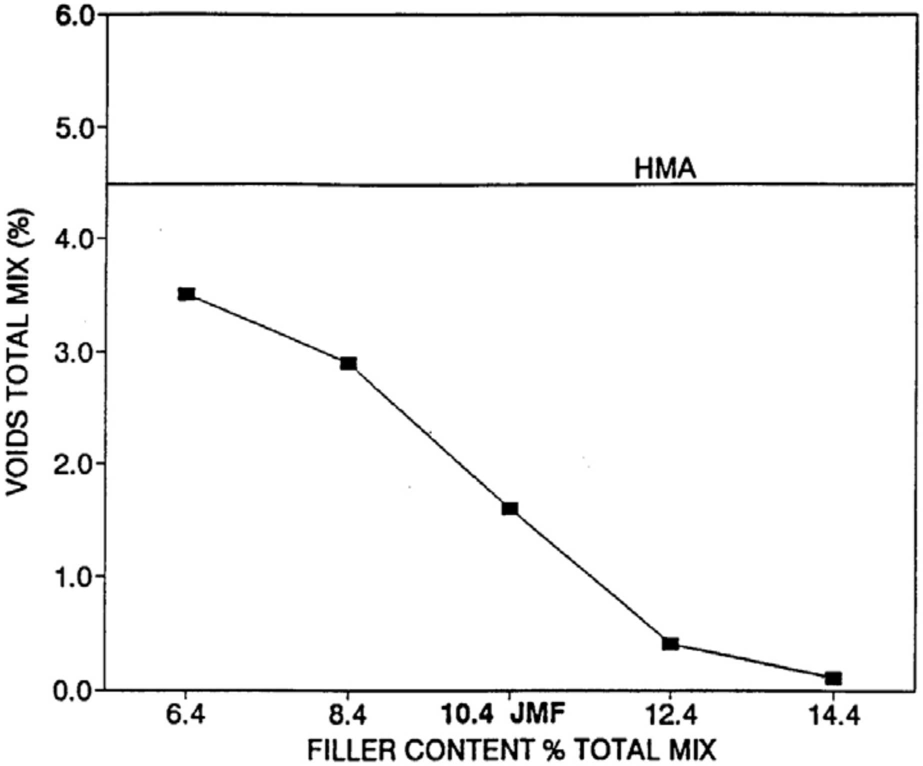

Figure 4: Voids Total Mix Vs. Filler Content for SMA.

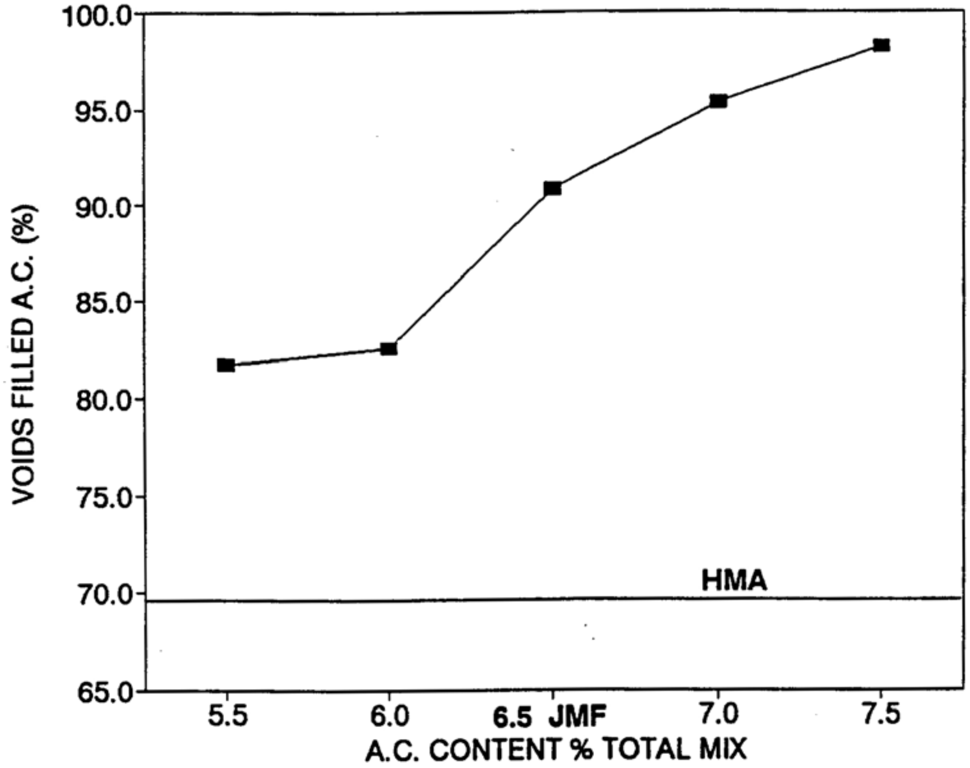

Figure 5: Voids filled with Asphalt versus Asphalt Content in SMA.

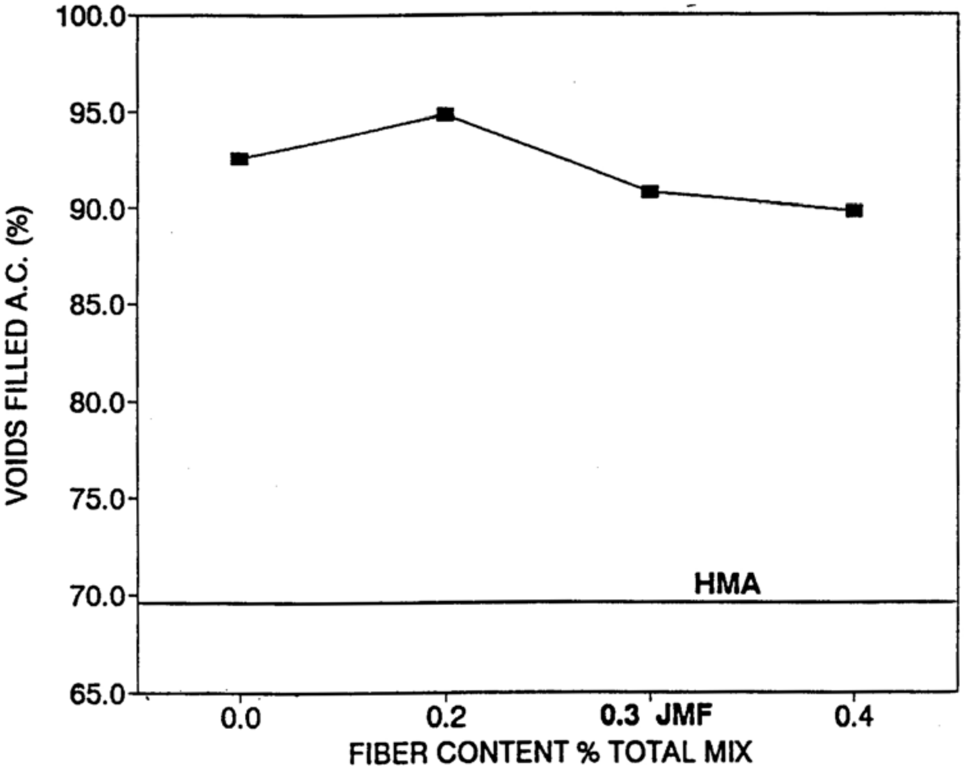

Figure 6: Voids filled with Asphalt versus Fiber Content in SMA.

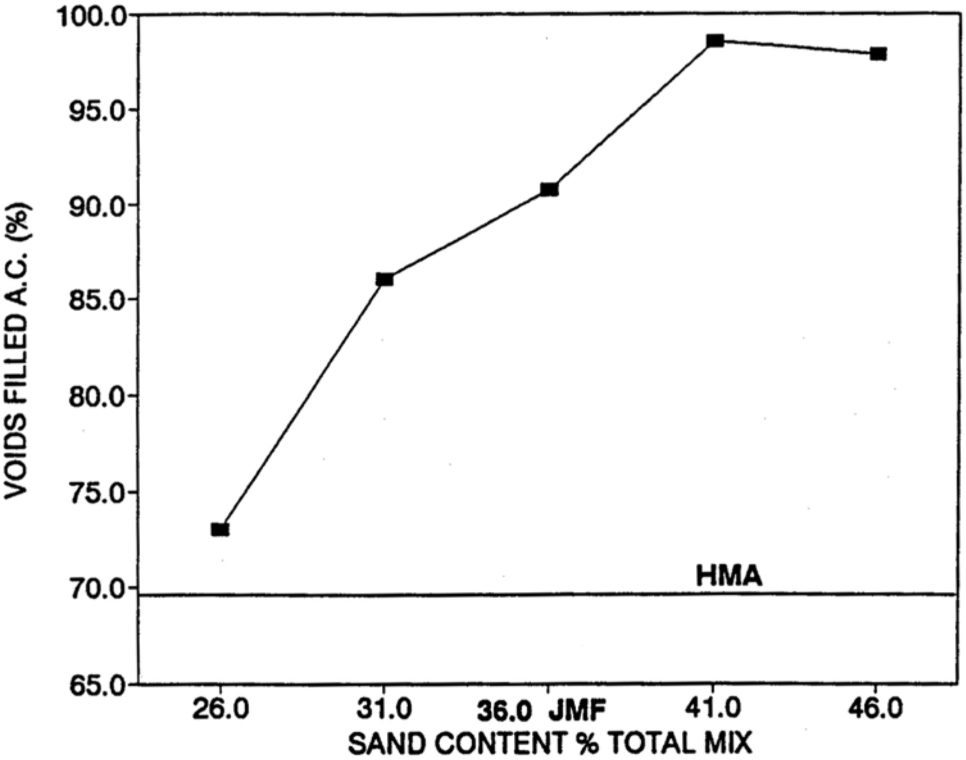

Figure 7: Voids filled with Asphalt versus Sand Content.

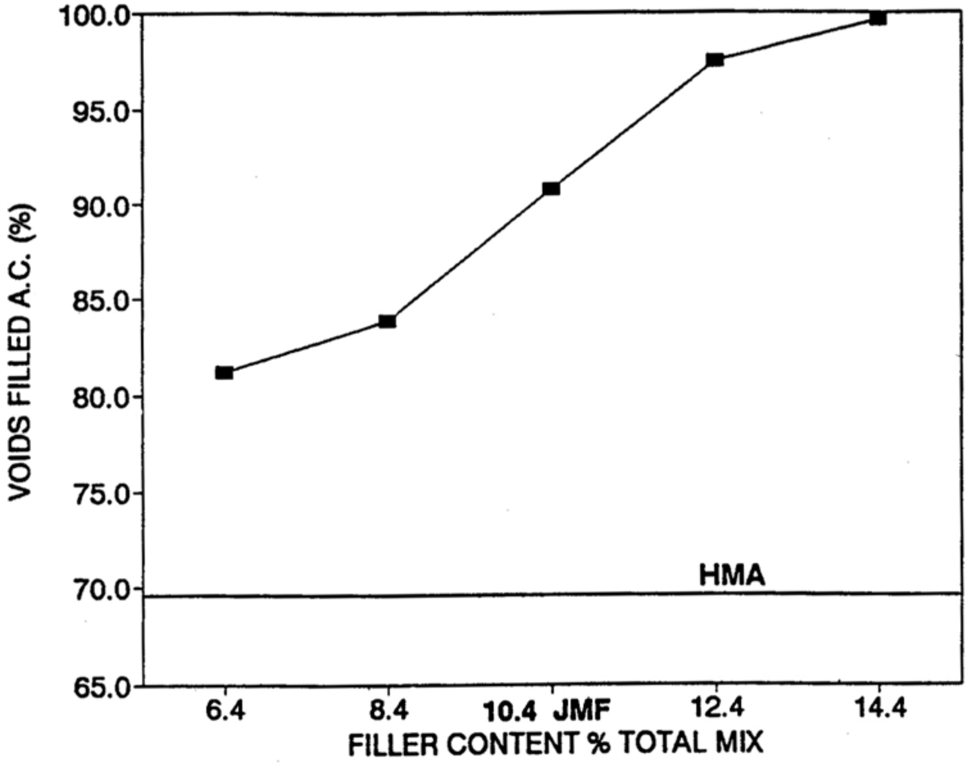

Figure 8: Voids filled with Asphalt versus Filler Content in SMA.

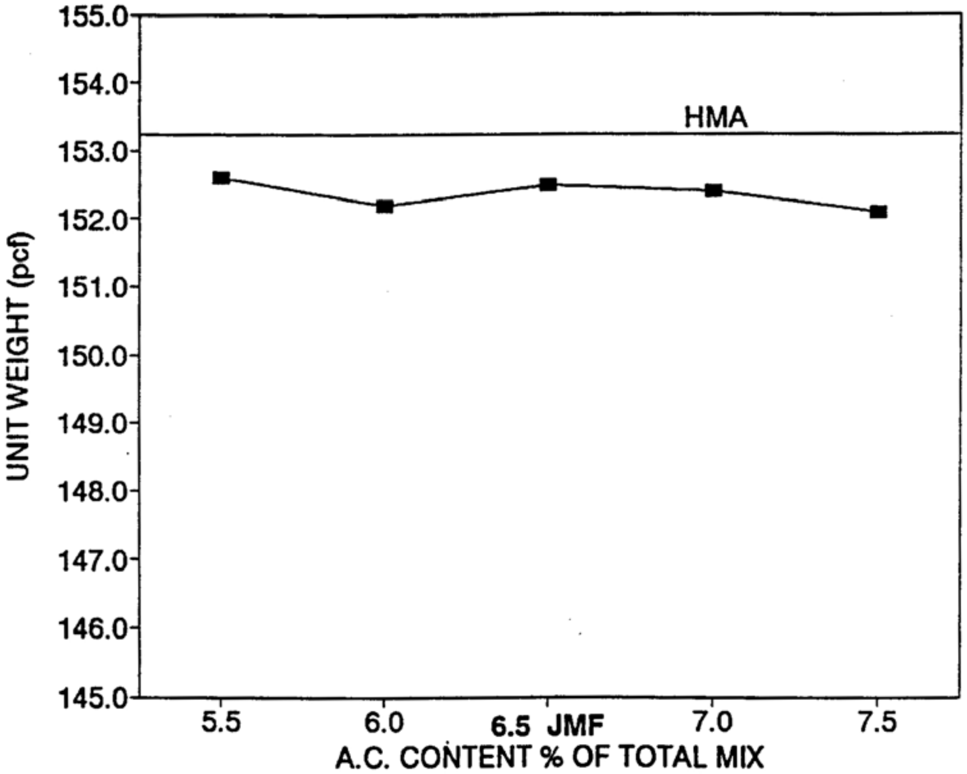

Figure 9: Unit Weight versus Asphalt Content for SMA.

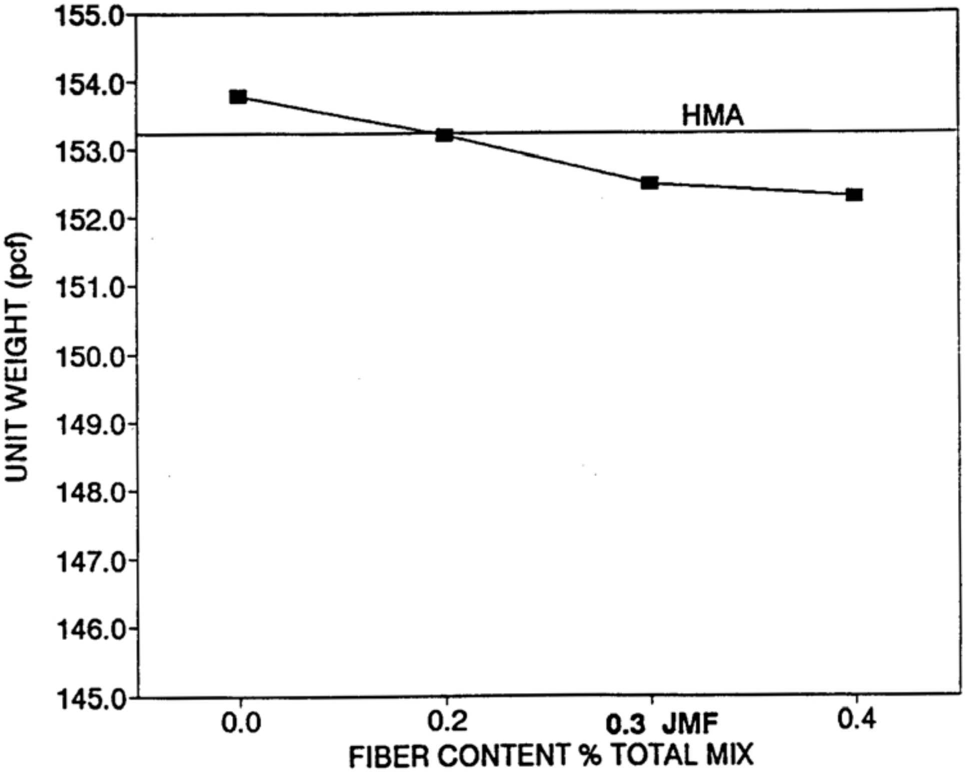

Figure 10: Unit Weight versus Fiber Content for SMA.

produces a significant increase in unit weight (Figure 11) resulting in lower VTM. An increase in filler content also produces an increase in unit weight (Figure 12) and results in lower VTM.

