NCAT Report No. 97-3

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ABSTRACT

Stone Matrix Asphalt (SMA) has been used successfully in Europe for over 20 years to provide better rutting resistance and to resist studded tire wear. Since 1991, the use of SMA has increased steadily in the United States. At present, some states routinely use SMA even though a standard mixture design procedure is not available. A mixture design procedure that provides guidance on material properties, aggregate gradation, determination of optimum asphalt content, and mixture properties is needed. This paper presents a mixture design procedure for SMA mixtures developed by the National Center for Asphalt Technology. Data for the development of the procedure was collected from a laboratory study conducted with various samples of aggregates, fillers, asphalt binders, and stabilizing additives. Compacted mixtures were tested to evaluate the effects of aggregate structure, asphalt binder, and binder-fine aggregate mortar. Specific conclusions from this study were: (1) The Los Angeles abrasion loss showed good correlation with aggregate breakdown, (2) It appeared that the 3:1 or 2:1 flat and elongated particles provided much better classification for the various aggregates than a 5:1 ratio, (3) The flat and elongated particle ratio showed excellent correlation with aggregate breakdown, (4) In a SMA mix, the percent passing the 4.75 mm sieve must be below 30 percent to ensure proper stone-on-stone contact, (5) The percent passing the 0.02 mm sieve did not show a correlation

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with mortar stiffness. However, the dry compacted volume, as obtained from the Penn State test method, did show a good correlation with mortar stiffness and can be utilized to characterize the shape of fillers. Generally, a more angular filler tends to produce a higher air voids result in this test, (6) In-place results from about 86 projects showed that very little rutting has occurred in SMA pavements constructed in the United States since 1991. However, for the pavements with air voids falling below the 3 percent range, some rutting was observed. (7) A VMA significantly lower than specified VMA can be obtained due to aggregate breakdown. Hence, the mix designer must consider aggregate type, compactor type and compactive effort along with the gradation in meeting the required VMA criteria. Specifying a minimum asphalt content can result in different requirements for aggregates with different specific gravity, (8) Fifty blows of Marshall hammer were found to be approximately equal to 100 revolutions of the Superpave gyratory compactor in terms of resultant density. The Superpave gyratory compacter was found to produce less aggregate breakdown than the Marshall hammer, (9) Fiber stabilizers were found to be more effective in reducing draindown than polymer stabilizers. However, mixes modified with polymer showed better resistance to rutting in laboratory wheel tracking tests.

DEVELOPMENT OF A MIXTURE DESIGN PROCEDURE FOR STONE MATRIX ASPHALT (SMA)

INTRODUCTION

Background

Stone Matrix Asphalt (SMA) is a type of hot mix asphalt (HMA) consisting of a coarse aggregate skeleton and a high binder content mortar. This type of mixture has been used in Europe for over 20 years to provide better rutting resistance, and to resist studded tire wear. Because of its success in Europe, five states, through the cooperation of the Federal Highway Administration (FHWA), constructed SMA pavements in the United States in 1991 (1). Since that time, the use of SMA in the U.S. has increased significantly. At present, some states routinely use SMA even though a standard mixture design procedure is not available. A mixture design procedure that provides guidance on material properties, aggregate gradation, determination of optimum asphalt content, and mixture properties is needed. The goal of the mixture design procedure should be to design a high quality SMA mixture by using a simple, straightforward, and repeatable method. This paper presents a mixture design procedure for SMA, developed by the National Center for Asphalt Technology (NCAT). The work was funded by the National Cooperative Highway Research Program (NCHRP) Project 9-8 "Designing Stone Matrix Asphalt Mixtures. "

Objective

The objective of this study was to develop a simple, straightforward, and practical mixture design procedure for SMA. Material and mixture criteria for SMA mixtures were also evaluated.

Scope

A mixture design procedure was developed for SMA using either the Marshall hammer or Superpave gyratory compactor (SGC) to compact specimens. Data was collected from a laboratory study conducted with various types of aggregates, fillers, asphalt binders, and stabilizing additives. The effects of varying different SMA mixture material components were evaluated. Compacted mixtures were tested to evaluate the effects of aggregate structure, asphalt binder, and mortar. Background information was collected from the FHWA sponsored SMA Technical Working Group (TWG) in publication IS 118 (2).

This paper consists of an overview of SMA and the presentation of important aspects of the mixture design procedure. Data to support the design procedure is also presented. Details of the results from this study can be found in References (3) and (4).

SMA MIXTURE DESIGN PROCEDURE OVERVIEW

The SMA mixture design procedure was developed to ensure that SMA mixtures have an adequate coarse aggregate skeleton and satisfactory mixture volumetric. No strength test is recommended as part of this procedure; it is anticipated that the testing protocol eventually adopted for Superpave will also be used for evaluating the quality of SMA mixtures.

The five basic steps in the mixture design procedure are:

1. Select materials,
2. Determine optimum aggregate gradation,
3. Determine optimum asphalt binder content,
4. Evaluate asphalt binder draindown potential, and

5. Evaluate moisture susceptibility using AASHTO T 283.

Many of the specifications for material properties, gradation, and volumetric were established by the TWG (2). As a result of this study, many of these requirements were verified or modified; in some cases, new requirements were developed.

Table 1 lists the suggested requirements developed by the TWG (2) as well as those parameters evaluated as part of this study. As indicated in Table 1, the SMA mixture design study investigated aggregate toughness, flat and elongated particles, mixture aggregate gradation, percent passing 0.020-mm sieve, stone-on-stone contact, Voids in the Total Mixture (VTM), Voids in the Mineral Aggregate (VMA), asphalt binder content, compactive effort, and asphalt binder draindown. These variables were chosen for inclusion in the study, because they seemed to more directly affect the mixture design procedure than those factors that were not included. For those elements not evaluated in this study, it is recommended that the requirements proposed by the TWG be used. For those variables evaluated in this study, a discussion of the findings is provided below.

DISCUSSION OF RESULTS

Aggregate Toughness

Aggregate toughness as measured by the Los Angeles abrasion test (AASHTO T 96) can potentially affect aggregate breakdown and hence should be considered when designing all types of HMA mixtures. A maximum loss value of 30 percent is specified in the TWG guidelines. In evaluating aggregate toughness, the answers to two questions were sought: 1) Does the Los Angeles abrasion loss correlate well with aggregate breakdown, and if so, 2) What should be

Table 1. Properties of SMA Materials and Mixtures (1)

Property	Criteria Established by SMA TWG	Criteria Evaluated in SMA Mix Design Study
Coarse Aggregate		
L.A. Abrasion (AASHTO T 96)	30 Max	x
Flat and Elongated Particles (ASTM D 4791)	3:1, 20% Max	x
	5:1, 5% Max	x
Sodium Sulfate Soundness (AASHTO T 104)	15% Max	
Percent Fractured Faces		
One or more	100% Min	
Two or more	90% Min.	
Absorption (AASHTO T 85)	2% Max	
Coarse and Fine Durability Index (AASHTO T 210)	40 min	
Fine Aggregate	100 % Crushed	
Sodium Sulfate Soundness (AASHTO T 104)	15% Max	
Liquid Limit (AASHTO T 89)	25% Max	
Total Aggregate - Gradation		
19.0 mm	100	
12.5 mm	85-95	
9.5 mm	75 Max	
4.75 mm	20-28	x
2.36 mm	16-24	
600 µm	12-16	
300 µm	12-15	
75 µm	8-10	x
20 µm	3 Max	x
Asphalt Cement	AASHTO M 226	
Mineral Filler		
PI	4 Max	
Percent Passing 20 µm	20%	x
Stabilizer		
Cellulose	0.3%	
Mineral Fiber	0.4%	
Polymer	---	
Stone on Stone Contact	--	x
Voids in Total Mix	3-4	x
VMA	17	x
Asphalt Content	6.0% Min.	x
Compactive Effort	50 Blow	x
Draindown	0.3% Max.	x

specified as the limiting criteria for coarse aggregates used in SMA mixtures?

Test results from eight aggregates having abrasion loss values varying from 17 to 55 percent are shown in Figures 1 and 2. To obtain this data, the asphalt binder was extracted from