Voids in Mineral Aggregate (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 13 shows that an increase in AC 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 AC is forcing the aggregate particles apart and thus increasing the VMA. This will result in a mix that is not stable under traffic and which may result in permanent deformation. As stated earlier, the design AC content was a little on the high side.

The fiber content has little effect on the VMA (Figure 14). This means that the optimum asphalt content can not 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 15). Higher sand contents produced lower VMAs. With SMA mixtures, the voids between the coarse aggregate particles are not filled with sand size material, hence, using a higher percentage of sand tends to fill these voids similar to minus 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 becomes unstable.

The filler content also affected the VMA (Figure 16). 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 -200 material and the percent passing the No. 4 Sieve.

Gyratory Stability Index (GSI)

For dense graded mixes, the GSI has been shown to be an indicator rut (*1*). When the GSI exceeds 1.1 to 1.2, for a dense graded mix it has a high probability of rutting. The amount of asphalt cement and fiber content appears to have little effect on GSI (Figures 17 and 18). The GSI values for the asphalt cement and fiber content evaluated are below 1.05. High sand content or filler content produced mixes with high GSI values (Figures 19 and 20). These mixes with high sand and filler contents would be more likely than mixes with lower sand and filler contents would be more likely to shove and rut. 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 and No. 200 Sieves.

Gyratory Elastic Plastic Index (GEPI)

Dense graded mixtures with high GEPI values are more likely to rut than mixtures with low GEPI values. Sufficient work has not been performed to set a maximum value for GEPI but it is

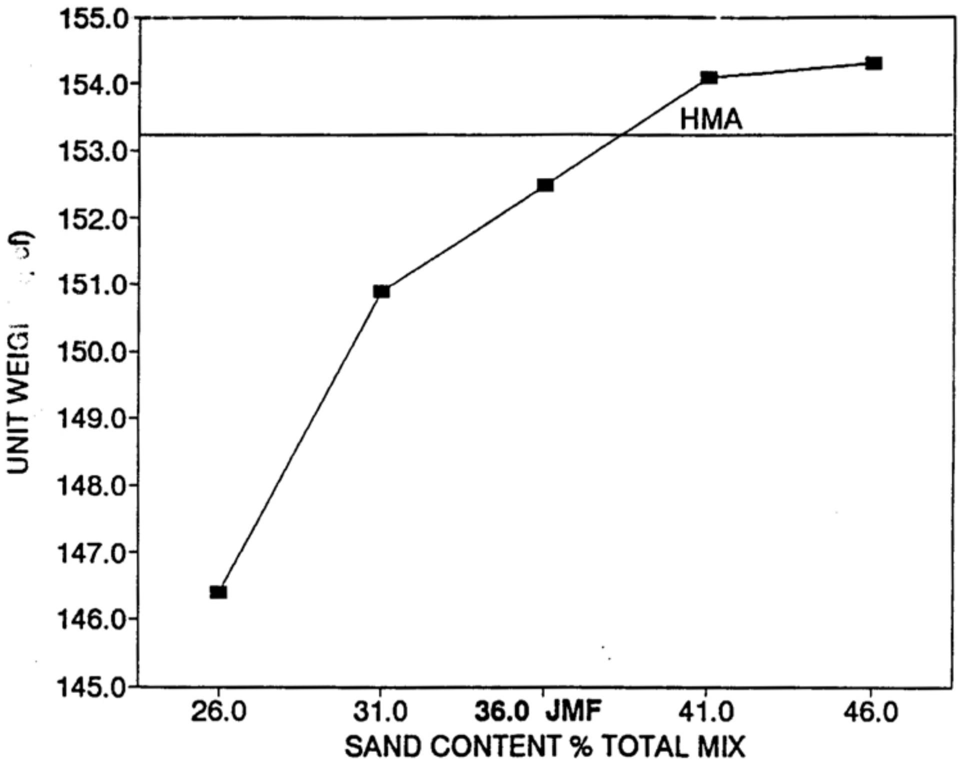

Figure 11: Unit Weight versus Sand Content for SMA.

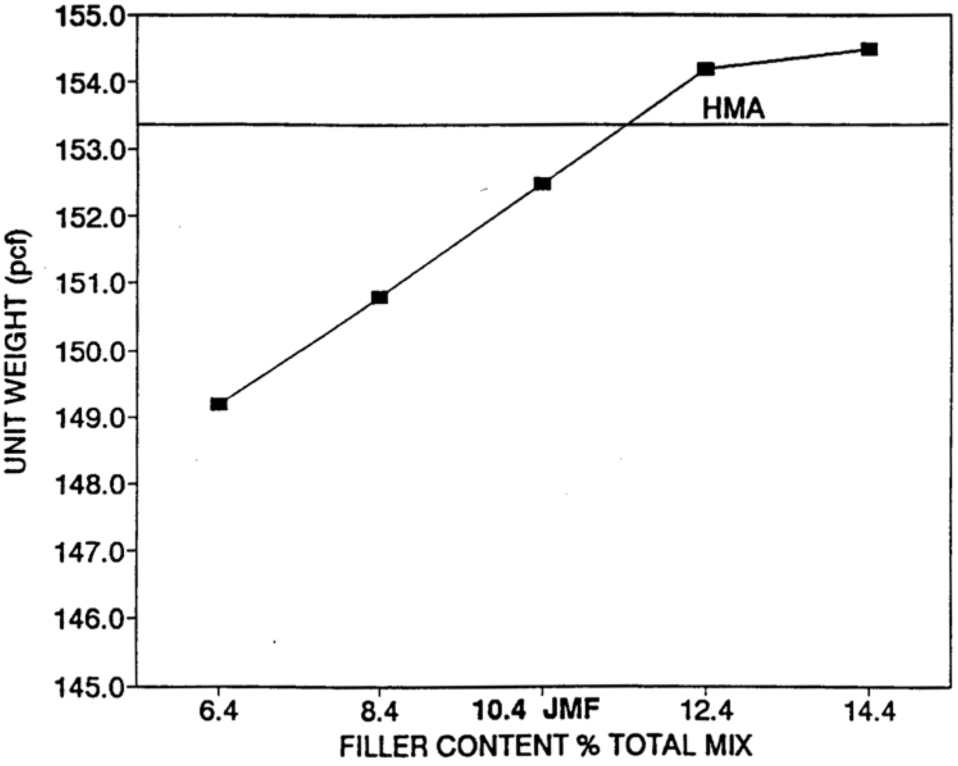

Figure 12: Unit Weight versus Filler Content for SMA.

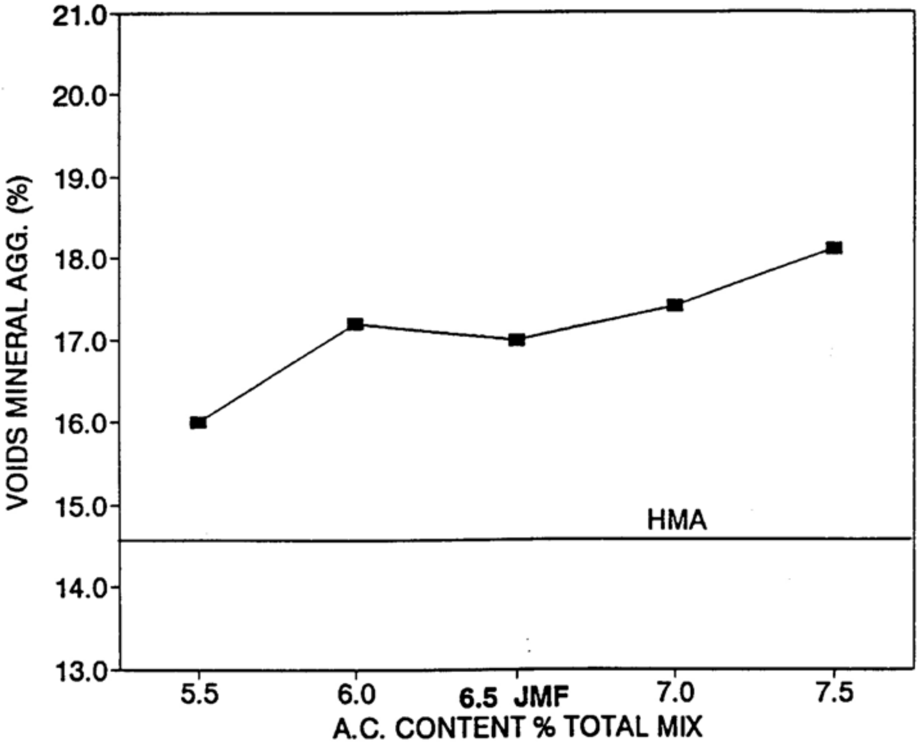

Figure 13: Voids in Mineral Aggregate versus Asphalt Content for SMA.

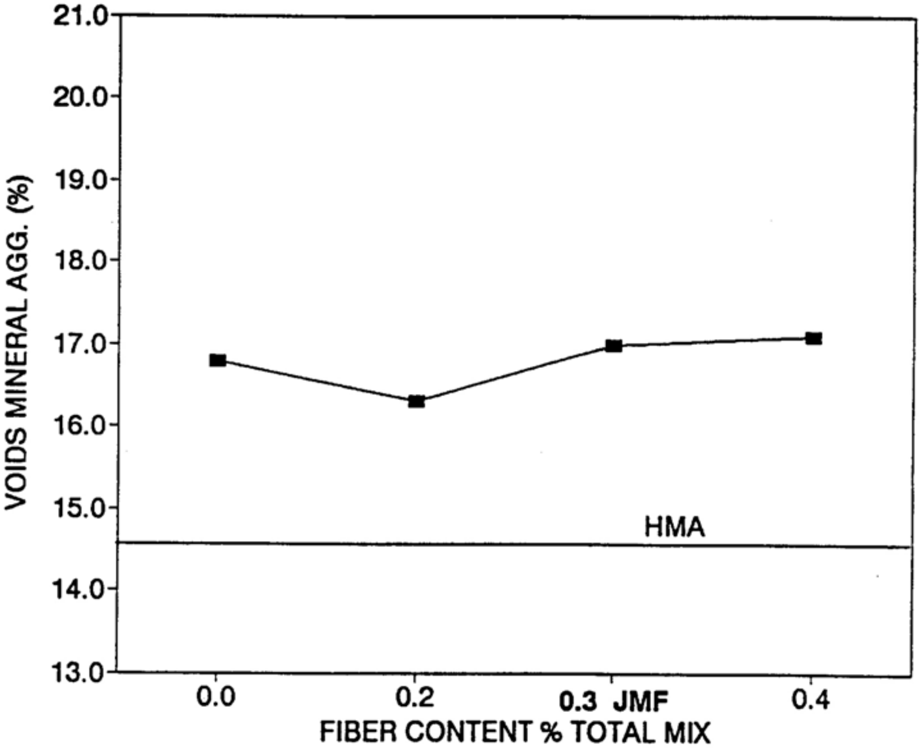

Figure 14: Voids in Mineral Aggregate versus Fiber Content in SMA.

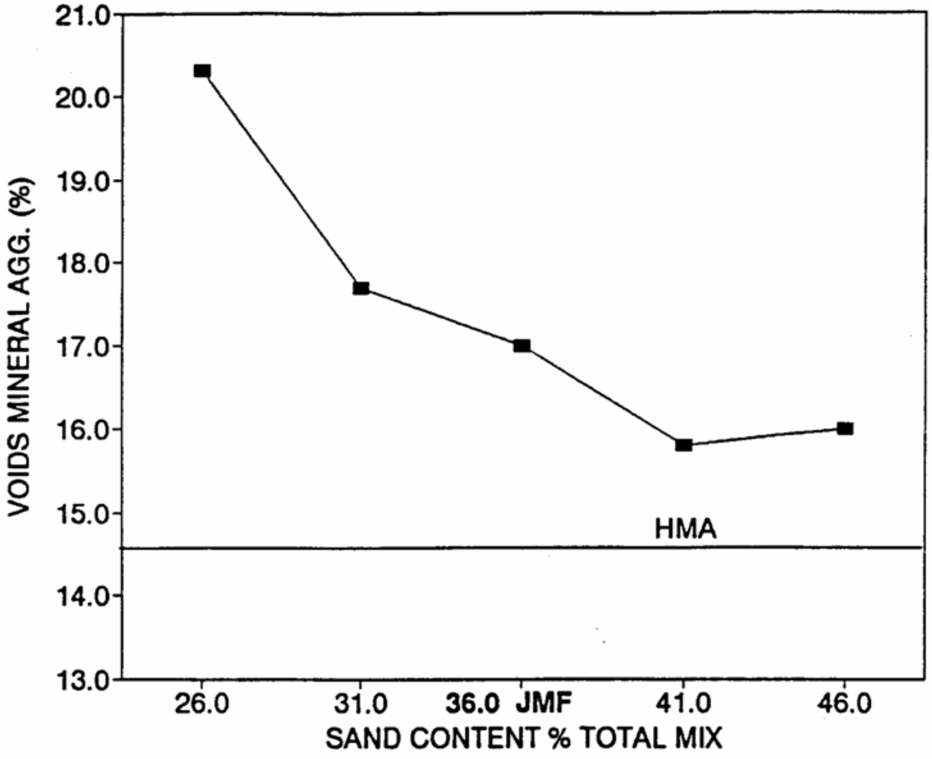

Figure 15: Voids in Mineral Aggregate versus Sand Content in SMA.

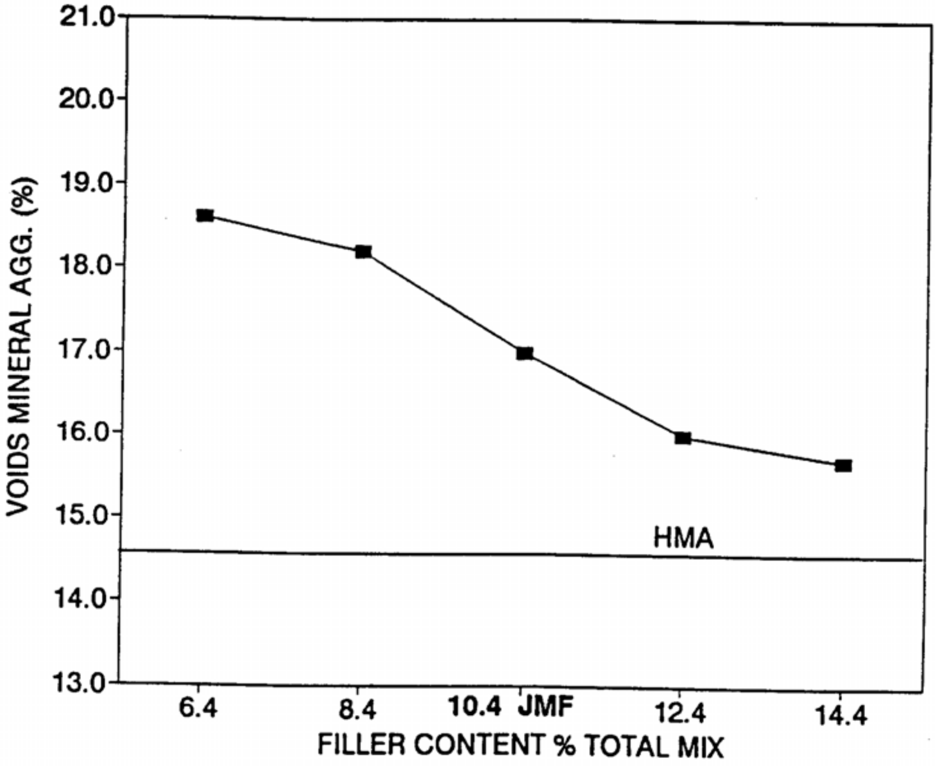

Figure 16: Voids in Mineral Aggregate versus Filler Content in SMA.

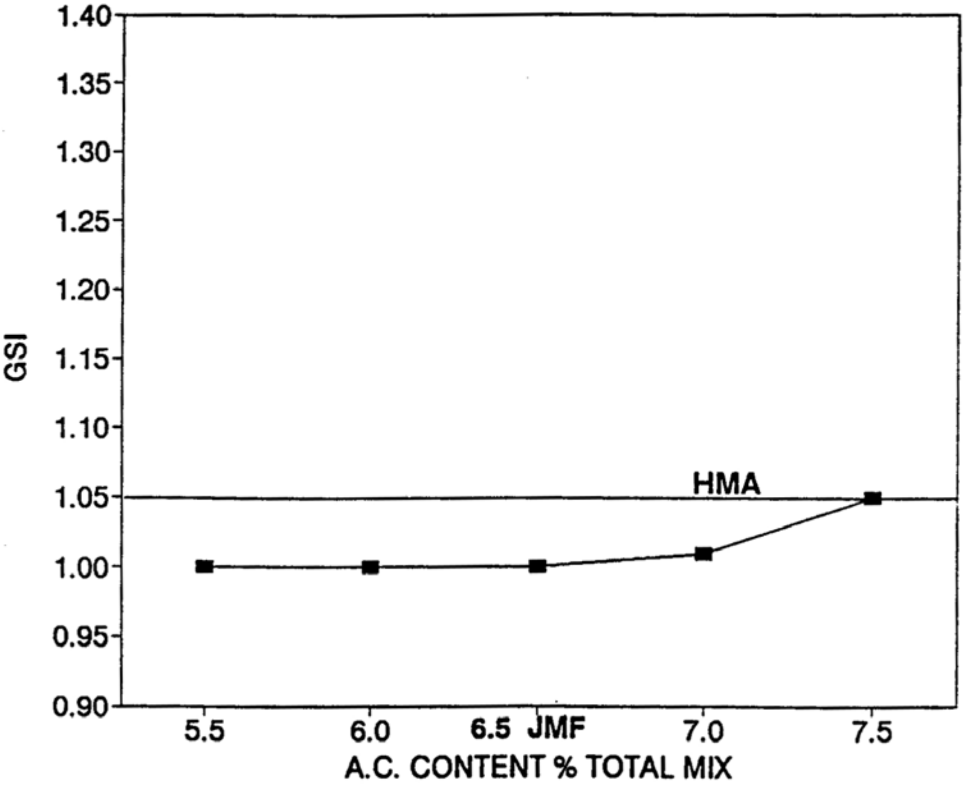

Figure 17: Gyratory Stability Index versus Asphalt Content in SMA.

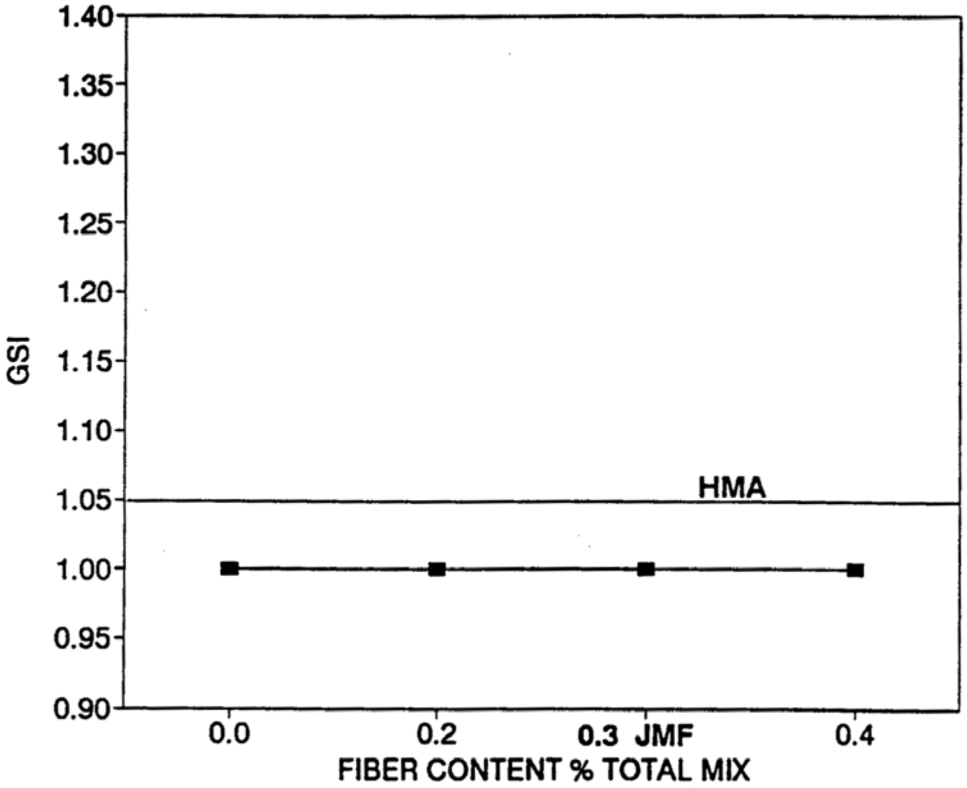

Figure 18: Gyratory Stability Index versus Fiber Content in SMA.

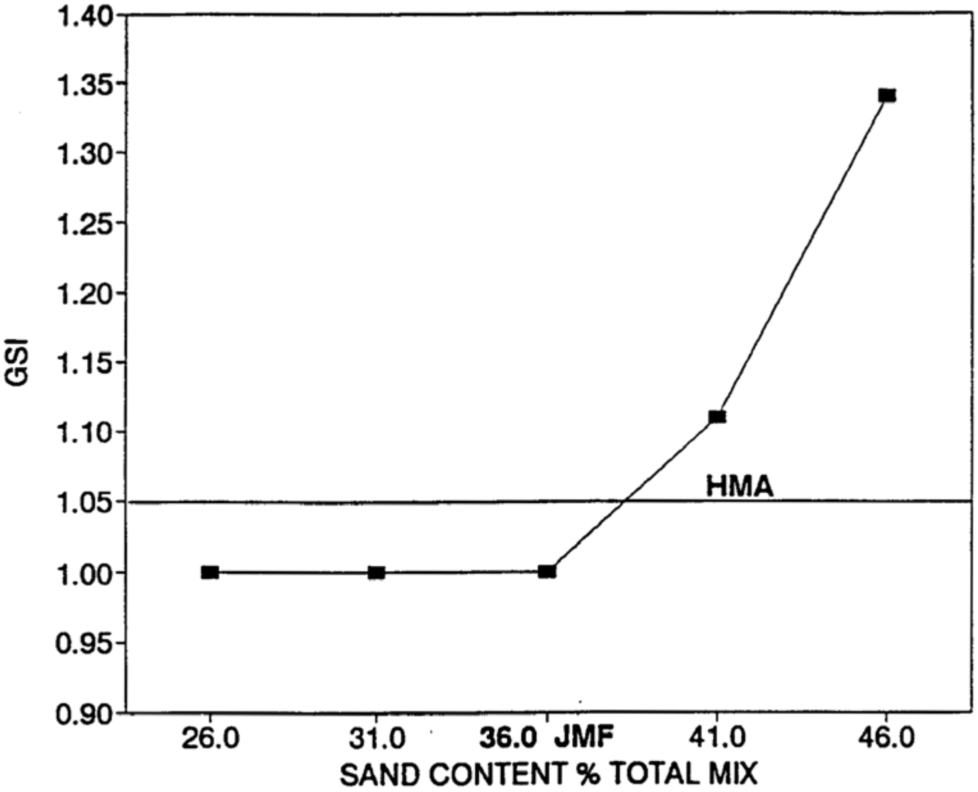

Figure 19: Gyratory Stability Index versus Sand Content in SMA.

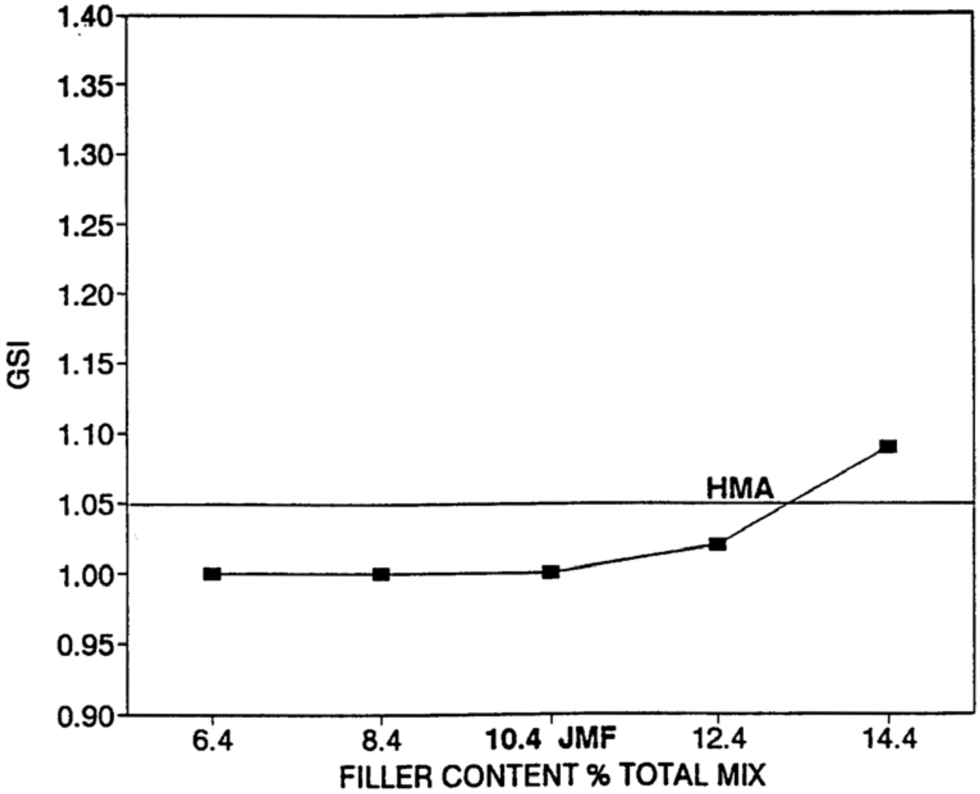

Figure 20: Gyratory Stability Index versus Filler Content in SMA.

an indicator of performance. All of the SMA mixtures had GEPI values higher than the corresponding HMA mixtures (Figures 21-24). Based on studies of dense graded mixes, these higher GEPI values indicate a higher probability of rutting. However, the GEPI property may not be a good measure of performance with SMA mixtures or the criteria maybe different from that for dense graded mixtures.

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 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 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 25-28). Asphalt content and fiber content appear to have little effect on the measured shear stress. This data appears to indicate that SMA mixtures are less sensitive to a change in asphalt content than 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 SMA mixtures are unstable.

Marshall Stability

The Marshall Stability test was developed to evaluate consistency and quality of dense graded mixes. It has not proven to be a good test for predicting performance for dense graded mixes and it is likely less useful for SMA. The asphalt content and fiber content have very little effect on stability (Figures 29 and 30). Higher sand content and higher filler content appear to produce SMA mixtures with higher stabilities (Figures 31 and 32). These higher stabilities at high sand content and high fiber content are probably not indicators of higher resistance to rutting since many of the other tests showed poor performances at high sand and filler contents. The SMA mixtures overall have much lower stability values than the HMA mixture, but again this does not indicate that SMA mixtures are more susceptible to rutting. It does indicate that Marshall stability is not a good test for predicting performance in SMA.

Flow

High flow values for dense graded mixtures are an indicator that plastic flow or permanent deformation will likely occur during the life of the mixture. The SMA mixtures typically have higher flow values than the HMA mixture (Figures 33-36). The flow value for the SMA mixtures tends to increase with higher AC content, higher sand content, and higher filler content. There is no obvious trend between fiber content and flow. Flow was developed for HMA and appears to have little value using present requirements in predicting the performance of SMA mixtures except to possibly indicate high asphalt content. The criteria should likely be changed however.

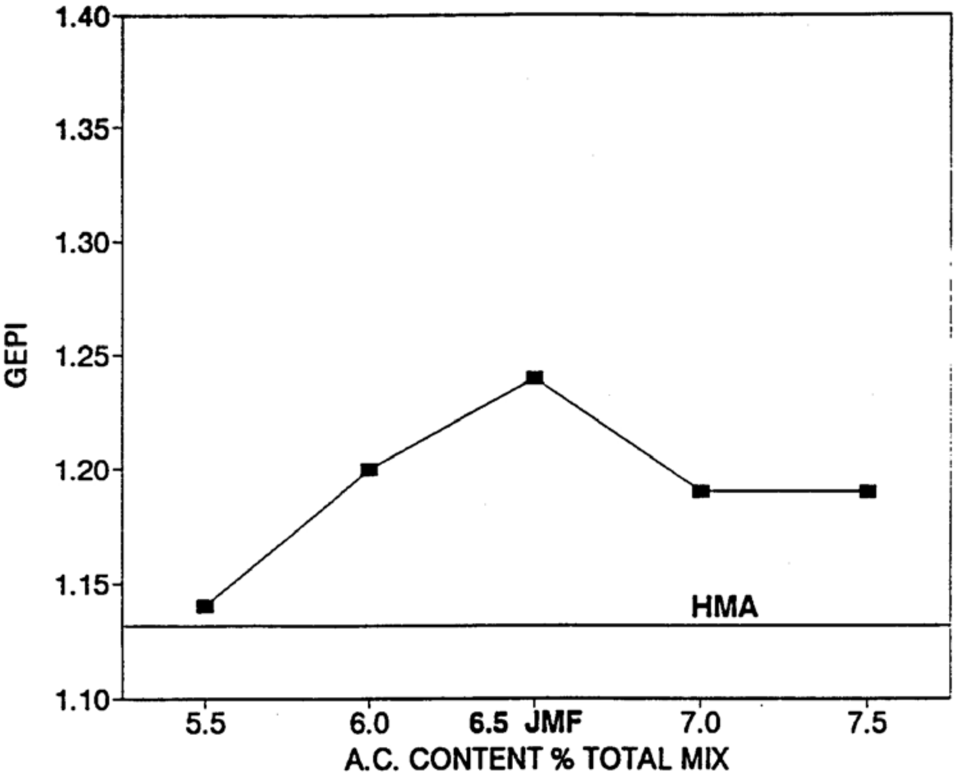

Figure 21: Gyratory Elasto-Plastic Index versus Asphalt Content in SMA.

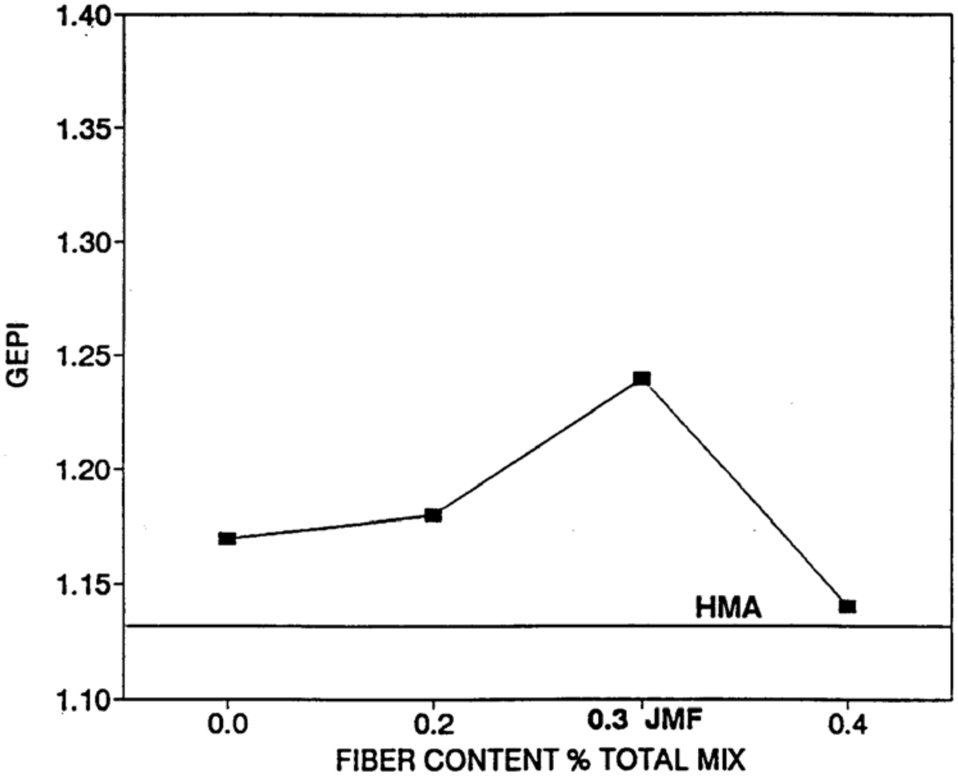

Figure 22: Gyratory Elasto-Plastic Index versus Fiber Content in SMA.