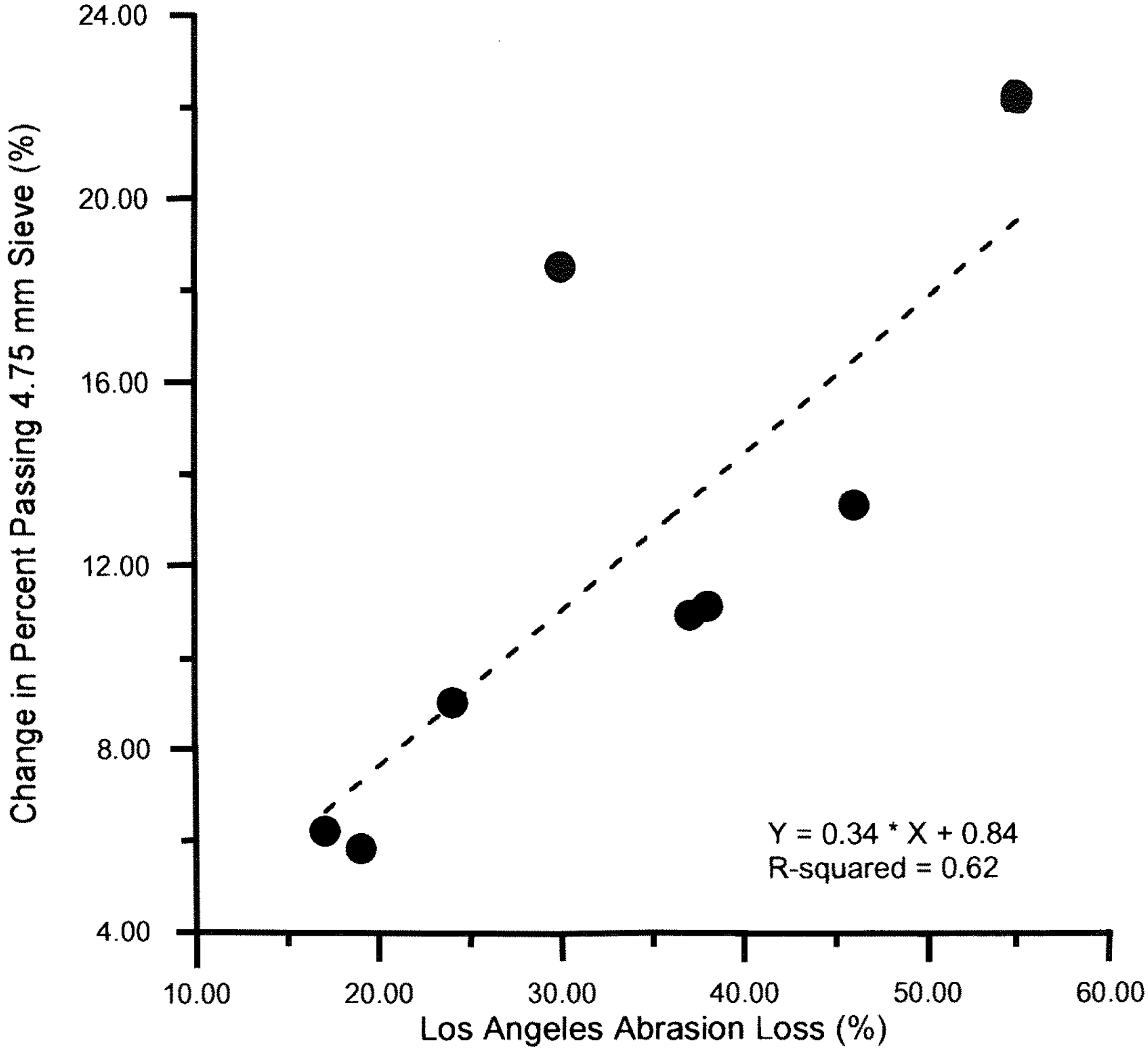

Figure 1. Los Angeles abrasion loss versus change in percent passing 4.75 mm sieve (50 blow marshall compaction).

the compacted samples and the remaining aggregate graded according to AASHTO T27 and T 11. This after compaction gradation was then compared to the before compaction gradation to establish the amount of aggregate breakdown during compaction. Figure 1 shows the correlation between aggregate breakdown and aggregate toughness as measured by the abrasion loss for Marshall compacted (50 blows) SMA samples. Figure 2 shows the same comparison for

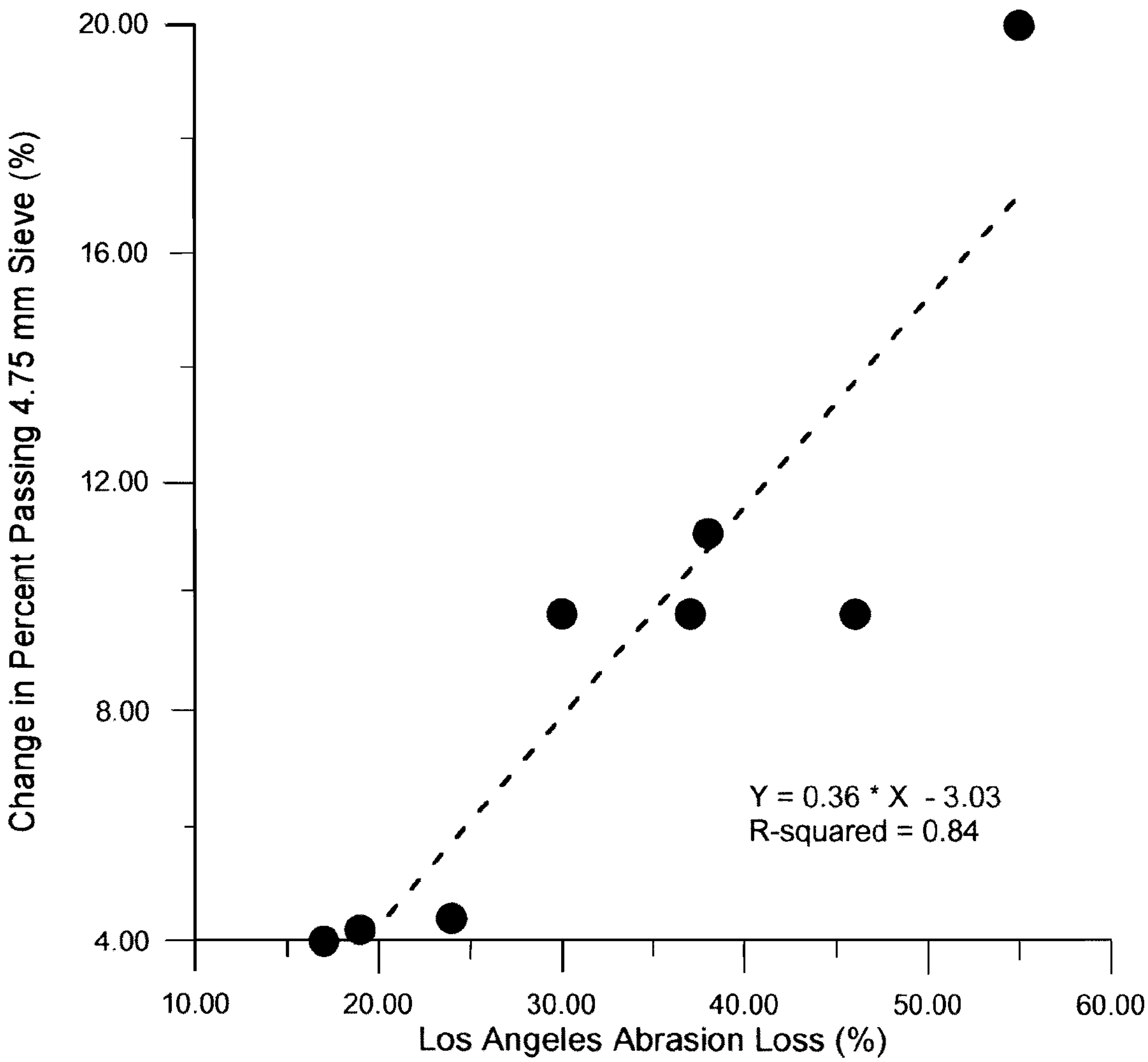

Figure 2. Los Angeles abrasion loss versus change in percent passing 4.75 mm sieve (compaction with 100 revolutions of SGC).

Superpave Gyratory compacted (100 revolutions) samples at optimum asphalt content. In both figures, the Y-axis shows change (increase) in percent passing the 4.75 mm sieve due to compaction and the X-axis shows the corresponding abrasion loss value. A greater change in percent passing the 4.75 mm sieve indicates a higher amount of aggregate breakdown.

Figures 1 and 2 indicate that there is a good correlation between aggregate toughness as measured by the Los Angeles abrasion test for both Marshall (R^2 = 0.62) and SGC (R^2 = O. 84) compaction. For both compactors, the amount of breakdown is approximately 8-10 percent for an abrasion loss of 30 percent. This number increases to 12-14 percent at an abrasion loss value of 40 percent. However, while there is an evident correlation between aggregate toughness and breakdown, the data does not show clearly that a 30 percent Los Angeles abrasion requirement is satisfactory for SMA aggregates; it does show that increasing the permissible Los Angeles abrasion loss value can result in greater aggregate breakdown. Therefore, an appropriate method of establishing an abrasion loss criteria for SMA coarse aggregates may be to first determine the amount of breakdown that occurs during SMA production and placement. After collecting this data, the relationships in Figures 1 and 2 can be applied in selecting an acceptable abrasion loss value.

Flat and Elongated Particle Content for Aggregate

To evaluate the effect of flat and elongated particles, aggregates from one source were crushed using two different methods. One method produced flat and elongated particles, the other more cubical particles. Using these two fractions in various proportions provided SMA mixtures with varying amounts of flat and elongated particles. Mixtures were prepared with the 100 percent flat and elongated aggregate fraction, 75/25 percent flat and elongated/cubical, 50/50 percent flat and elongated/cubical, 25/75 percent flat and elongated/cubical, and 100 percent cubical aggregate to provide five different SMA mixtures. Samples of these five mixtures were compacted with 50 blows of the Marshall hammer and their before and after compaction gradations were compared as described previously. The results are shown in Figure 3. The change in percent passing the 4.75 mm sieve shows an increase (more breakdown) with increasing flat and elongated particle content. There is an excellent correlation between flat and elongated particle content and aggregate breakdown (R^2 = 0.89).

Current TWG guidelines specify limiting ratios of 3 to 1 and 5 to 1 for flat and elongated particles. Of the eight aggregates selected for this study (two limestones, two granites, traprock, dolomite, gravel, and slag), only the most flat and elongated aggregate had 2 percent of the particles failing to meet the 5 to 1 ratio, whereas two of the aggregates had more than 10 percent failing to meet the 3 to 1 ratio (Table 2). From an aggregate breakdown standpoint a limit needs to be placed on the percentage of flat and elongated particles allowed in SMA coarse aggregates. Note that the 5 to 1 ratio does not differentiate between the eight aggregates. In fact, not one of the eight aggregates fails to meet the current TWG guidelines. More work is needed to better establish these limits.

SMA Mixture Aggregate Gradation

The strength of SMA is primarily derived from a stone-on-stone contact skeleton structure provided by properly graded aggregate material. The TWG aggregate gradation guidelines suggest a range of 20-28 percent passing the 4.75 mm sieve to help ensure the formation of a proper coarse aggregate skeleton and stone-on-stone contact in the SMA mixture. Previous work by NCAT (5) has shown that the percent passing the 4.75 mm sieve is a critical factor in the formation of stone-on-stone contact in SMA. Figure 4 shows the change in VMA with change in percent passing the 4.75 mm sieve. As the percent passing the 4.75 mm sieve decreases, the VMA

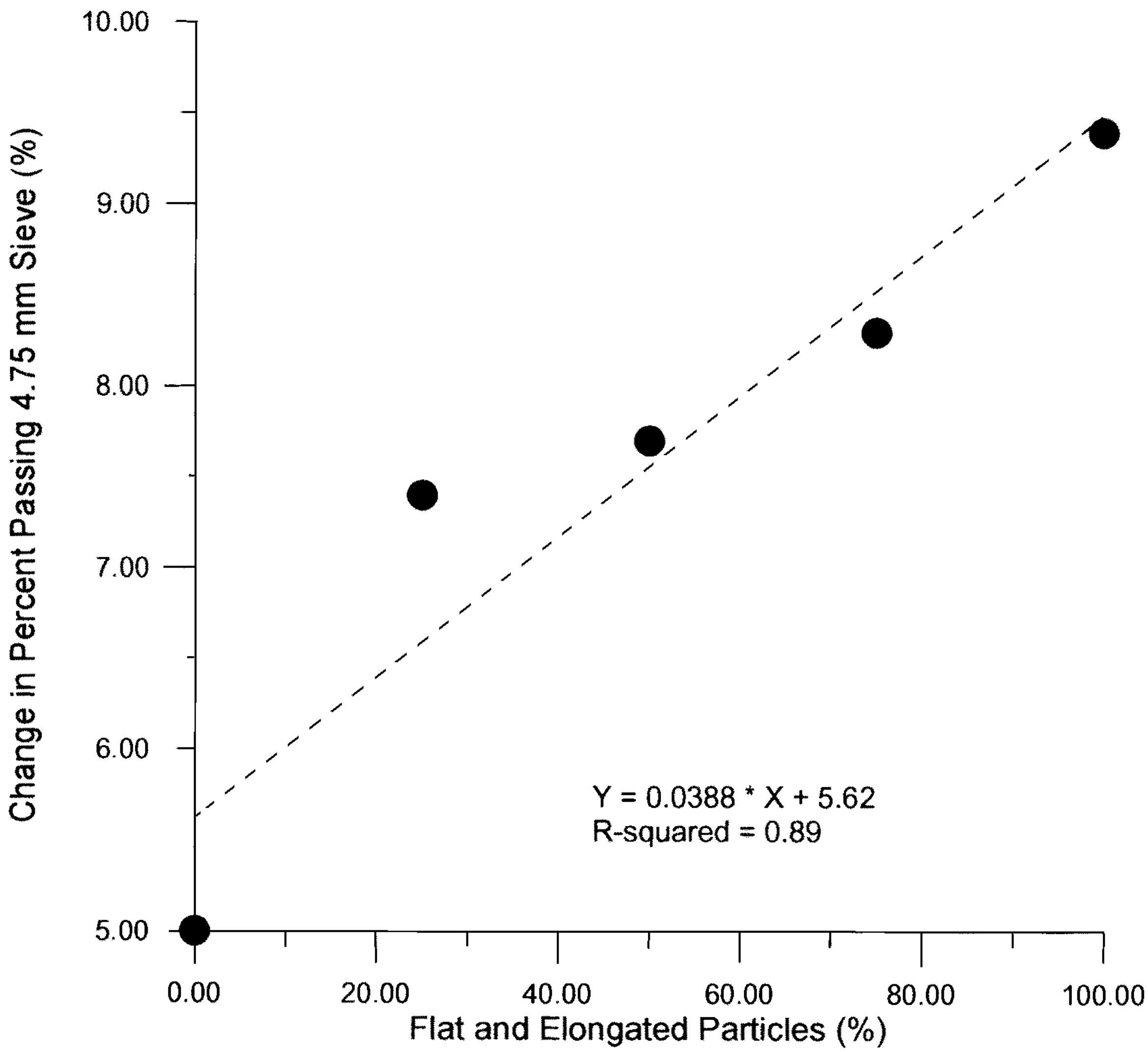

Figure 3. Flat and elongated particle content versus change in percent passing 4.75 mm sieve (50-blow marshall compaction).

remains nearly constant, and then begins to increase once the percent passing the 4.75 mm sieve reaches 30-40 percent. The point at which the VMA begins to increase defines the condition at which stone-on-stone contact begins to develop. Below 30 percent, a lowering of percent passing the 4.75 mm sieve tends to increase the VMA by opening up more space in the coarse aggregate structure. Hence, the percent passing the 4.75 mm sieve must be lowered below approximately 30

Table 2. Flat and Elongated Particle Property of Aggregates Used in the Study

	Flat and Elongated Particle Content (%)		
Aggregate Ratio	2:1	3:1	5:1
Limestone (1)	37	13	2
Granite (1)	28	2	0
Traprock	21	3	1
Granite (2)	20	3	0
Dolomite	16	5	1
Limestone (2)	10	2	0
Slag	12	0	0
Gravel	25	5	0

percent to ensure the formation of stone-on-stone contact.

For mix design purposes it is suggested that the presence of an adequate aggregate skeleton be verified by measuring the voids in coarse aggregate (VCA). This can be accomplished by completing a dry rodded test (AASHTO T19) on the coarse aggregate fraction (material retailed on the 4.75 mm sieve) of the mixture gradation. The VCA in the dry rodded condition can be calculated as follows:

$$VCA_{DRC}\ (\%) = \frac{G_{sb}\gamma_w - \gamma_s}{G_{sb}\gamma_w}\ X\ 100$$

where,

G_{sb} = bulk specific gravity of coarse aggregate,

γ_w= unit weight of water (999 kg/m^2), and

γ_s = unit weight of aggregate in the dry-rodded condition (kg/m^2).

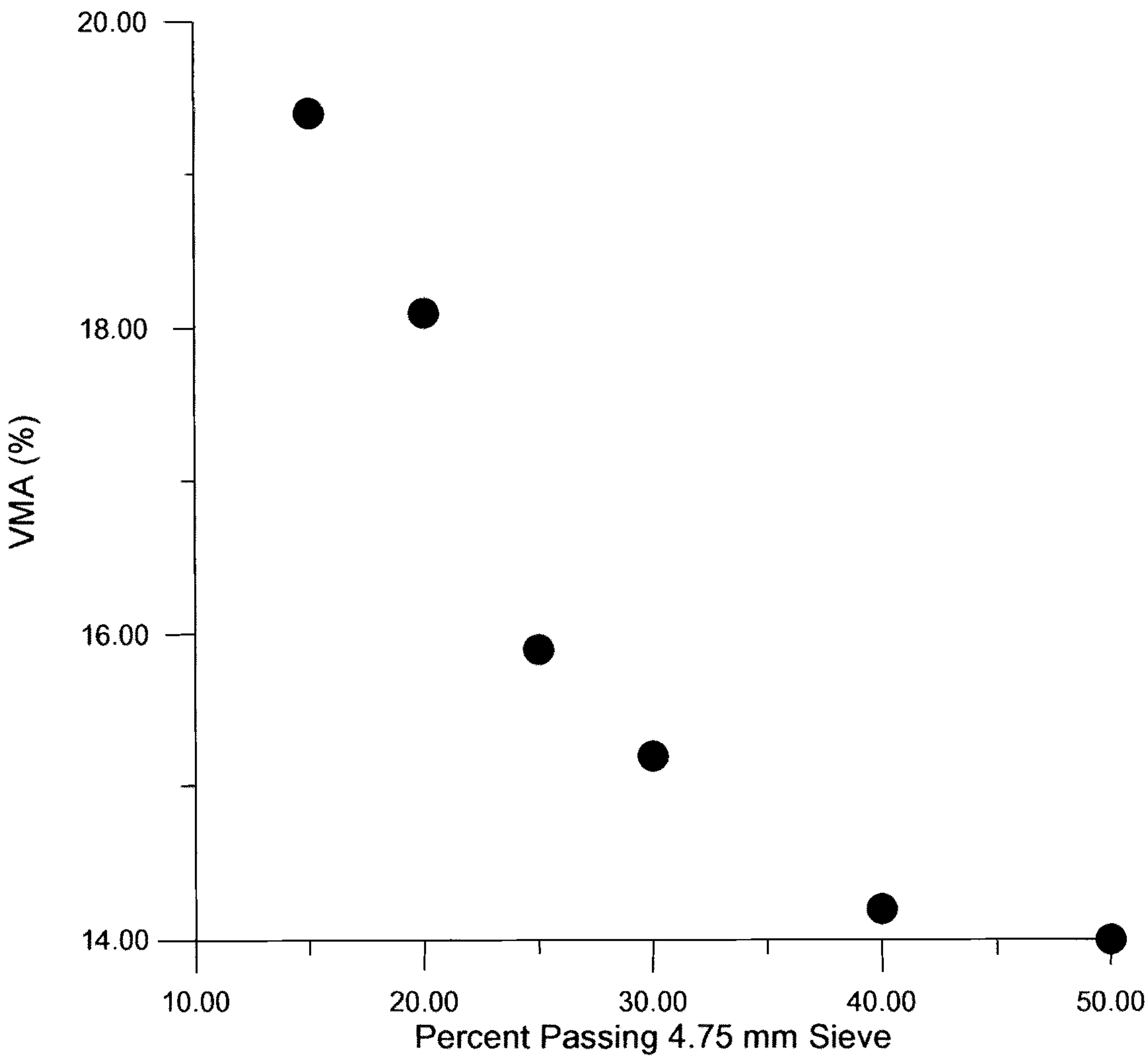

Figure 4. Percent passing 4.75 mm sieve versus VMA (gravel mixes, 50-blow marshall compaction).