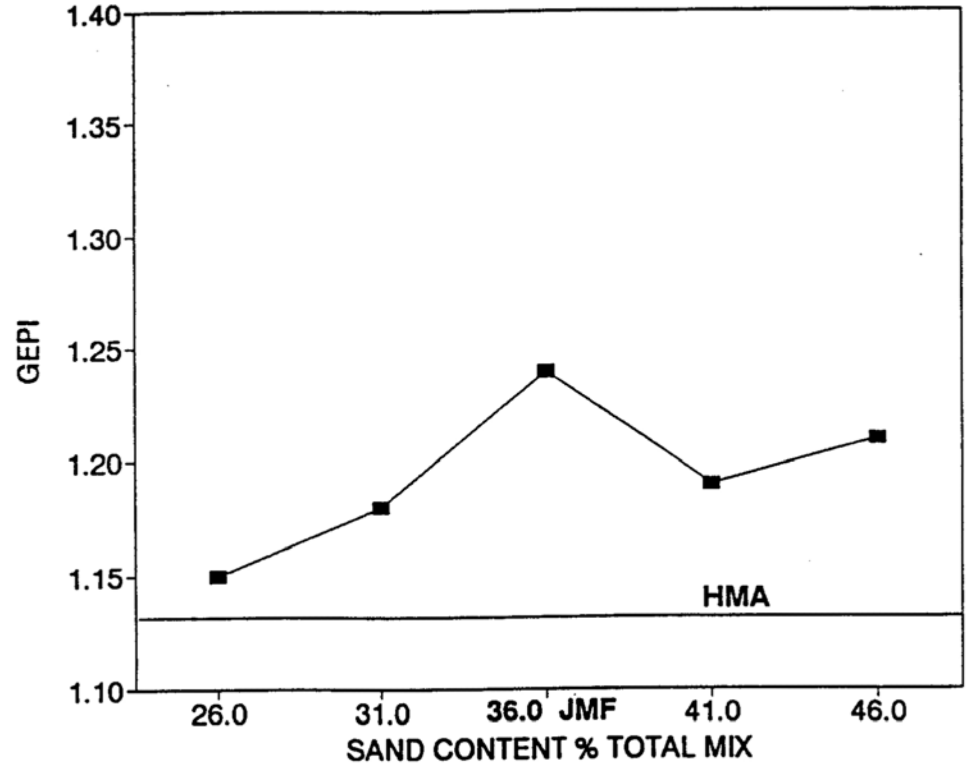

Figure 23: Gyratory Elasto-Plastic Index Sand Content in SMA.

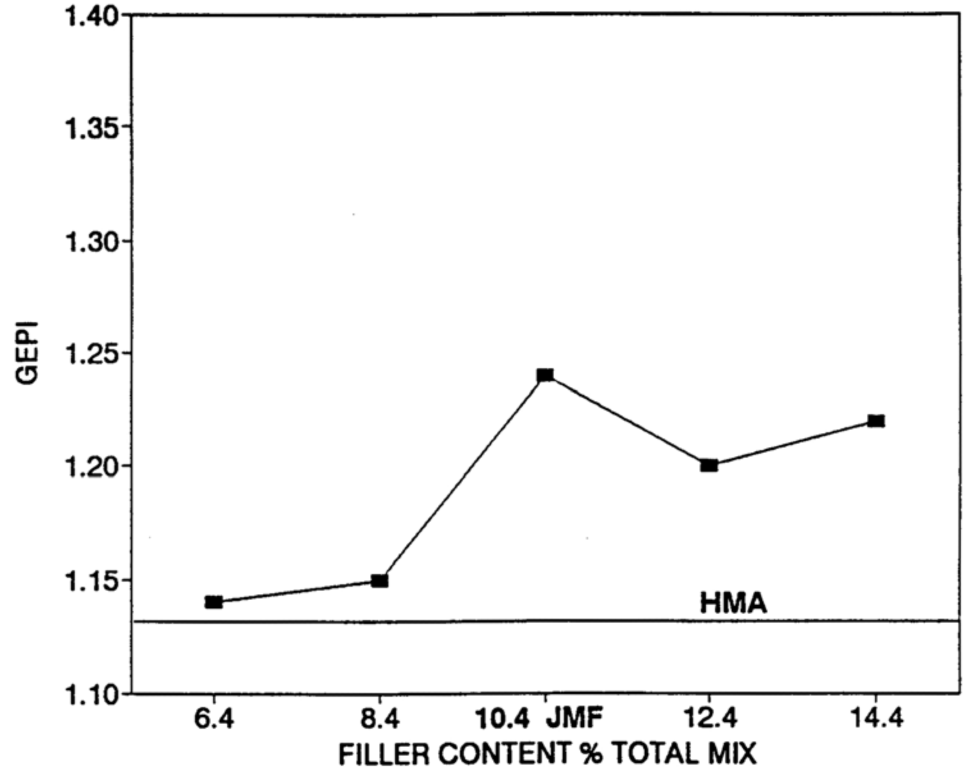

Figure 24: Gyratory Elasto-Plastic Index versus Filler Content in SMA.

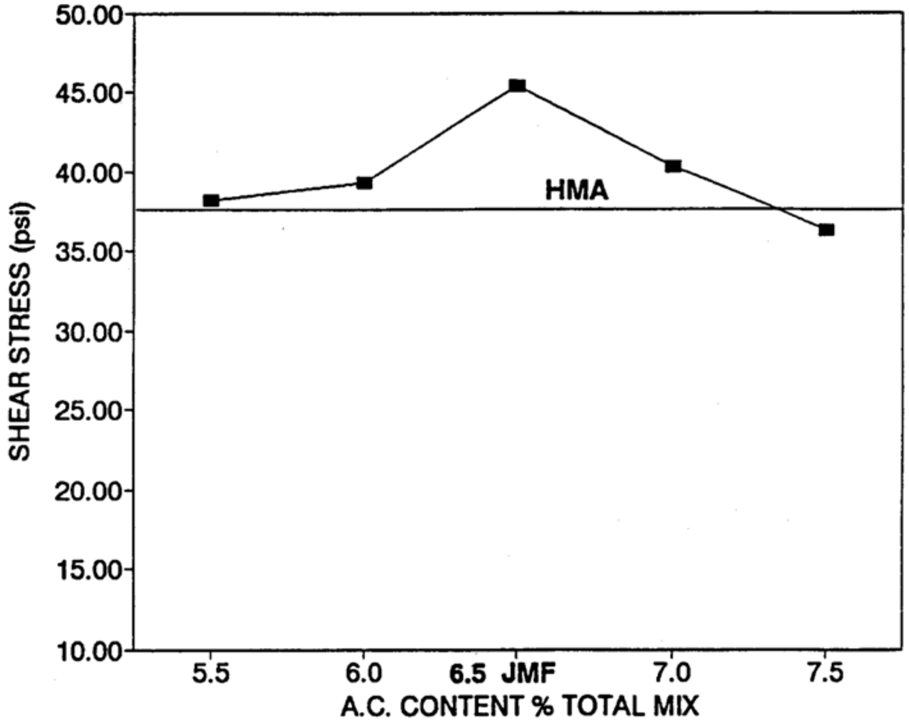

Figure 25: **Gyratory Shear Stress to Produce 1 Degree Angle of Strain versus Asphalt Content in SMA.**

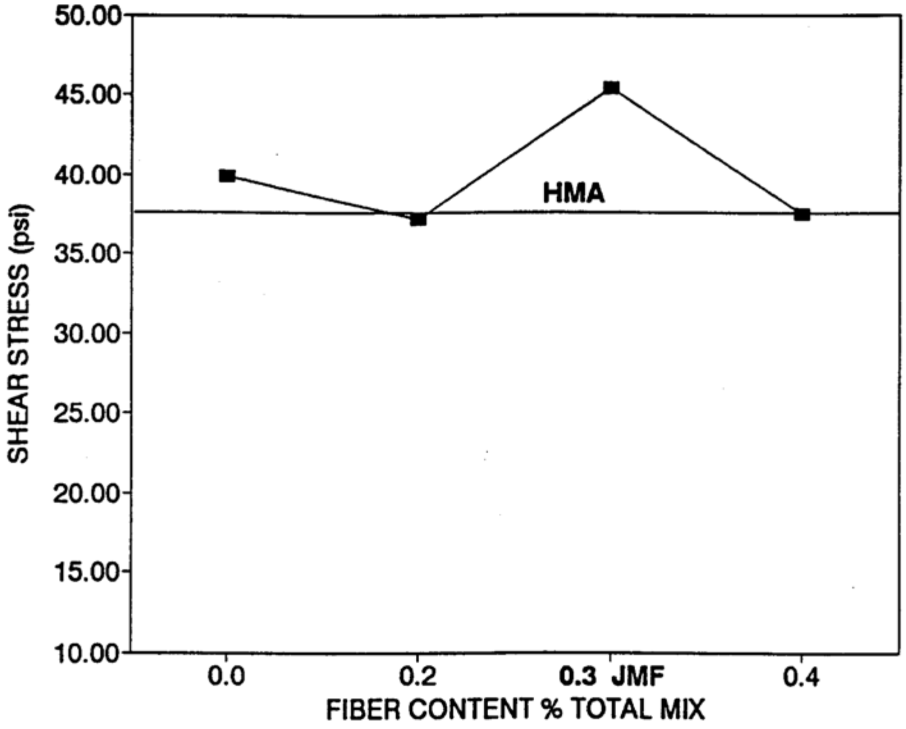

Figure 26: **Gyratory Shear Stress to Produce 1 Degree Angle of Strain versus Fiber Content in SMA.**

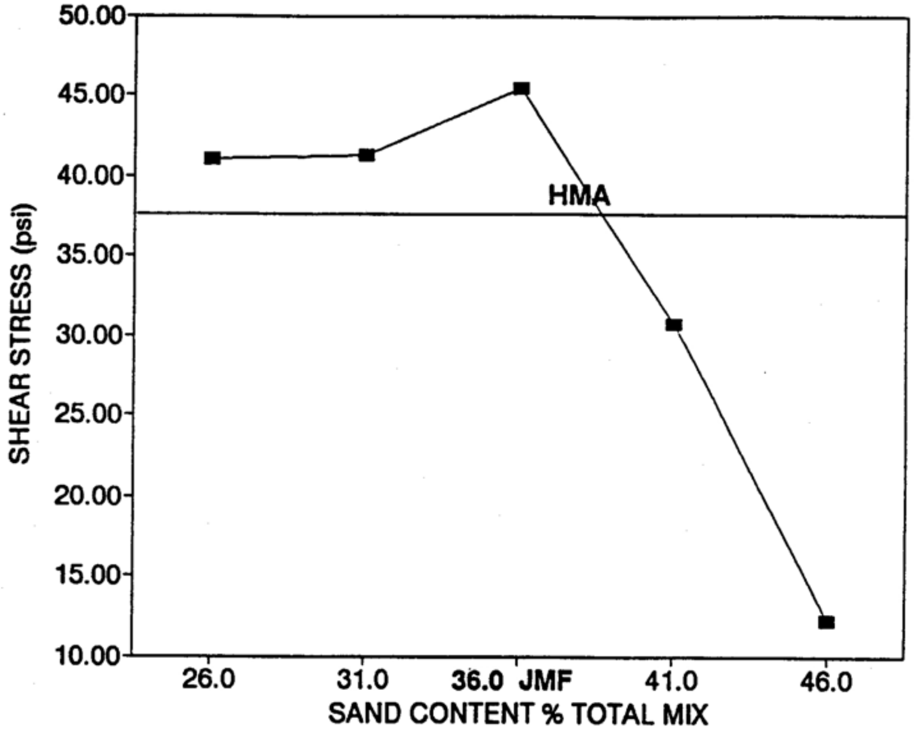

Figure 27: **Gyratory Shear Stress to Produce 1 Degree Angle of Strain versus Sand Content in SMA.**

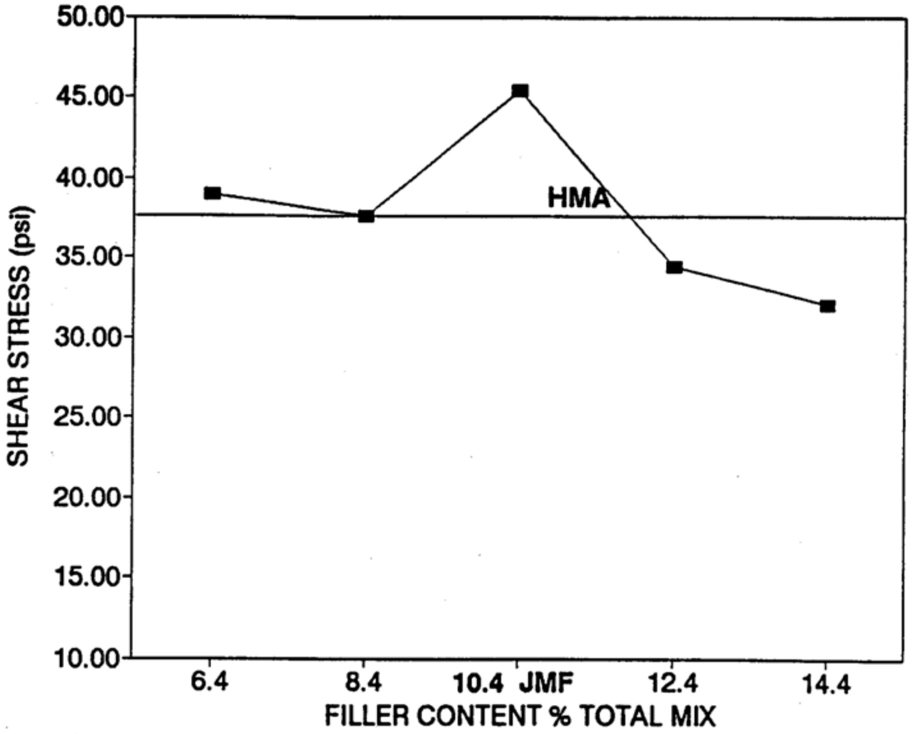

Figure 28: **Gyratory Shear Stress to Produce 1 Degree Angle of Strain versus Filler Content in SMA.**

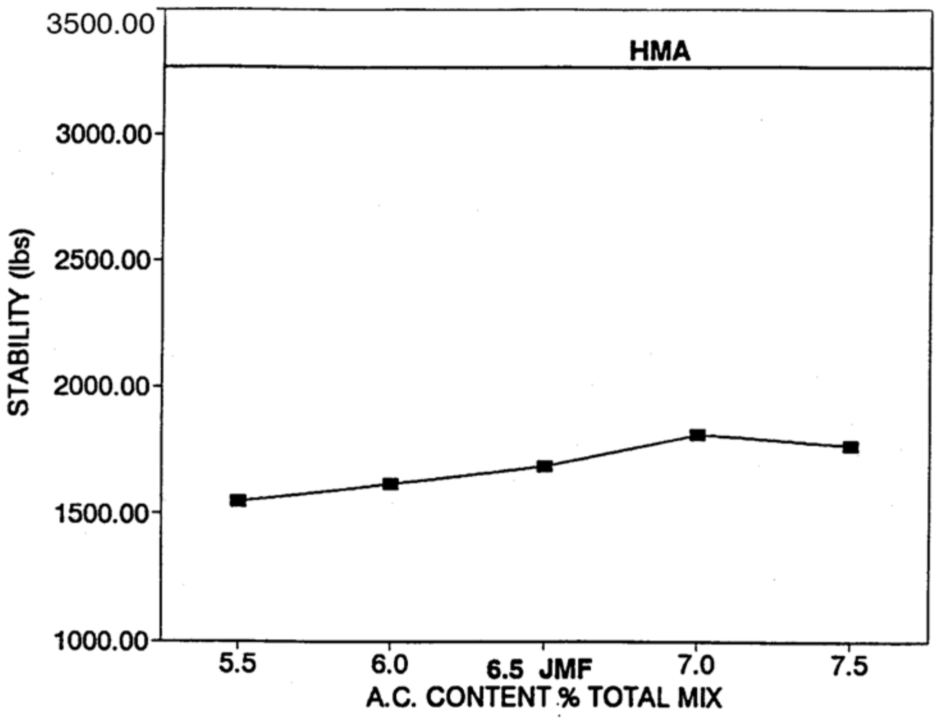

Figure 29: Marshall Stability versus Asphalt Content in SMA.