VCA has been correlated to change in percent passing the 4.75 mm sieve. Results from previous NCAT work (5) are shown in Figure 5. As the percent passing the 4.75 mm sieve decreases, the VCA decreases. However, the slope of the plot begins to decrease at

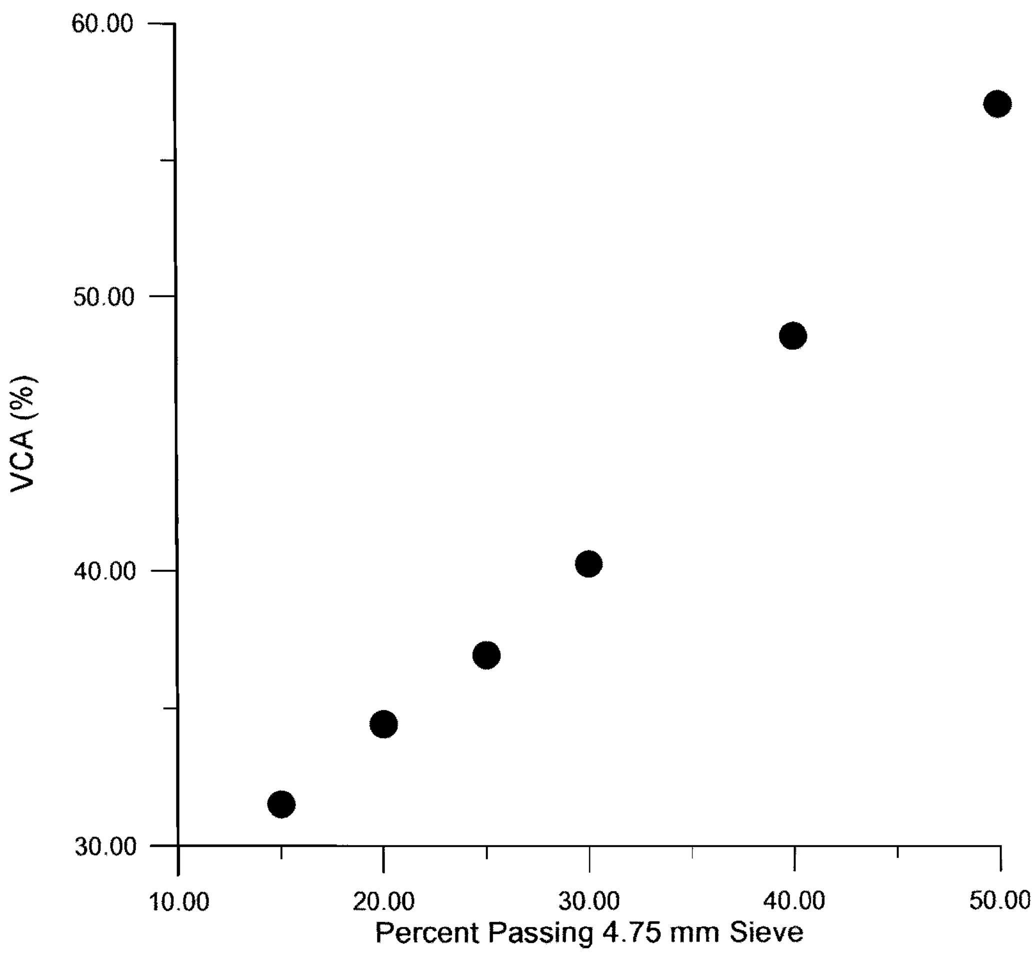

Figure 5. Percent passing 4.75 m sieve versus VCA (gravel mixes, 50-blow marshall compaction).

approximately 30 percent passing the 4.75 mm sieve. This is the point at which stone-on-stone contact begins to develop. For SMA mixtures, the percentage of aggregate material passing the 4.75 mm sieve apparently needs to be less than 30 percent to ensure an adequate aggregate skeleton and provide sufficient VMA.

Mineral Filler

The function of mineral filler is essentially to stiffen the binder rich SMA. A higher percentage of very fine filler may stiffen the mixture excessively, making it difficult to work with and resulting in a crack susceptible mixture. Current TWG guidelines attempt to control the stiffening effect of the filler by regulating the amount of filler that is finer than 0.02 mm. However, any restriction placed on the filler should be based on its effect on mortar stiffness. To investigate this effect, the fine mortar (mineral filler, asphalt binder and stabilizing additive) was tested in the dynamic shear rheometer (DSR). Ten different mineral fillers, each having a different percentage of material finer than 0.02 mm were used. Plots of DSR stiffness for the 10 fine mortars at 58° and 70°C are shown in Figures 6 and 7. From the figures it appears that no correlation exists between the mortar stiffness and the percentage of mineral filler finer than 0.02 mm. The R^2 values for the analyses are 0.00 and 0.01 for 58° and 70°C, respectively. The results seem to indicate that a restriction on material finer than 0.02 mm does not seem to be justified.

In an effort to characterize the mineral filler shape, the Penn State test method for determining the void volume in dry-compacted dust was used. The test was performed according to the method outlined in Reference 6. The method involves packing the mineral filler in a standard cylinder using a specified compactive effort. The mass of the cylinder with the mineral filler inside is then determined. The air voids in the mineral filler sample can be determined from the tare mass of the cylinder as well as the cylinder volume. More angular particles tend to produce higher air void results in this test. The dry-compacted voids results for the 10 fillers were correlated against DSR stiffness at 58° and 70°C, as shown in Figures 8 and 9. Note that the correlations are better (R^2 = 0.62 and 0.46 for 58° and 70°C, respectively) than those for material

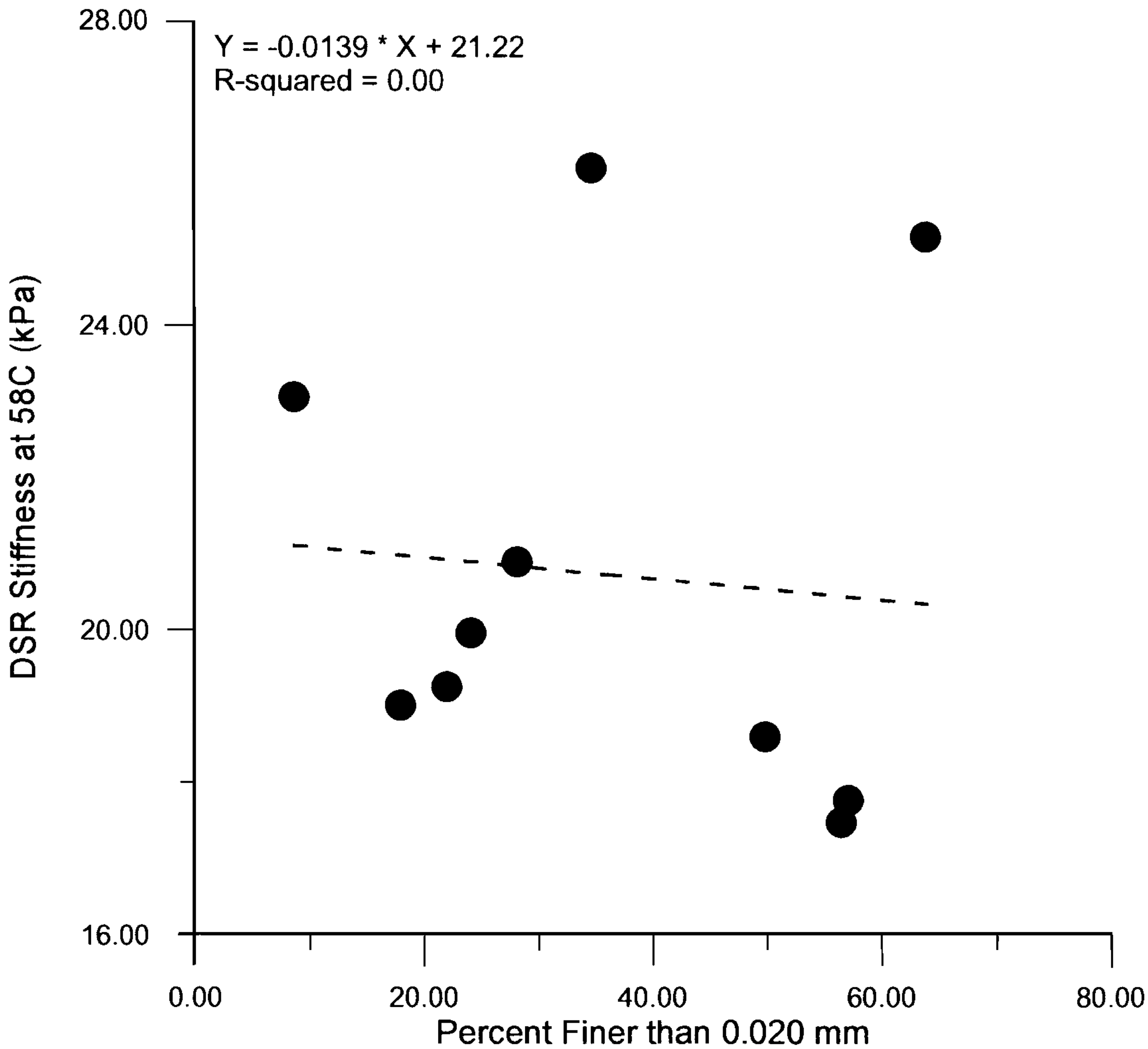

Figure 6. Percent finer than 0.020 mm versus DSR stiffness at 58°C.

finer than 0.02 mm. Thus, the more angular the particles in a given mineral filler, the more it should stiffen the mortar. Other researchers (7) have also obtained similar results. The results indicate that the dry-compaction test might serve as a screening test for mineral fillers.

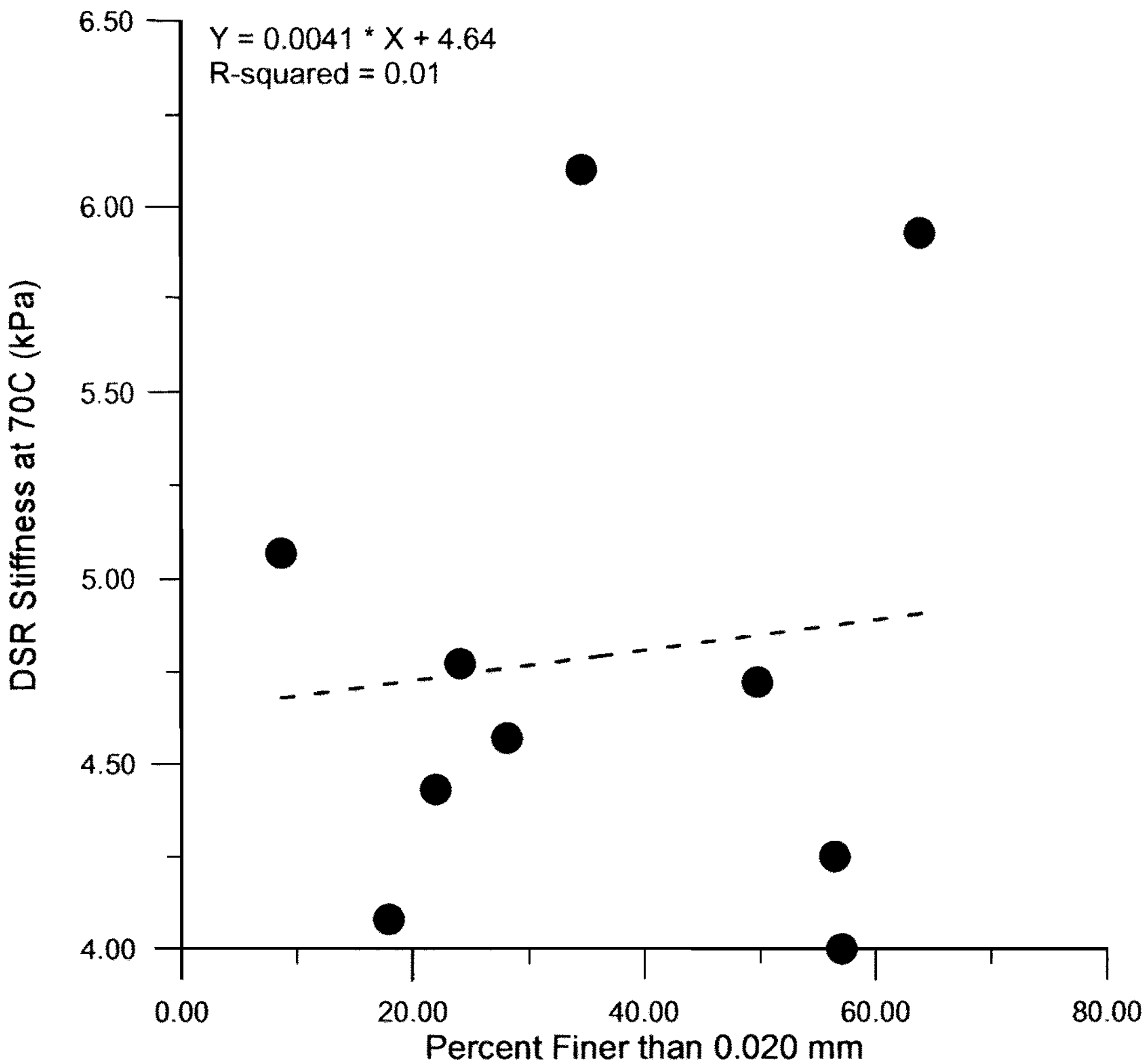

Figure7. Percent finer than 0.020 mm versus DSR stiffness at70°C.

Voids in the Total Mix (VTM)

The TWG guidelines recommend a mixture design air void range of 3-4 percent. This specification is based on European experience. One concern for SMA mixes is the occurrence of fat spots. Fat spots are caused by flushing of asphalt cement from a mix. Long haul distance,

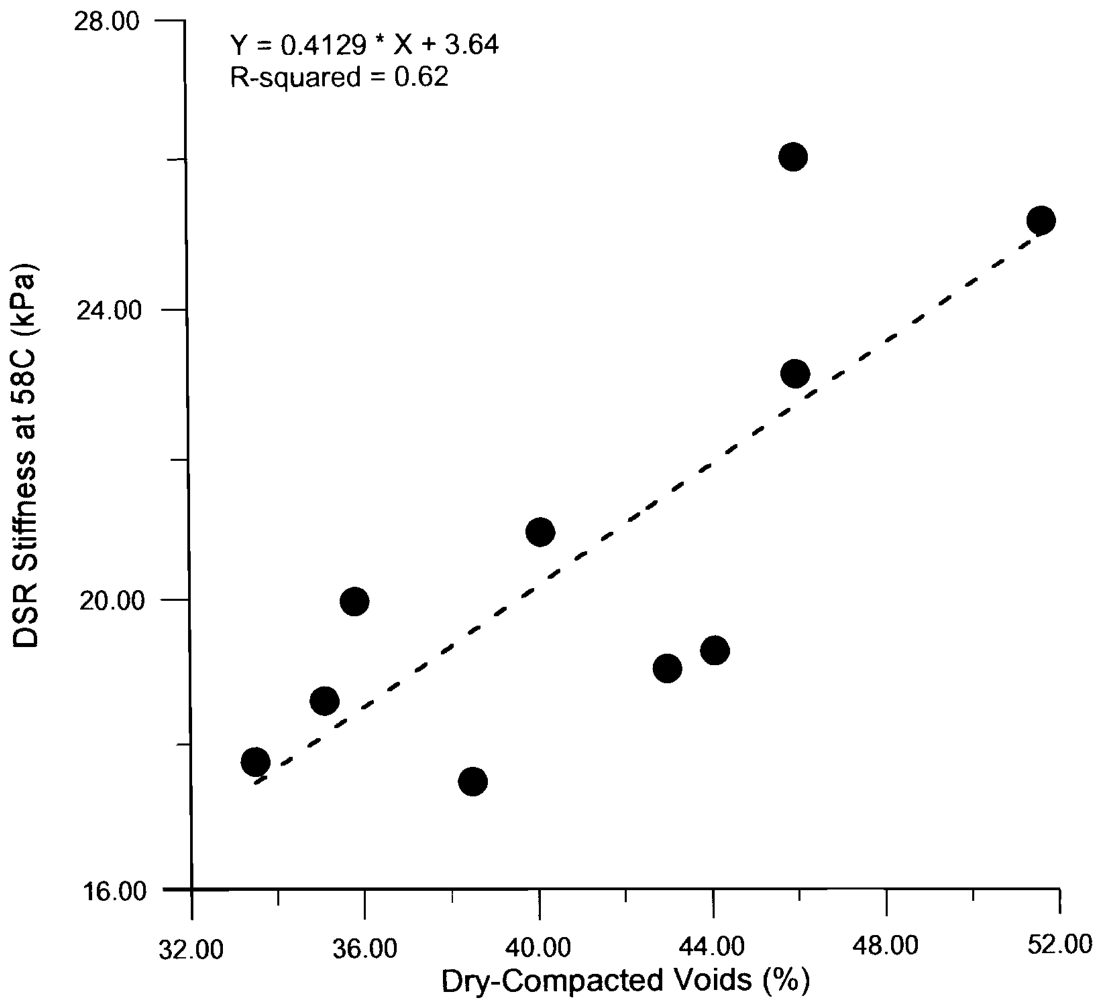

Figure 8. Dry-compacted voids versus DSR stiffness at58°C.

coarse gradation, high asphalt content, inadequate stabilizer or very high mix temperature can result in localized fat spots. All of these factors have a significant effect on air voids, and the laboratory air voids can serve as an indicator of fat spot potential. A field study to evaluate performance of SMA mixtures has shown that the only SMA mixtures to experience significant rutting had low voids (8). Usually the laboratory compacted samples had air voids ranging

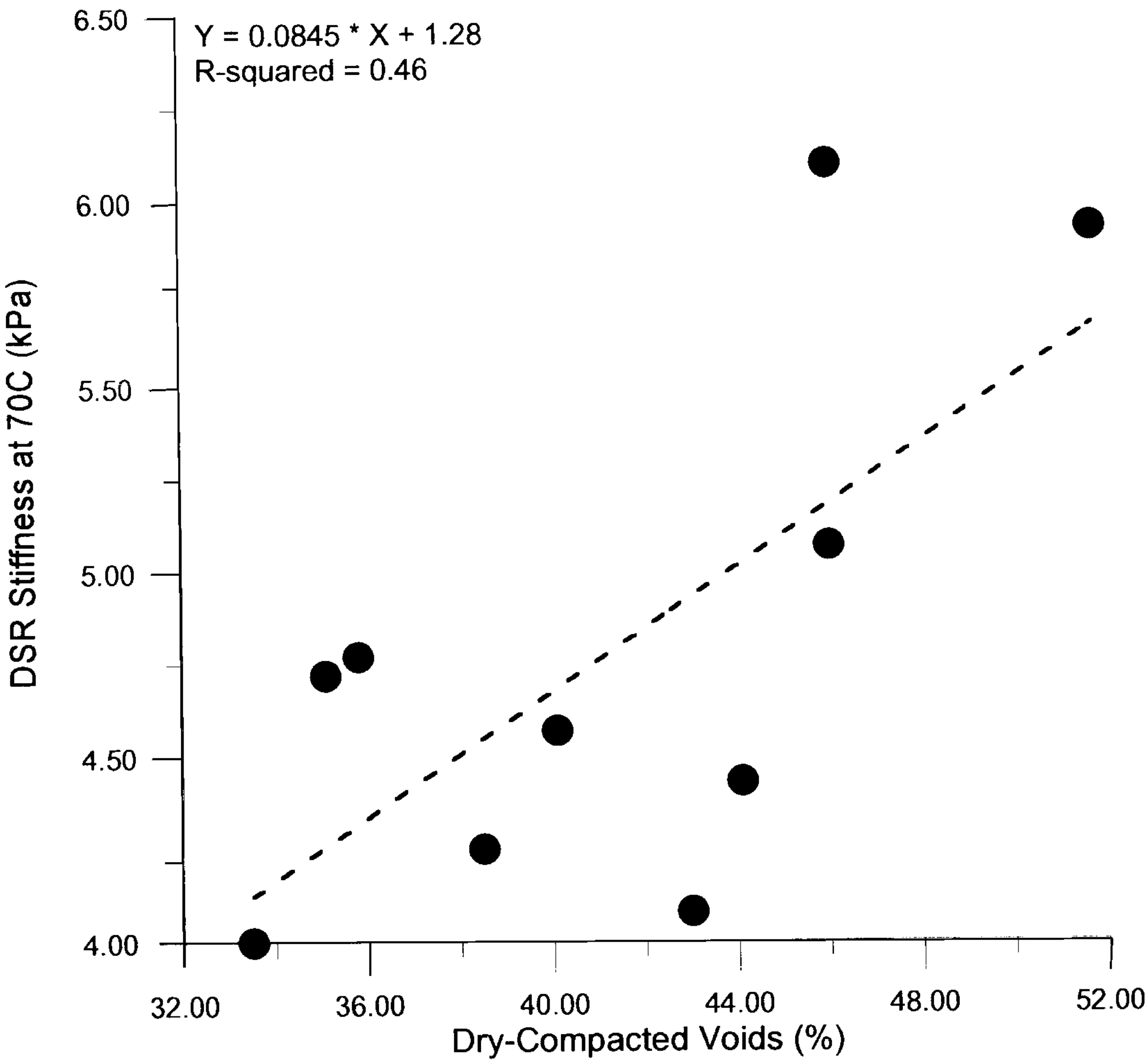

Figure 9. Dry-compacted voids versus DSR stiffness at70°C.

between 2 and 3 percent. Setting the minimum air void level at 3 percent appears to be reasonable. To minimize fat spots and rutting the air voids in warmer climates should be designed closer to 4 percent.