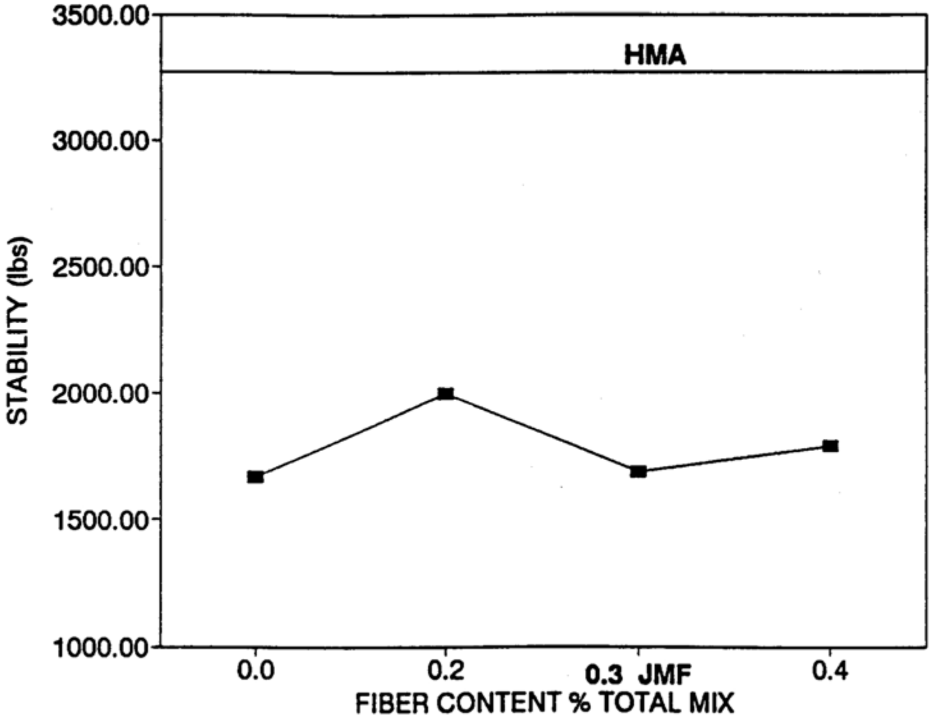

Figure 30: Marshall Stability versus Fiber Content in SMA.

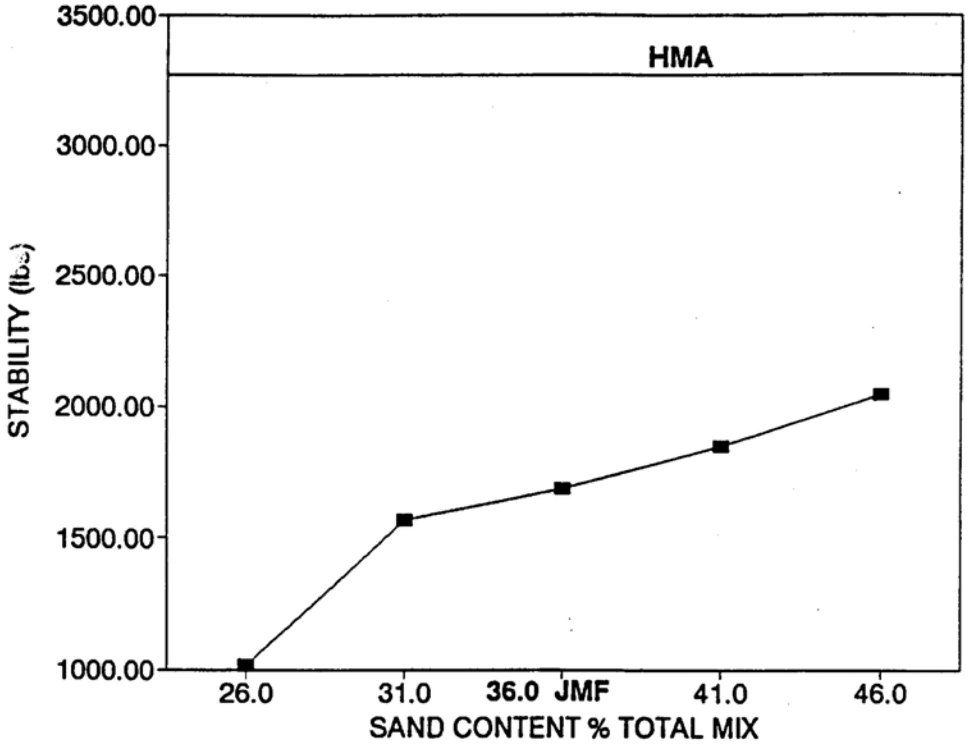

Figure 31: Marshall Stability versus Sand Content in SMA.

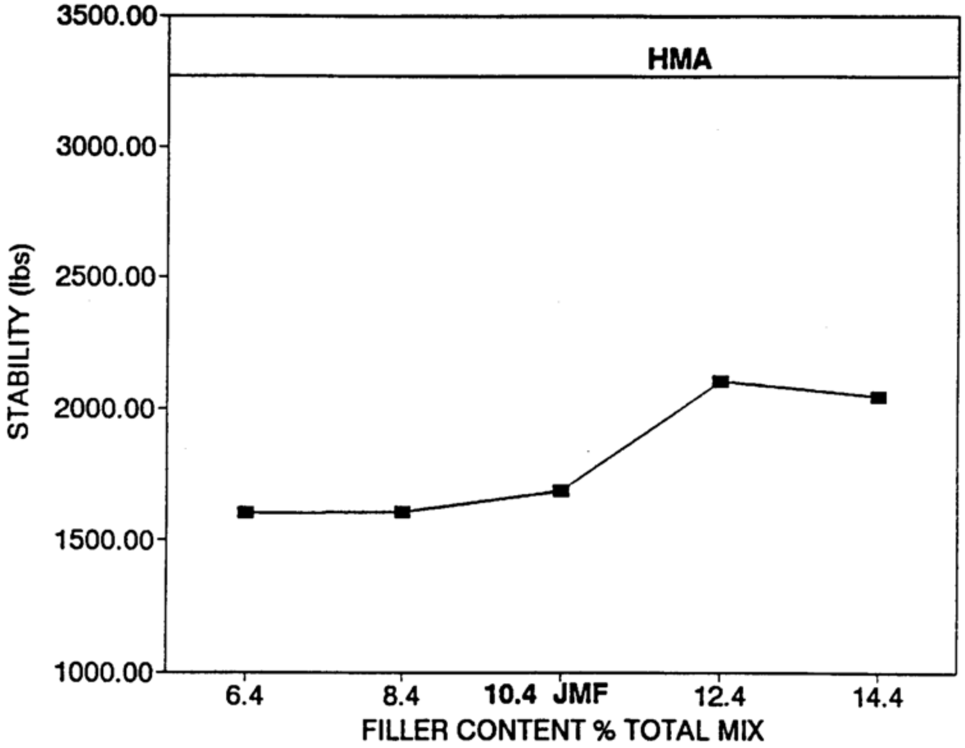

Figure 32: Marshall Stability versus Filler Content in SMA.

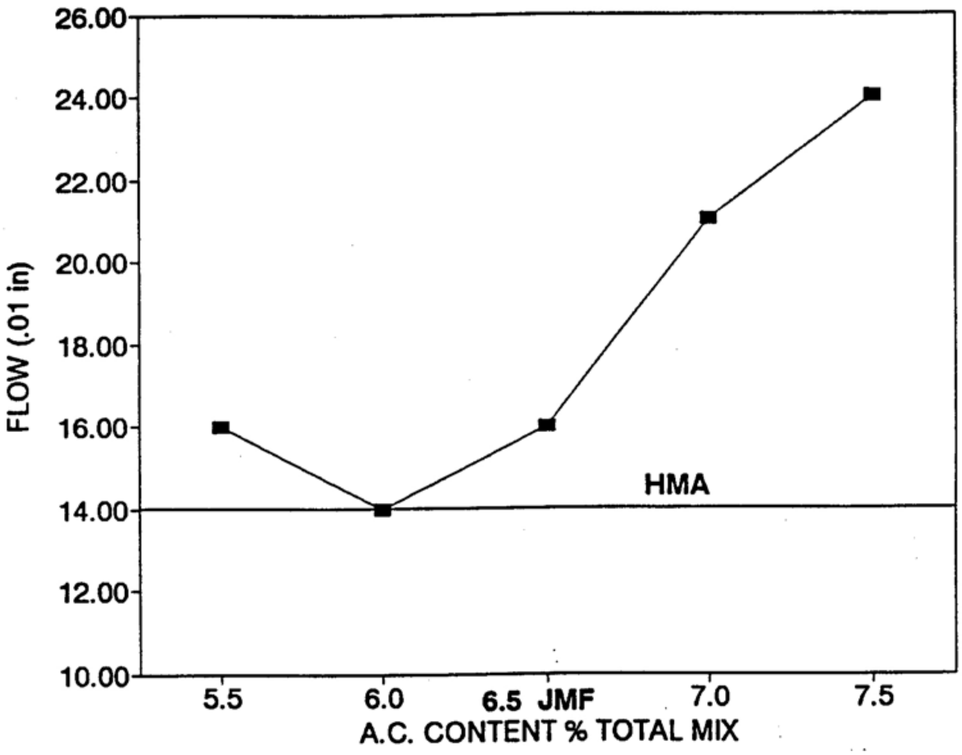

Figure 33: Marshall Flow versus Asphalt Content in SMA.

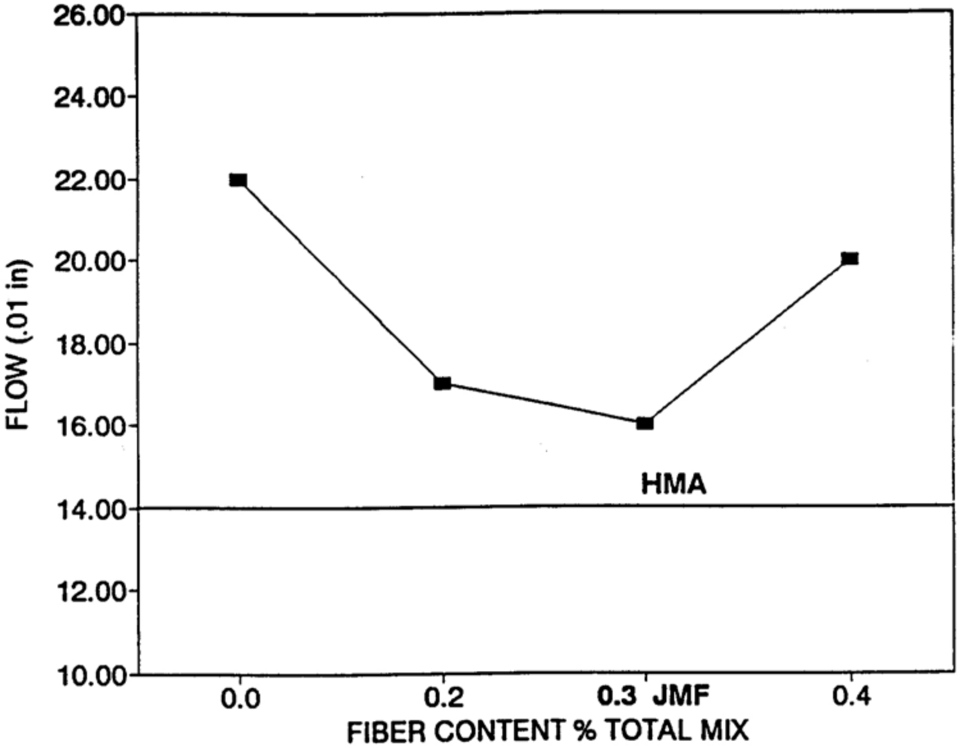

Figure 34: Marshall Flow versus Fiber Content in SMA.

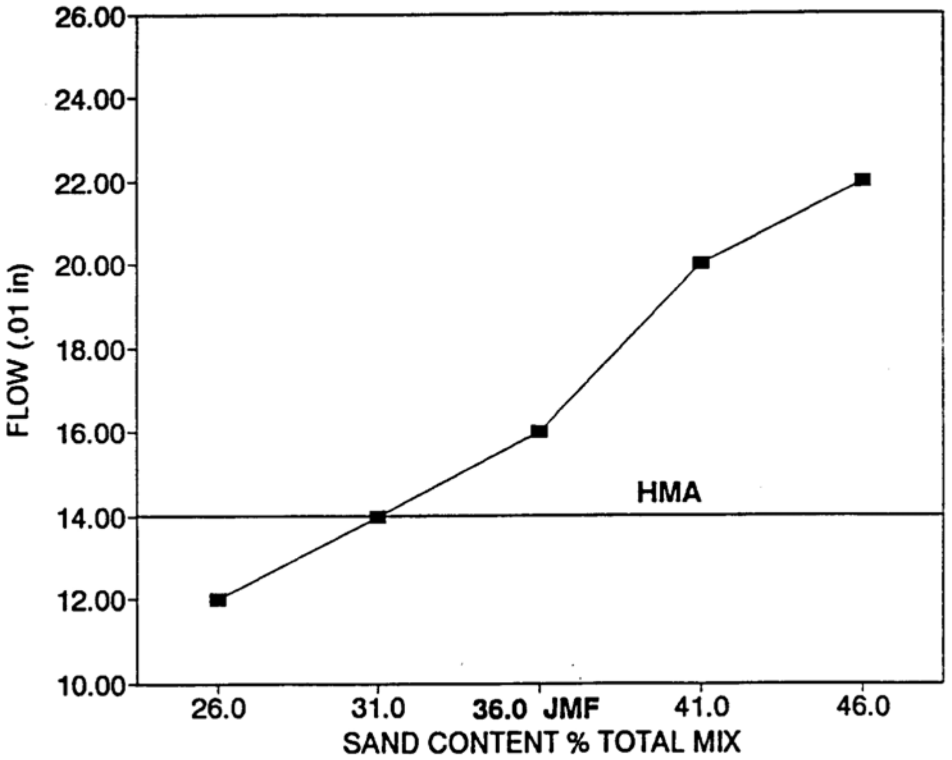

Figure 35: Marshall Flow versus Sand Content in SMA.

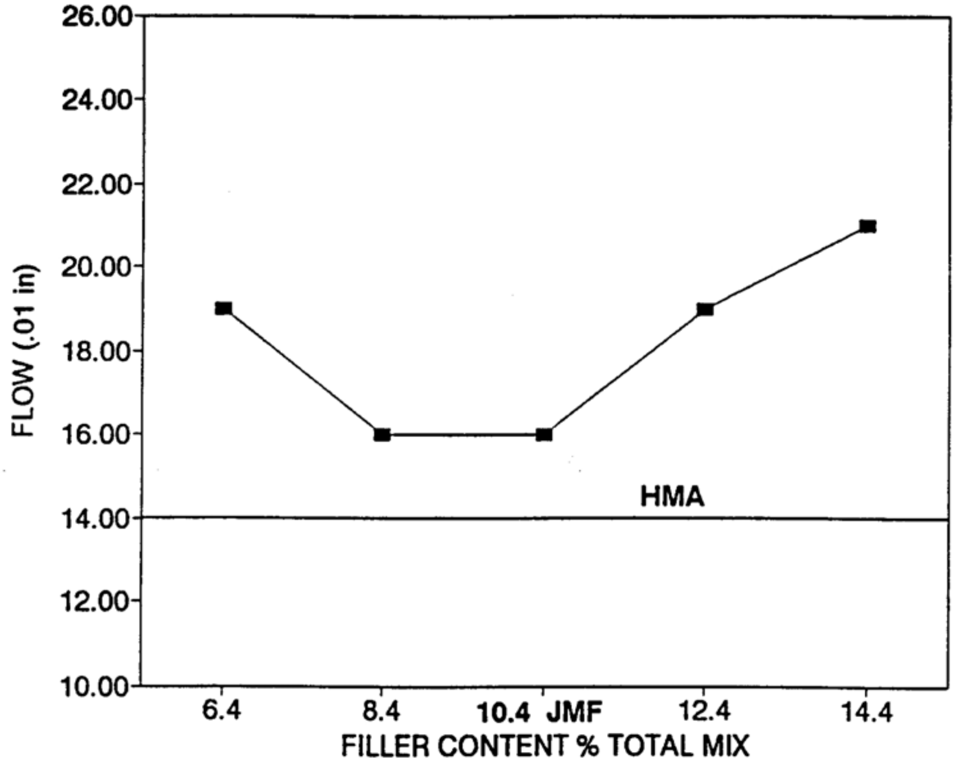

Figure 36: Marshall Flow versus Filler Content in SMA.