Voids in the Mineral Aggregate (VMA)

The primary purpose of the VMA requirement is to ensure a reasonably high asphalt content. This can be accomplished by specifying a minimum asphalt content or a minimum VMA. The best approach is to specify minimum VMA because it is calculated on a volume basis and is not affected by aggregate specific gravity. Also, it is often difficult to meet minimum asphalt content requirements when high specific gravity aggregates are used.

Establishing the gradation limits so that 20-28 percent of the aggregate passes the 4.75 mm sieve helps to ensure that minimum VMA requirements are met. However, aggregates that tend to break down excessively during compaction may not provide a mixture that meets VMA requirements. Generally speaking, when the Los Angeles abrasion loss value is low (approximately 20 and lower), meeting VMA requirements is not difficult; when the abrasion loss is high (approximately 40 and higher), meeting the VMA requirement is more difficult.

Based on a number of mixture designs and limited field experience, it appears that a VMA requirement of 17 percent minimum is reasonable and should continue to be specified.

Asphalt Content

The TWG (2) has recommended that a minimum asphalt binder content of 6 percent be used in SMA mixtures. This requirement can be used but is not needed as long as minimum VMA requirements are met. The minimum asphalt binder content requirement should therefore be deleted in favor of the minimum VMA requirement.

Compactive Method and Effort

The compactive effort specified by the TWG (2) is 50 blows of the mechanical Marshall hammer. This was based on European experience where 50-blow Marshall has long been used for compacting SMA. With the advent of the Superpave system, it is now important for the mix designer to have the option of using the SGC for SMA mixtures. Recent work done by NCAT (5) indicates that 50 blows of the Marshall hammer produces a density in SMA mixtures approximately equivalent to 100 revolutions of the SGC. To investigate this, two mixture designs were completed for each of the eight aggregates used in the study. One design used 50-blow Marshall to compact the laboratory specimens. The second design used 100 revolutions of the SGC to compact specimens. The resulting data is shown in Figure 10 and indicates that 100 revolutions of the SGC, on the average results in the same optimum asphalt binder content and thus the same density as produced by 50-blow Marshall compaction. Until further guidance is provided, it is recommended that SMA mixtures be compacted with 50-blow Marshall or 100 revolutions of the SGC.

Aggregate Breakdown

The amount of aggregate breakdown produced by 50-blow Marshall and 100 revolutions of the SGC was quantified and compared. This was done by extracting the asphalt binder from compacted specimens, performing a gradation analysis, and comparing the results to the pre-compaction gradation. The results for the 4.75 and 0.075 mm sieves are shown in Figures 11 and 12, respectively. The results show that the SGC produces less aggregate breakdown than does the Marshall hammer.

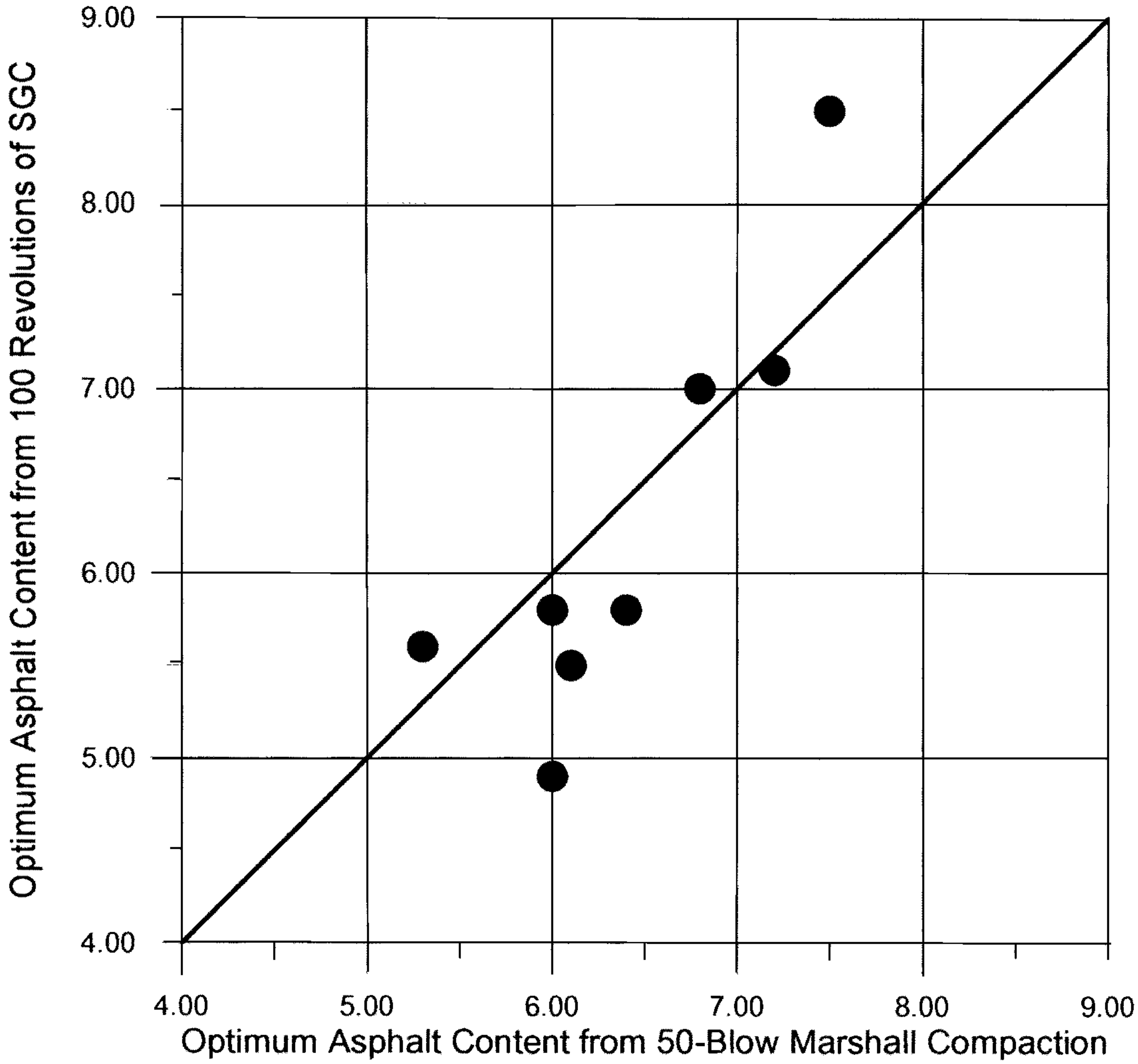

Figure 10. Optimum asphalt content from marshall compaction versus optimum asphalt Content from SGC compaction.

A further investigation of aggregate breakdown was done by comparing the amount of breakdown produced at different levels of Marshall and SGC compaction. Figures 13 and 14 show plots of changes in percent passing the 4.75 and 0.075 mm sieves for four different mixtures each compacted with 35, 50 and 75 blows of Marshall hammer. Results from dense-graded

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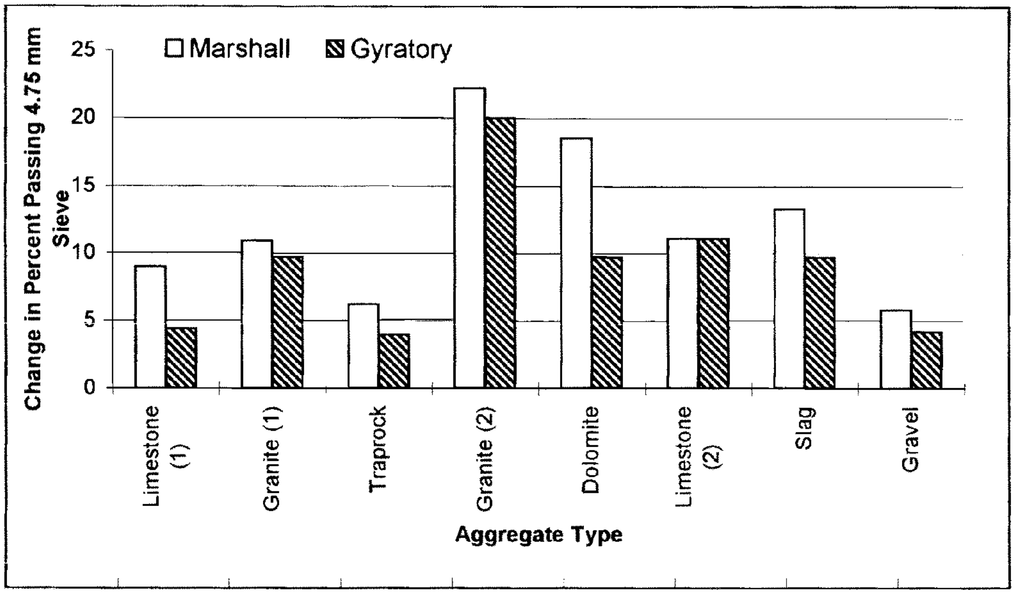

Figure 11. Aggregate type versus change in percent passing 4.75 mm sieve.

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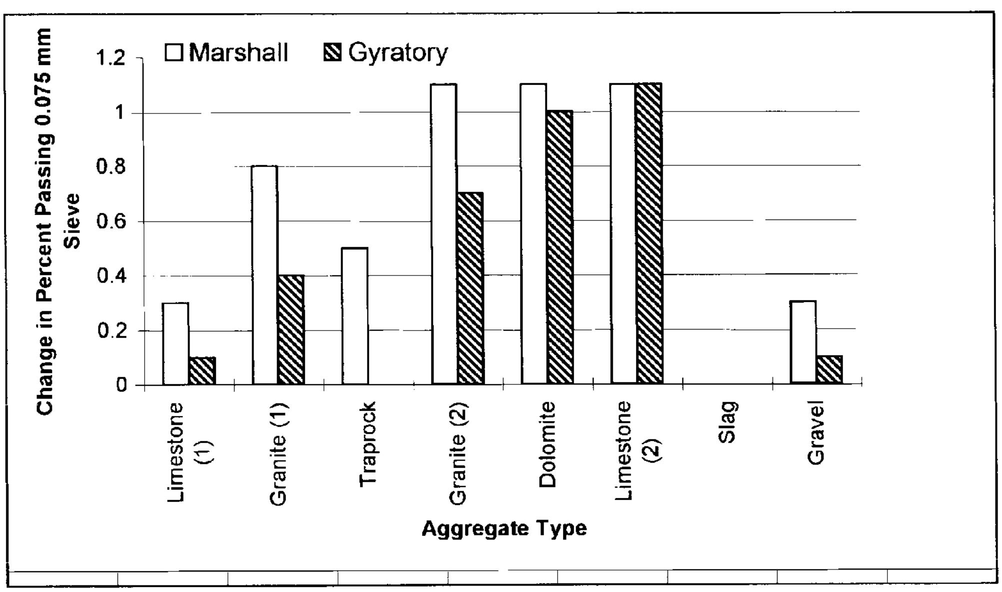

Figure 12. Aggregate type versus change in percent passing 0.075 m sieve.

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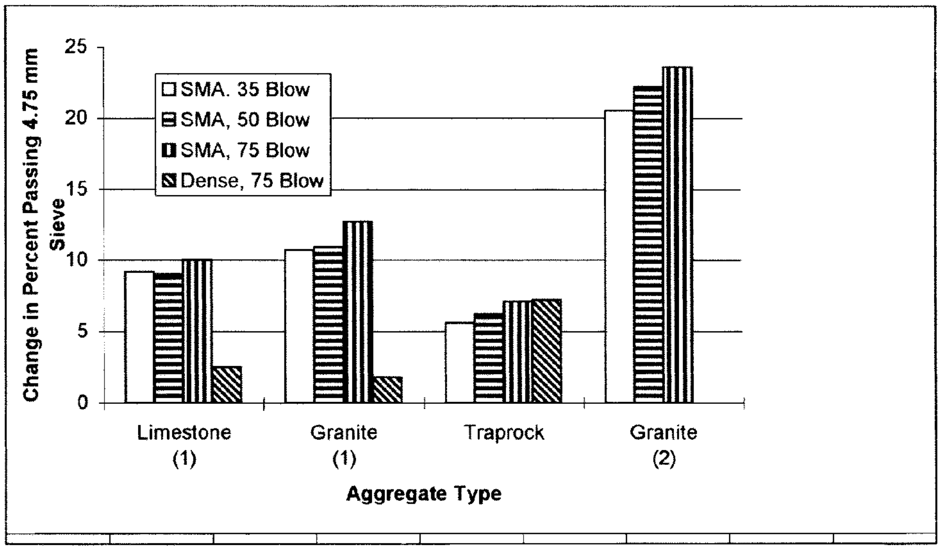

Figure 13. Aggregate type versus change in percent passing 4.75 mm sieve at different compaction levels (mixes compacted with marshall hammer).

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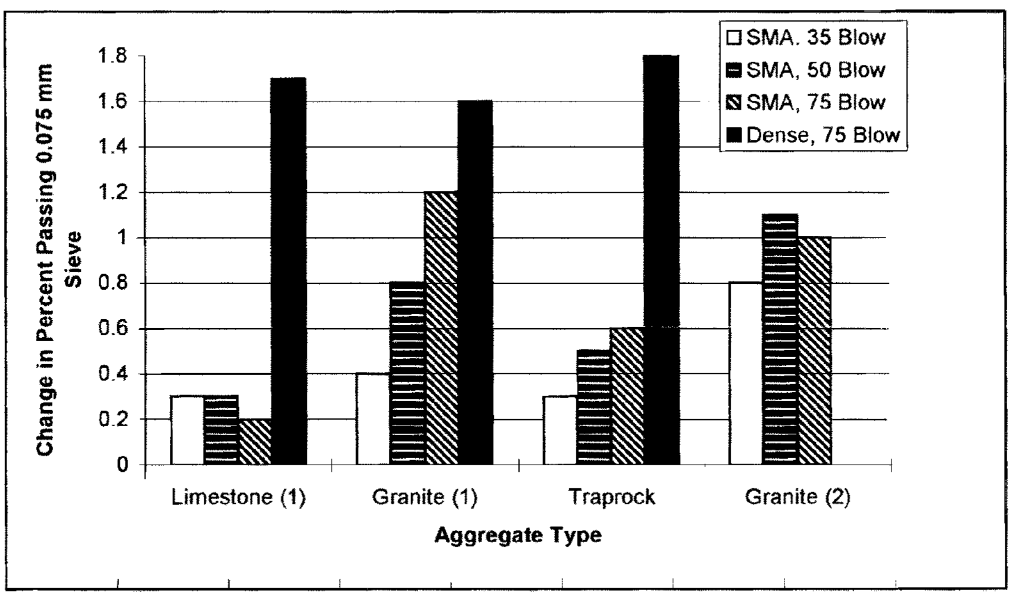

Figure 14. Aggregate type versus change in percent passing 0.075 mm sieve at different compaction levels (mixes compacted with marshall hammer).

mixtures for three aggregates and compacted with 75 blows are also shown. The data shows that the amount of aggregate breakdown does increase as the blow count increases. The amount of breakdown is also dependent on aggregate type for both the 4.75 and 0.075 mm sieves. When the breakdown of SMA and dense-graded mixtures is compared, it is observed that for the amount of coarse aggregate breakdown is higher for SMA mixtures than for dense-graded mixtures. However, the increase in dust (material passing the 0.075 mm sieve) is higher for the dense-graded mixture. One plausible explanation for this is that since the dense-graded mixtures have a graded aggregate structure, the coarse aggregate is not broken into smaller coarse aggregate particles, but rather they are degraded into much finer size. When added together this yields a significant increase in the amount passing the 0.075 mm sieve. In comparison, the SMA mixtures are gap graded and the majority of breakdown occurs in the coarse aggregate sizes where the particles are broken into smaller coarse aggregate particles.

Results from mixtures with different aggregates and compacted with 75, 100 and 125 revolutions of the SGC are shown in Figures 15 and 16. The plots indicate that breakdown on both the 4.75 and 0.075 mm sieves increases only slightly with an increase in the number of SGC revolutions.

Draindown

When compared to conventional HMA, SMA mixtures generally have a higher asphalt content and more coarse aggregate. As a result, SMA mixtures must contain the proper type and amount of some stabilizing additive in order to retain the asphalt binder during production and placement. The TWG guidelines (2) recommend a maximum of 0.3 percent draindown (at one

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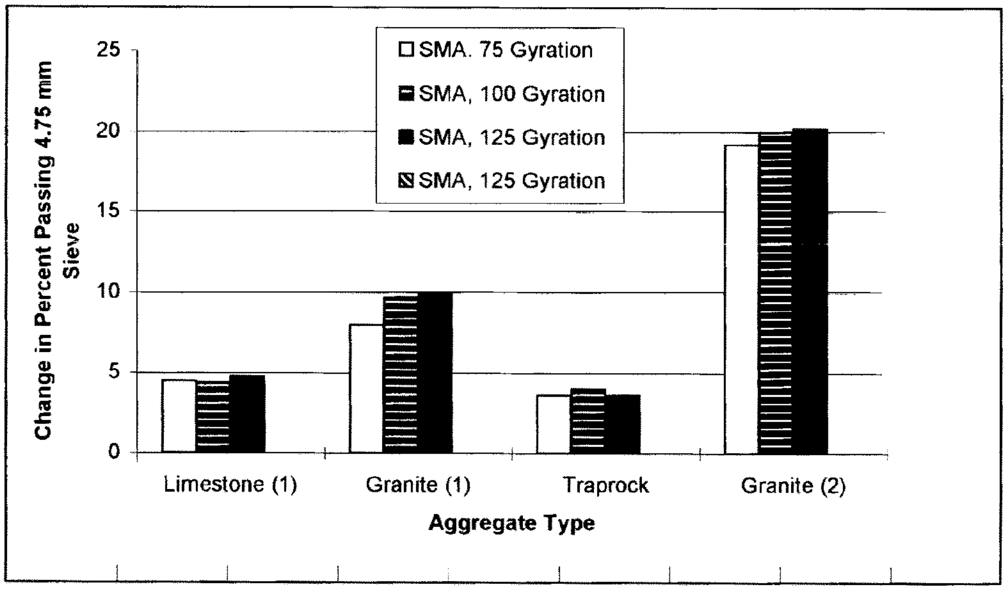

Figure 15. Aggregate type versus change in percent passing 4.75 mm sieve at different compaction levels (mixes compacted with SGC).