Indirect Tensile Strength

The indirect tensile strength of the SMA samples was determined at 77°F at a load rate of 2 inches per minute. The tensile strength results are shown in Figures 37-40. The tensile strength does not appear to be greatly affected by asphalt cement content or fiber content. There is much scatter in the data for fiber content which maybe partially due to difficulty in mixing the fibers in the laboratory. Higher sand contents and filler contents result in higher tensile strength. Tensile strength by itself cannot be used to predict performance of SMA. This strength is largely a function of the grade of asphalt cement. Low tensile strength can be a result of poor bond between the asphalt cement and aggregate, low compaction or several other problems. The strain at failure which was not measured in this study should be a better indicator of performance, in particular low temperature cracking.

Resilient Modulus

The resilient modulus test was conducted at three temperatures (40°, 77°, and 104°F). The load applied to these samples when determining the resilient modulus was approximately 15% of the indirect tensile strength. All resilient modulus values of SMA at 40°F were below that measured for HMA (Figures 41-44). The resilient modulus of the SMA at 77°F was much less than that for the SMA (Figures 45-48). The SMA also had very low resilient modulus values at 104°F (Figures 49-52). SMA has a relative high asphalt content and high VMA. Hence at high temperatures the asphalt cement of the SMA becomes soft which affects the SMA more than the HMA.

The resilient modulus is a highly variable test and has not been shown to be related to performance for dense graded mixtures and is likely not related to performance for SMA mixtures. The resilient modulus is a stiffness and allows one to calculate stresses and strains in a pavement structure. This is also a tensile test and therefore is not related to rutting. Ideally a good asphalt mixture would have high stiffness in shear and low stiffness in tension.

Creep

Results of the confined creep teat showed that the SMA mixtures usually had more permanent deformation than the HMA (Figures 53-56). The SMA creep results improve 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 seems to indicate that a properly designed SMA mixture would have as good as or better performance in the creep test than the standard HMA mixture. If the percent passing the No. 4 sieve had been approximately 30% or lower and if the voids in the mixture had been 3.0% or higher it appears that the SMA mixture would have the best creep performance. The creep test does show some potential for being a good test for evaluating SMA mixtures.

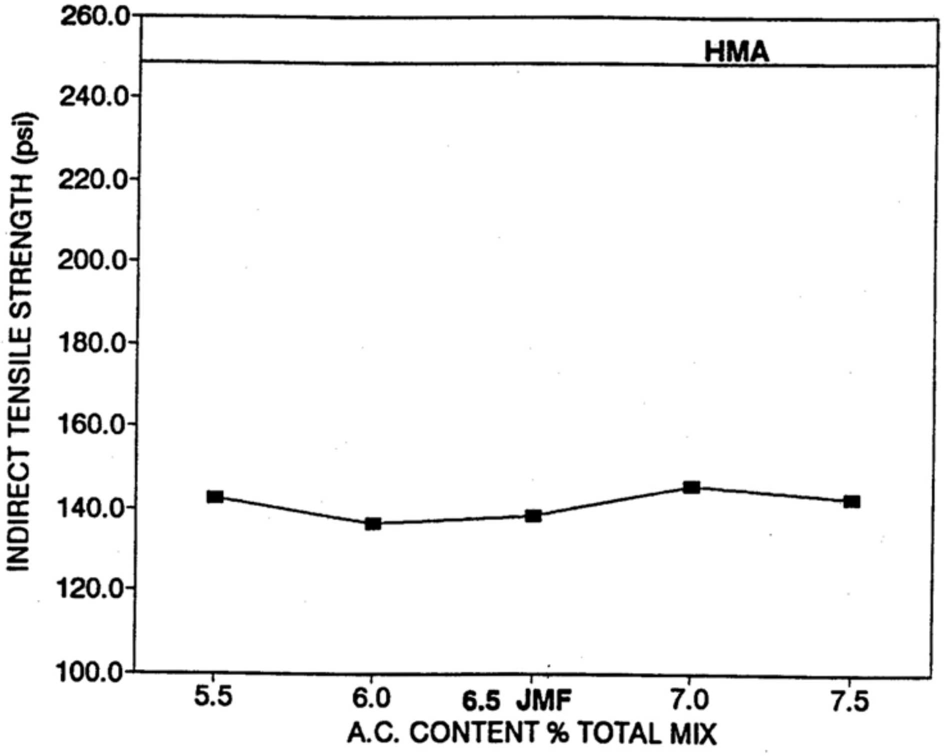

Figure 37: Indirect Tensile Strength versus Asphalt Content in SMA.

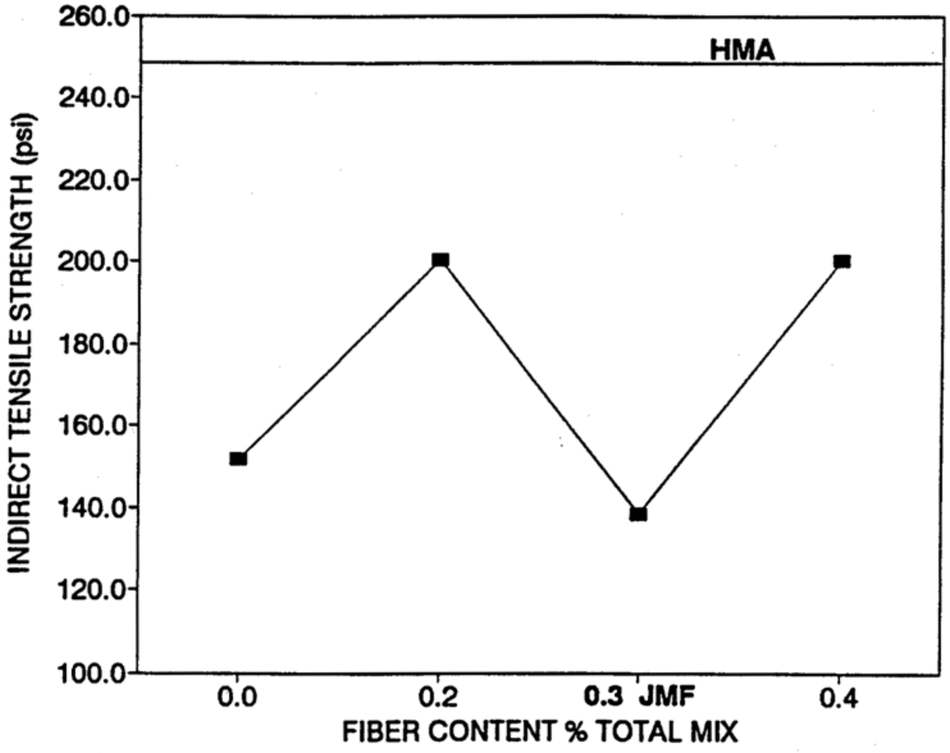

Figure 38: Indirect Tensile Strength versus Fiber Content in SMA.

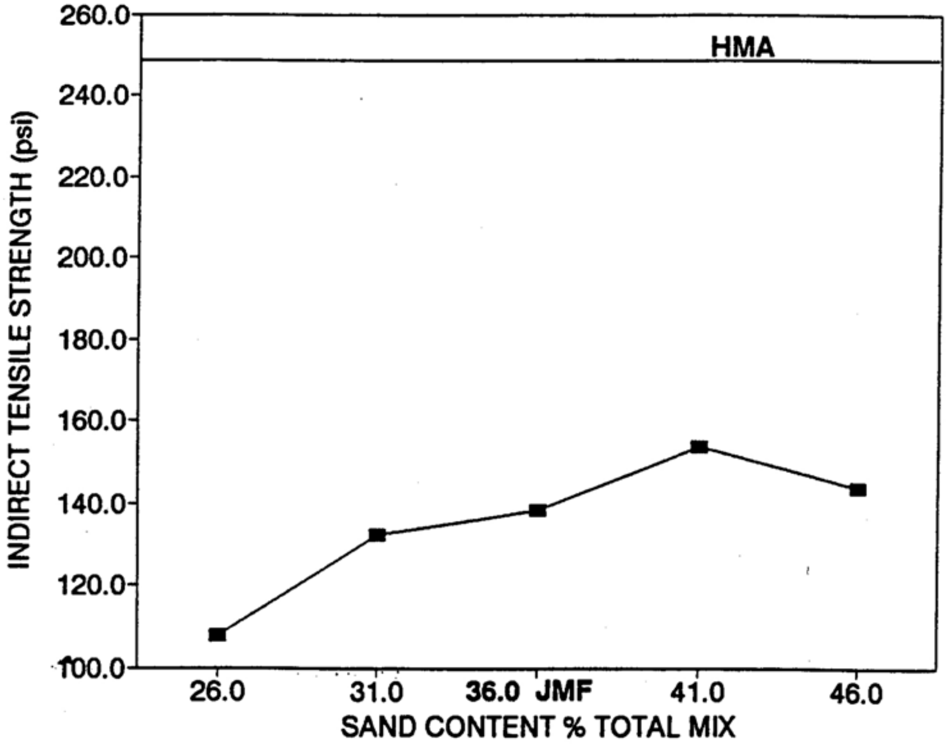

Figure 39: Indirect Tensile Strength versus Sand Content in SMA.

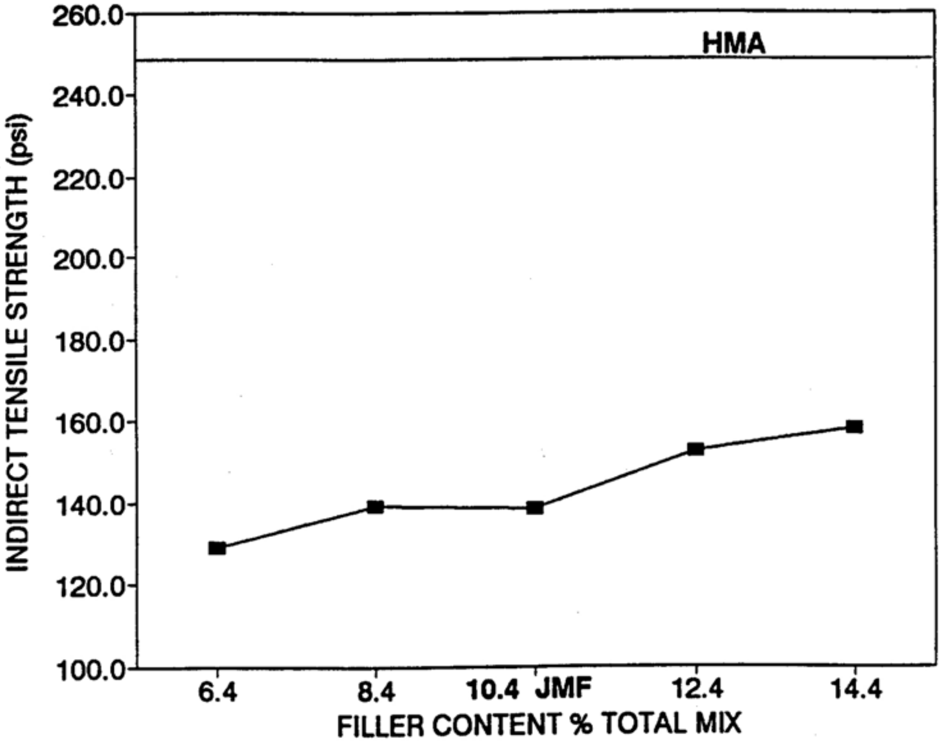

Figure 40: Indirect Tensile Strength versus Filler Content in SMA.

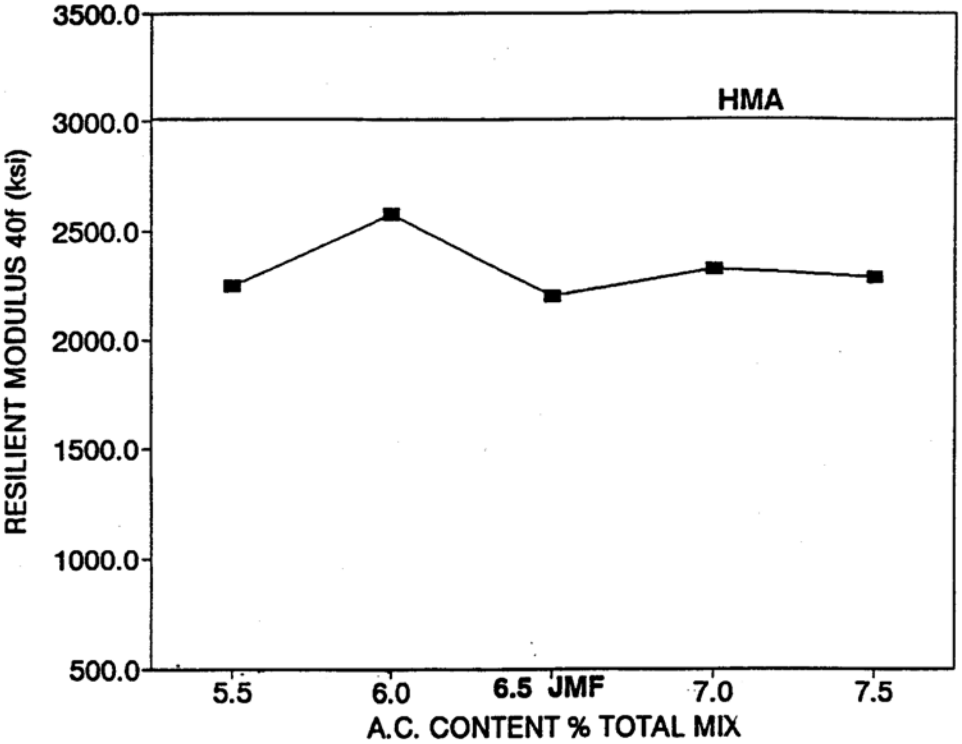

Figure 41: Resilient Modulus Values at 40°F versus Asphalt Content for SMA and HMA.

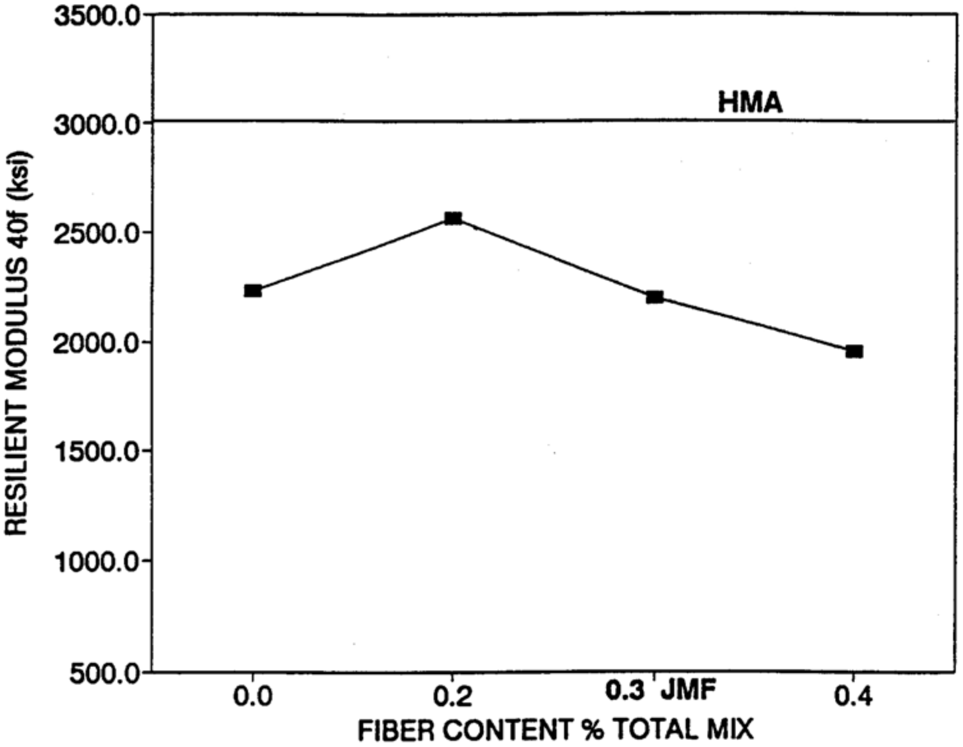

Figure 42: Resilient Modulus Values at 40°F versus Fiber Content for SMA and HMA.

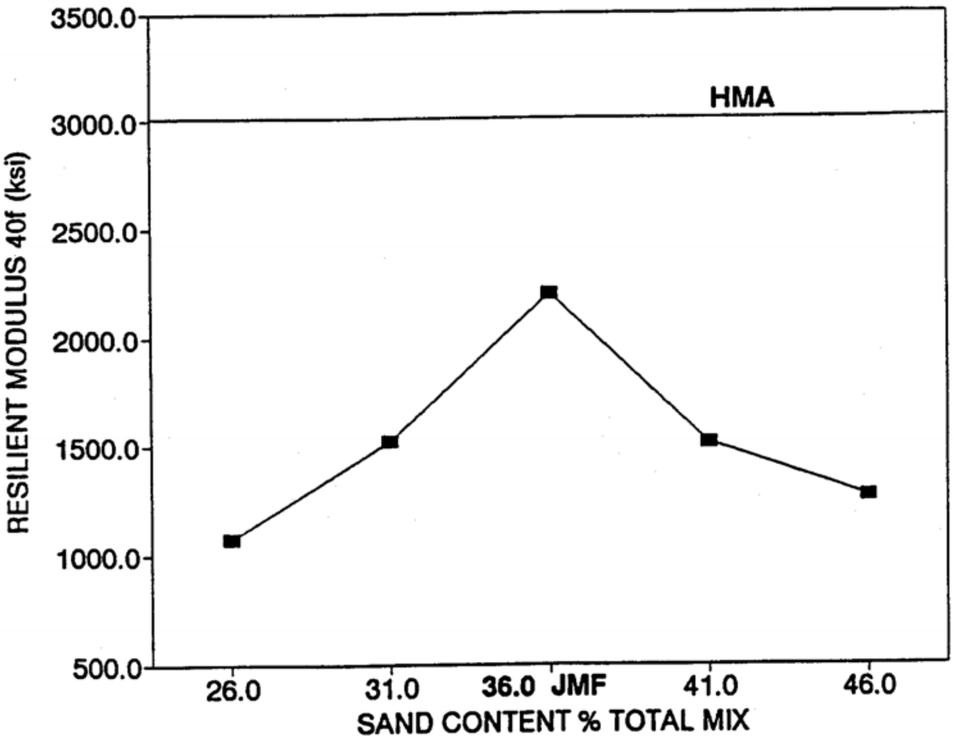

Figure 43: Resilient Modulus Values at 40°F versus Sand Content for SMA and HMA.

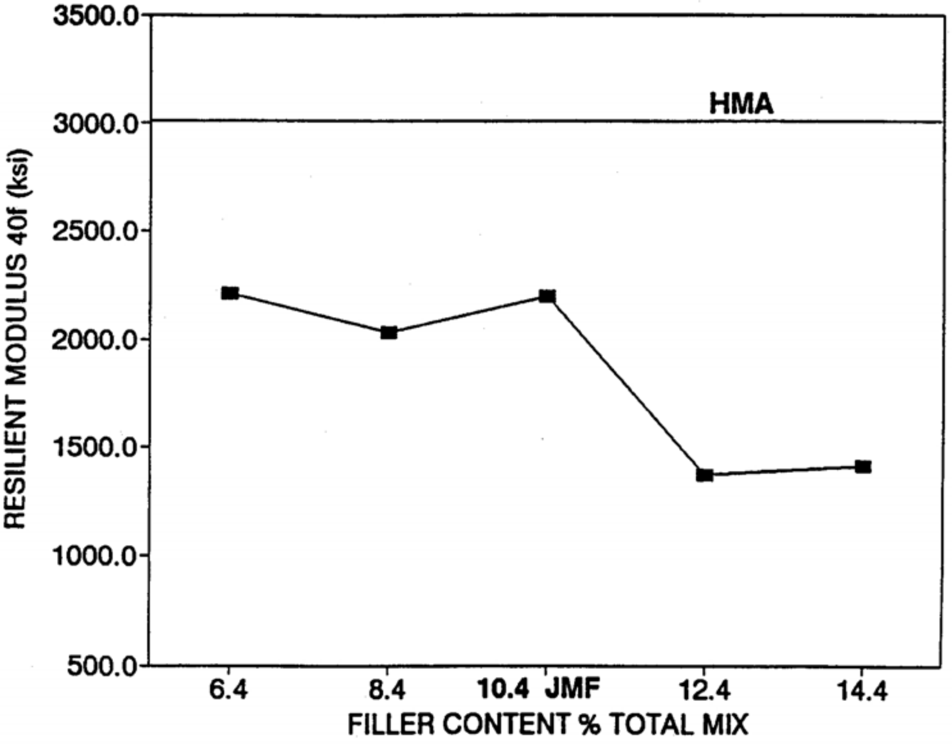

Figure 44: Resilient Modulus Values at 40°F versus Filler Content for SMA and HMA.

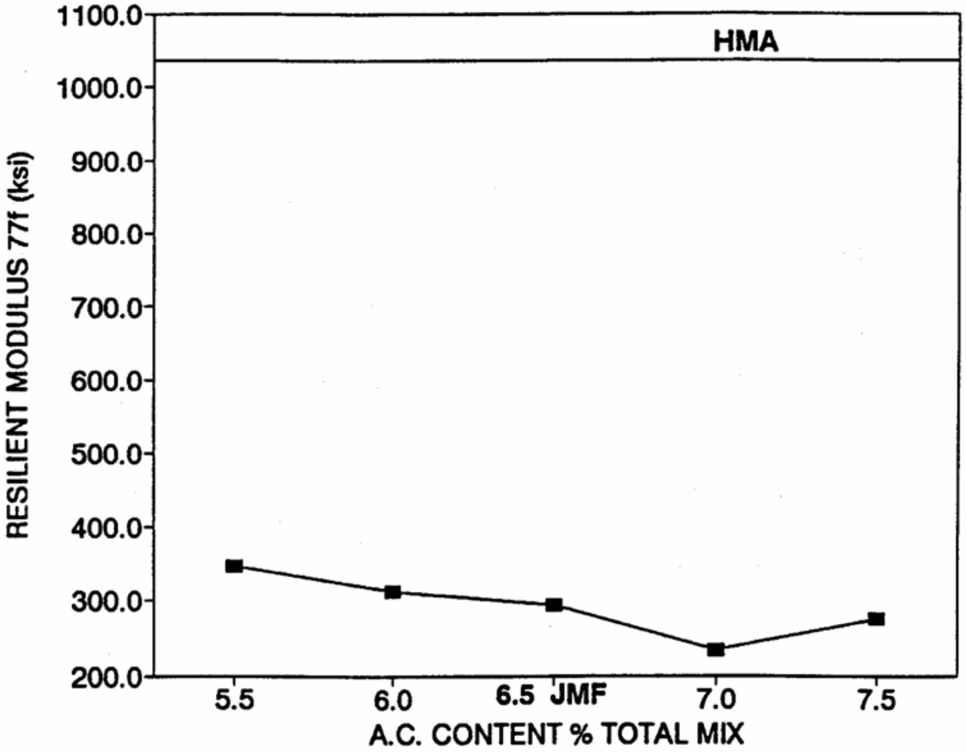

Figure 45: Resilient Modulus Values at 77°F versus Asphalt Content for SMA and HMA.

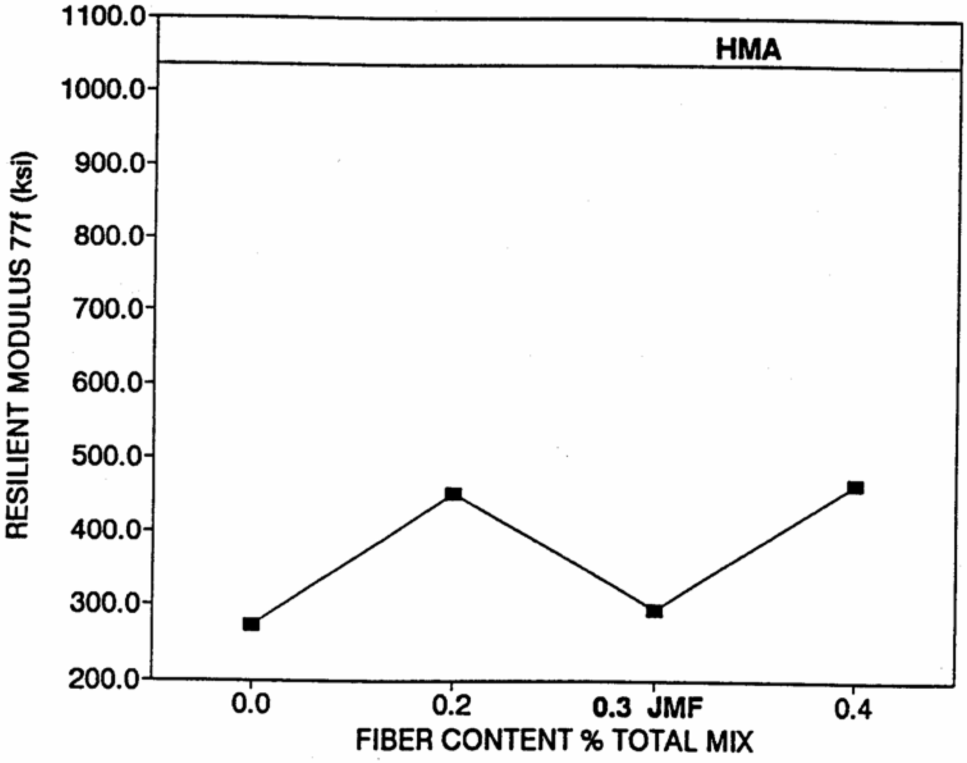

Figure 46: Resilient Modulus Values at 77°F versus Fiber Content for SMA and HMA.

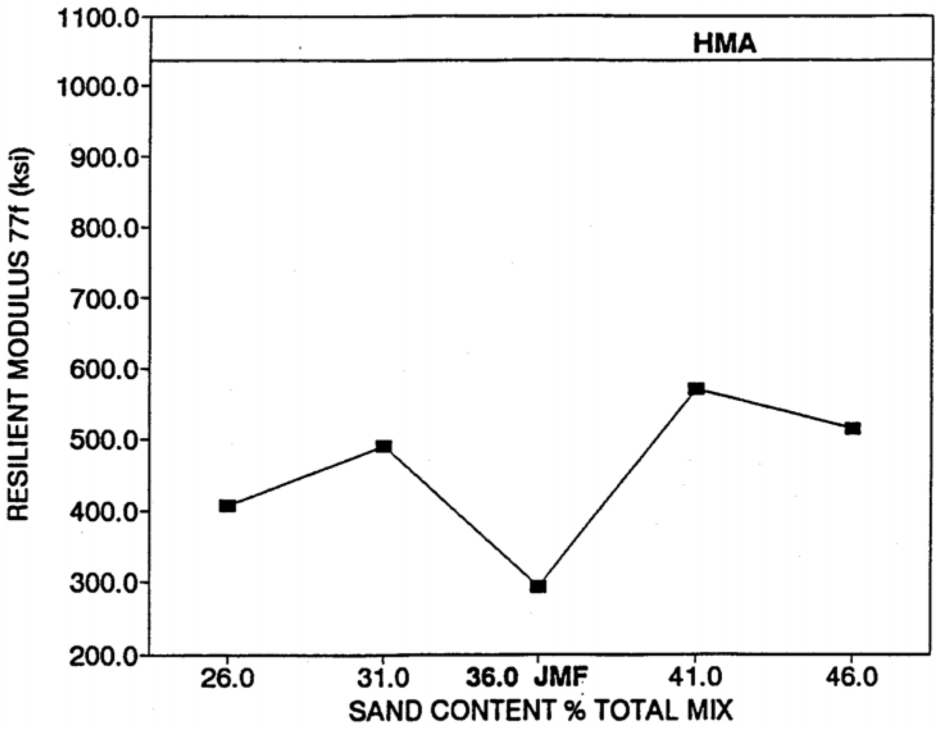

Figure 47: Resilient Modulus Values at 77°F versus Sand Content for SMA and HMA.

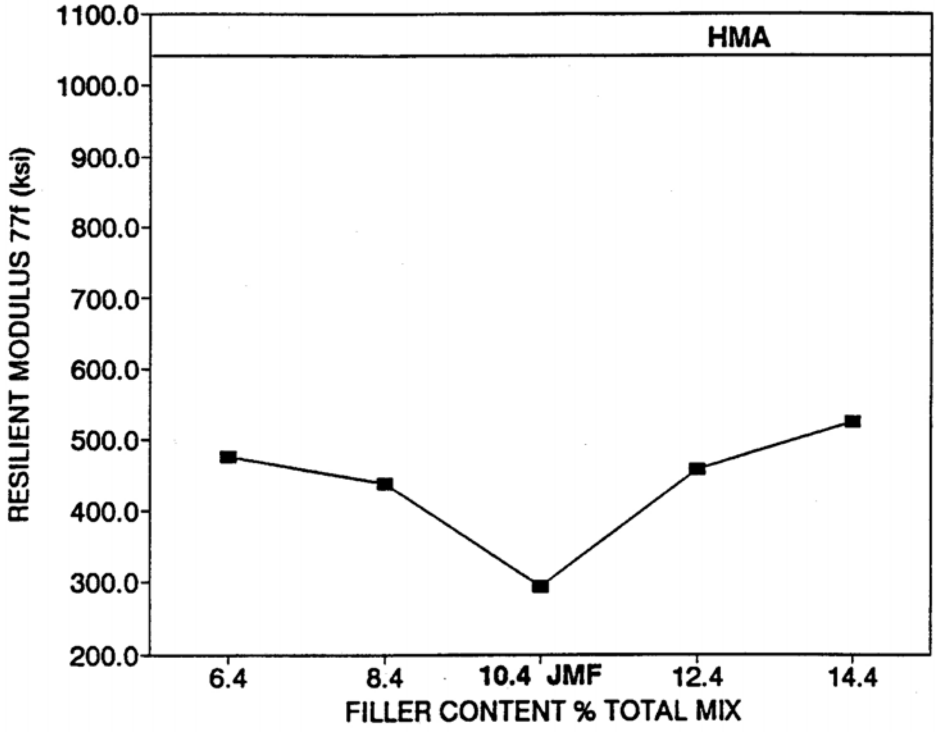

Figure 48: Resilient Modulus Values at 77°F versus Filler Content for SMA and HMA.

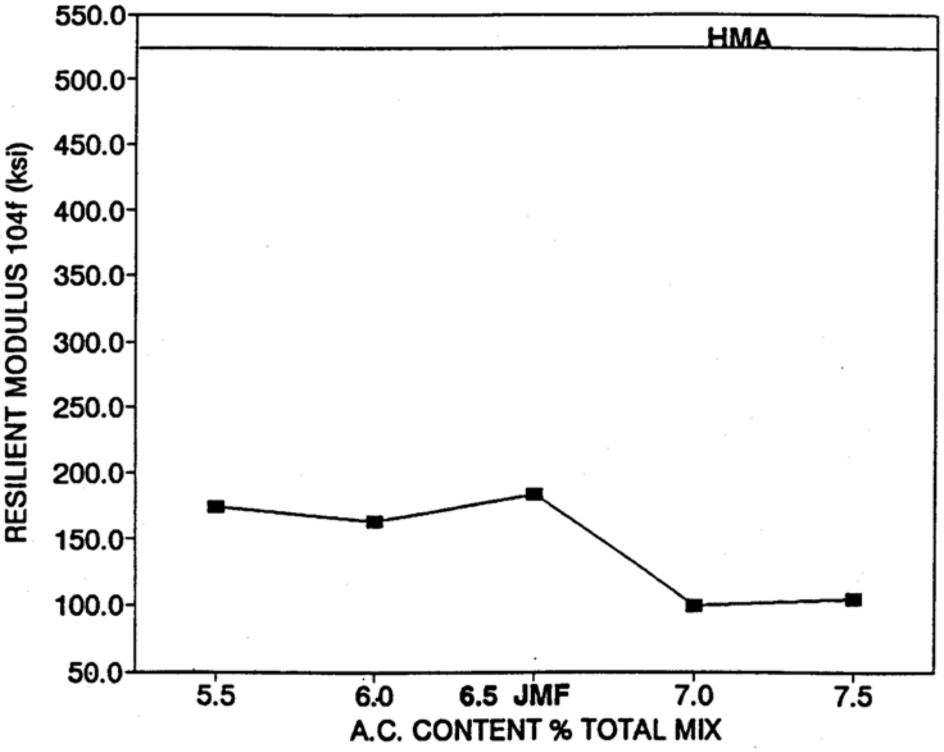

Figure 49: Resilient Modulus Values at 104°F versus Asphalt Content for SMA and HMA.

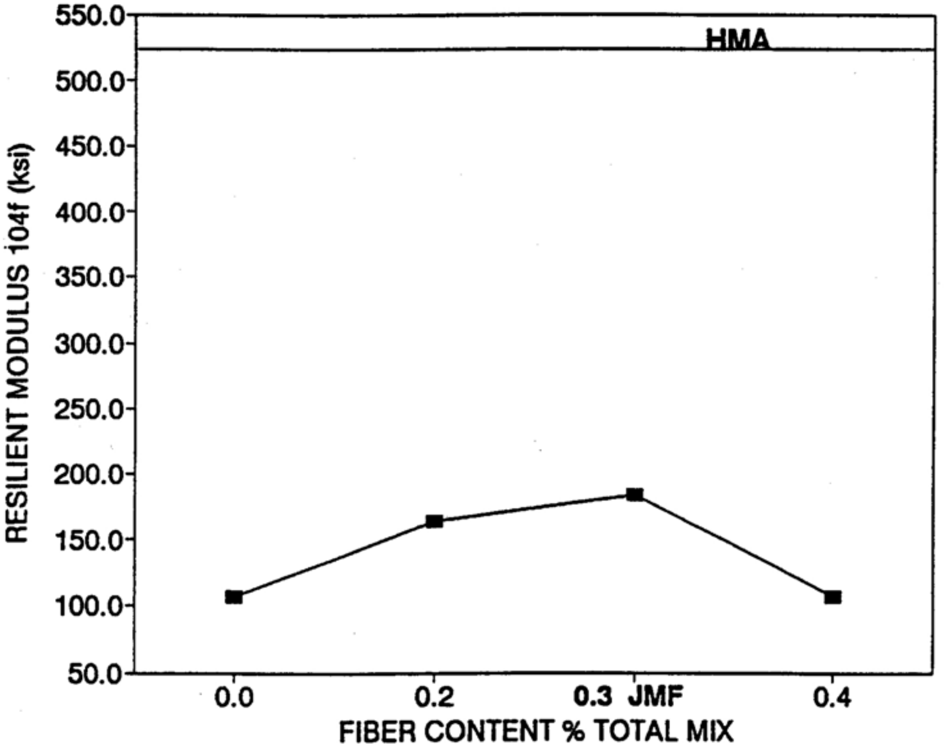

Figure 50: Resilient Modulus Values at 104°F versus Fiber Content for SMA and HMA.

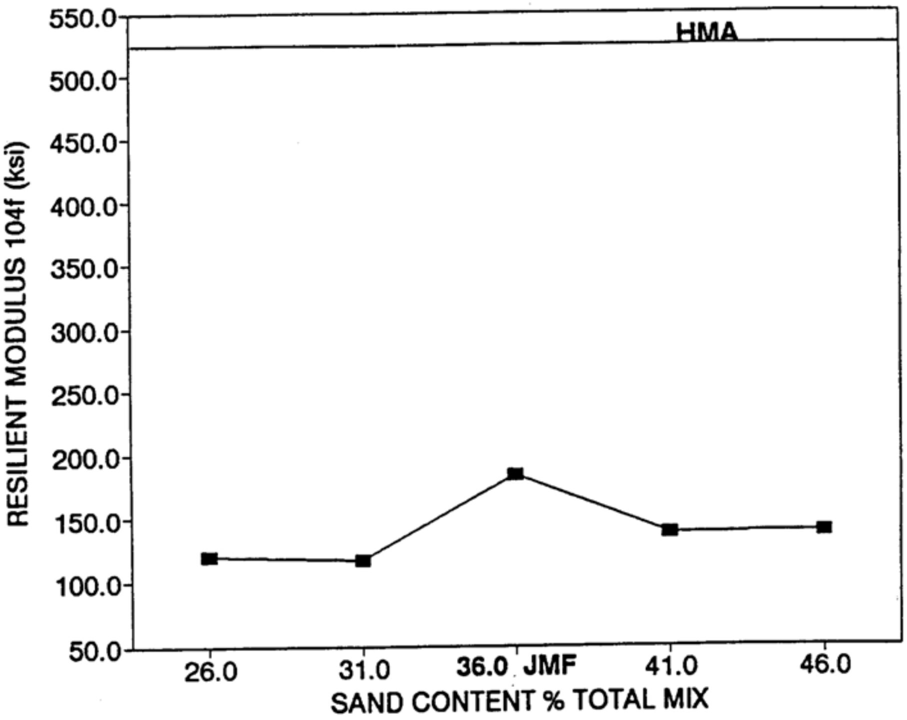

Figure 51: Resilient Modulus Values at 104°F versus Sand Content for SMA and HMA.

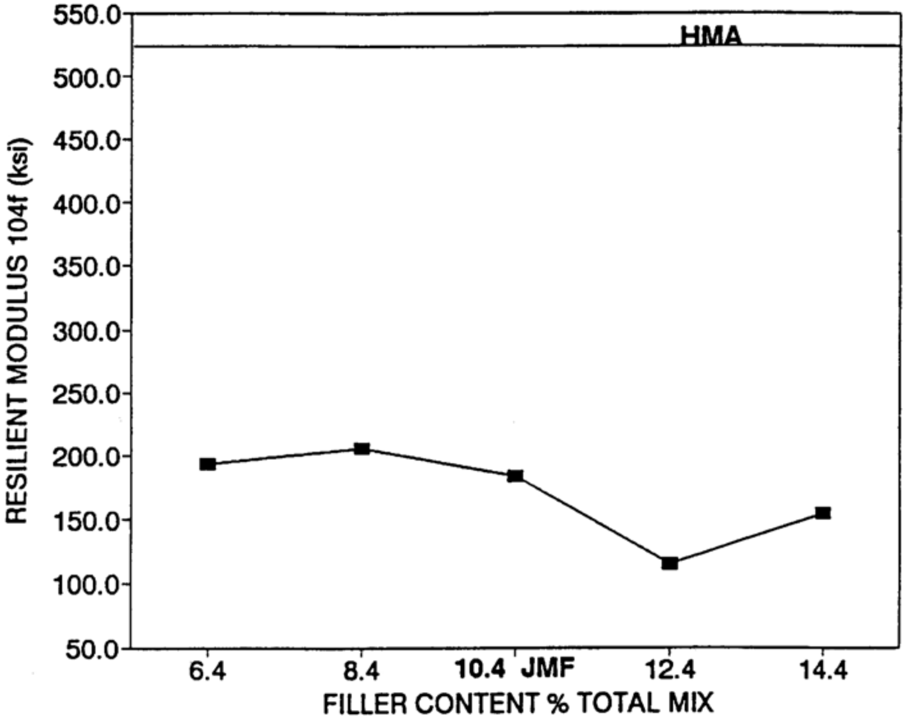

Figure 52: Resilient Modulus Values at 104°F versus Filler Content for SMA and HMA.

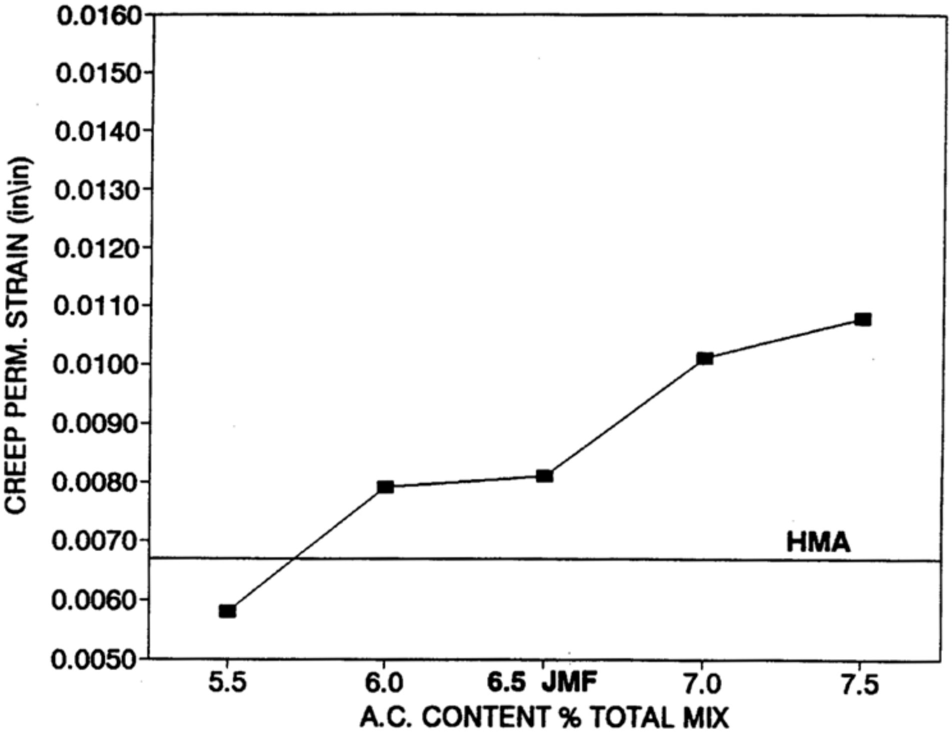

Figure 53: Permanent Strain versus Percent Asphalt Content.

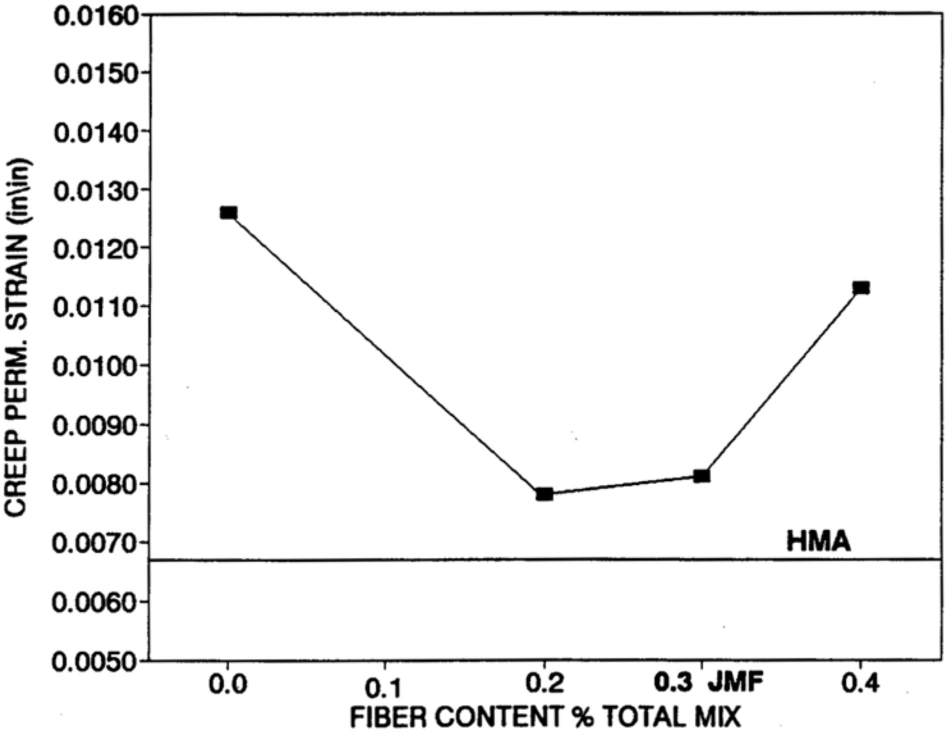

Figure 54: Permanent Strain versus Percent Fiber.

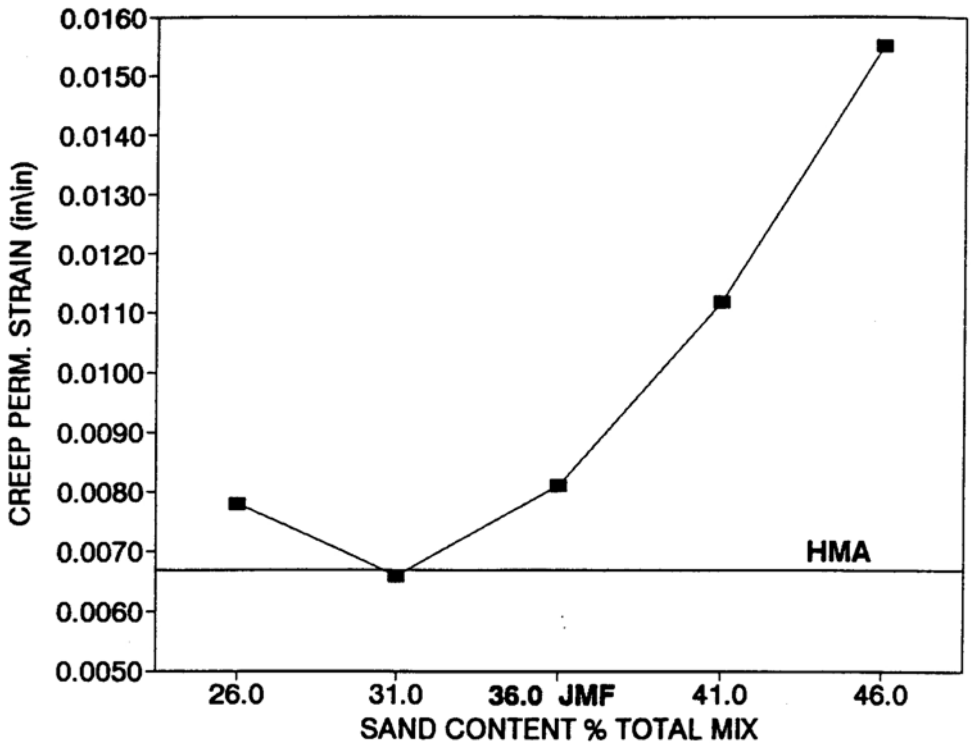

Figure 55: Permanent Strain versus Percent Sand.

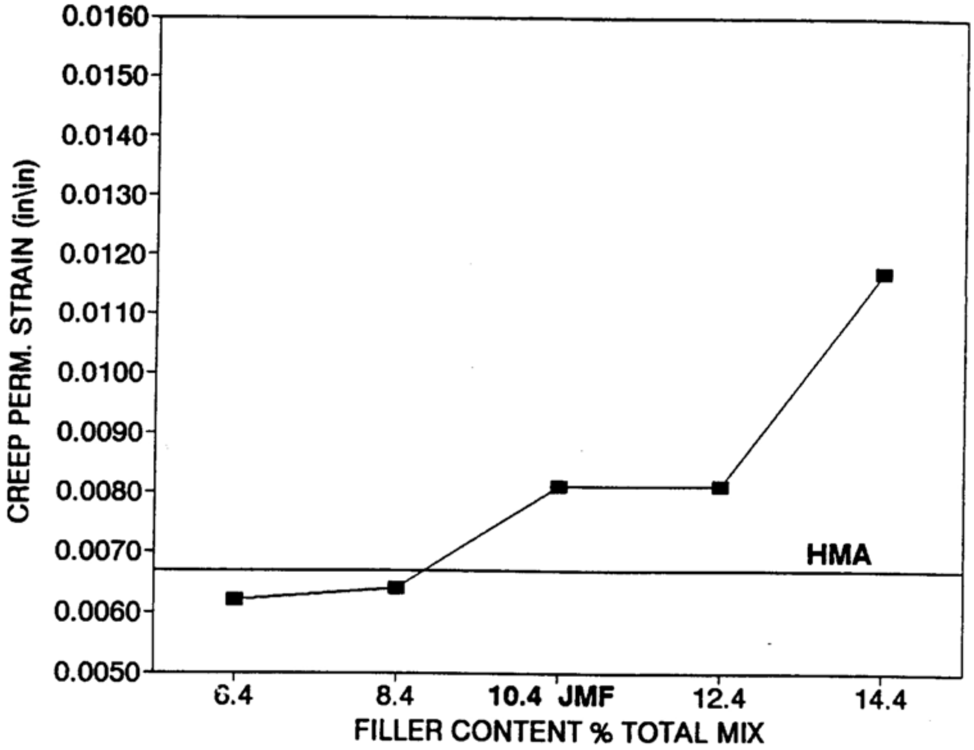

Figure 56: Permanent Strain versus Percent Filler.

Conclusions and Recommendations

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

1. The HMA performed better than the SMA in most laboratory tests. Most of the tests conducted in this study have not been shown to be closely related with performance so these test results do not mean that HMA will perform better than SMA on the roadway. Tests that are more related to performance are needed to better evaluate SMA mixtures. The creep and Gyratory tests appear to be the best tests conducted for predicting performance of the SMA mixture.
2. The addition of fiber had little effect on the VMA and the optimum asphalt content.
3. The best way to increase the optimum asphalt content is to lower the percent passing the No. 4 Sieve. Lowering filler content will also increase the optimum asphalt content but a decrease in filler content may result in asphalt cement drainage problems.
4. 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.
5. The SMA mixtures had much lower tensile strength values (indirect tensile strength and resilient modulus) than the HMA mixture. These lower tensile strength properties should not affect performance of SMA mixtures since it is the tensile strain that can be tolerated that is important.
6. The Gyratory shear stress to produce one degree angle is the one test that the SMA mixture generally performed better than 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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2. Brown, Elton R. and Stephen A. Cross, “A National Study of Rutting in Asphalt Pavements,” National Center for Asphalt Technology, Draft 1992.