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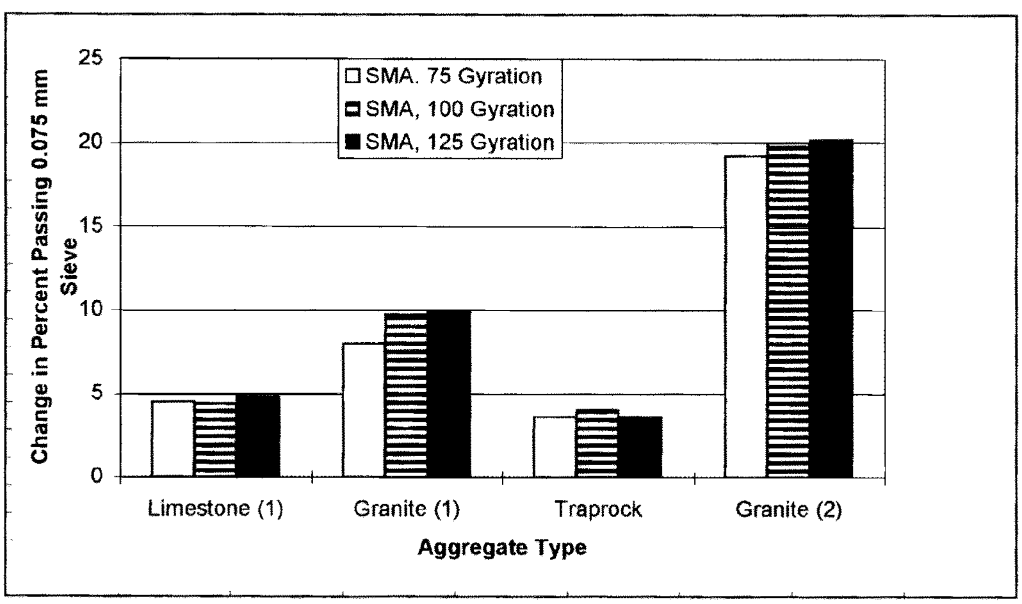

Figure 16. Aggregate type versus change in percent passing 0.075 mm sieve at different compaction levels (mixes compacted with SGC).

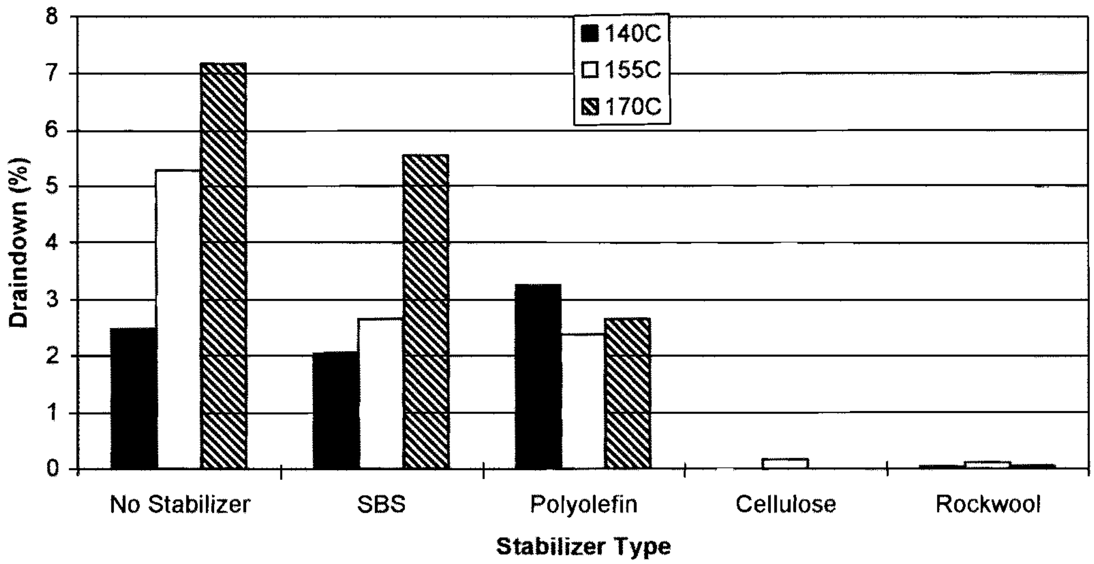

Figure 17. Stabilizer type versus draindown.

hour), as indicated by the NCAT Draindown Test. This fast and inexpensive test has been shown to be capable of evaluating the effect of mixture design parameters such as percent passing the 4.75 mm sieve, asphalt content, and type and amount of stabilizer. It should be noted that the results shown here are from laboratory tests. The draindown test can also be used as a field check tool. When used in the field, a lower specified value of draindown may be necessary to allow for variations.

To evaluate the effect of stabilizer type, five mixtures were tested in the draindown test. Each of the mixtures was equivalent except for the type of stabilizer employed. The stabilizer types were SBS, polyolefin, cellulose fiber, and rock wool fiber. The fifth mixture was a control and contained no stabilizing additive. The results at 140°, 155°, and 170°C are shown in Figure 17. The results clearly indicate the importance of using the proper type of stabilizing additive.

Note that fibers act to prevent draindown better than polymers.

Rut Resistance

The primary reason for using SMA mixtures is that they have proven to be superior to conventional HMA in terms of rutting resistance. However, the type of stabilizer can have an effect on SMA rut resistance capabilities. To evaluate this effect laboratory wheel tracking tests were conducted. Slab samples of SMA were prepared with traprock aggregates at optimum asphalt content, and using two different stabilizers, SBS polymer and rock wool fiber. Slabs with no stabilizer were also tested. The slabs were tested for rutting rate with a Danish wheel tracking device at 55°C. Temperature is maintained by water immersion. The total and the last hour rutting rate were obtained and are shown in Figure 18. Note that the mixture with no stabilizer has the highest rutting rate. Of the two mixtures with stabilizers, the SBS polymer mix has a significantly lower rutting late compared to the rock wool fiber mix. Hence, the indication is that polymer stabilizers produce better rut resistant mixes, but fiber stabilizers are superior in preventing draindown in SMA mixes. As noted elsewhere (9), a combination of fibers and polymers may provide the best properties in SMA mixtures.

SUMMARY

A list of requirements for SMA mixture design and construction was published by the National Asphalt Pavement Association in 1991. These requirements were developed by the SMA TWG and were based on the European experience with SMA. Hence, the criteria indicated by the SMA TWG in the NAPA report needed to be evaluated on the basis of mixture design and

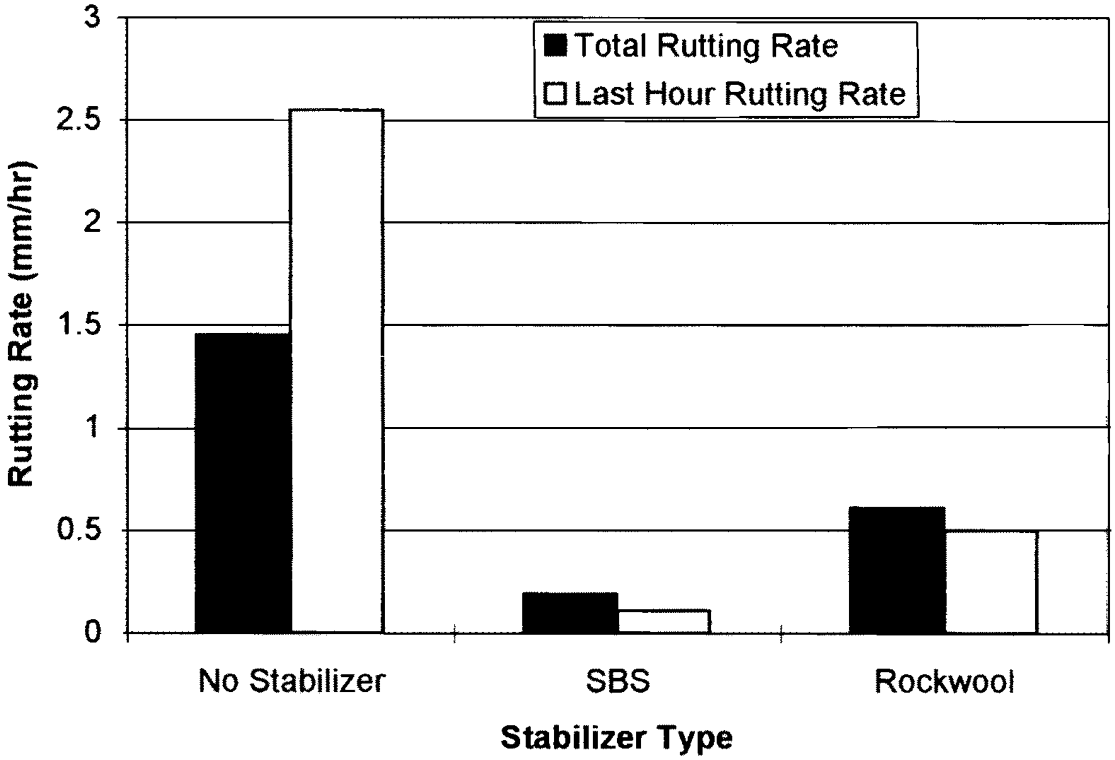

Figure 18. Stabilizer type versus rutting rate.

construction practices in the United States.

This study has produced a mixture design procedure and material evaluation procedure for SMA mixtures. Factors evaluated were Los Angeles abrasion loss, flat and elongated particle content, mixture aggregate gradation, percent of filler finer than 0.02 mm, stone-on-stone contact, VTM, VMA, asphalt binder content, compactive effort, draindown sensitivity, and rutting potential. The specific conclusions are as follows:

(1) Aggregate toughness as measured by the Los Angeles abrasion test showed good correlation with aggregate breakdown. An increase in abrasion loss resulted in an increase in aggregate breakdown for mixtures compacted with both the Marshall

hammer and Superpave gyratory compactor. Therefore, a limit on abrasion loss is justified to help minimize aggregate breakdown. The limit of 30 recommended by the SMA TWG appears to be reasonable.

(2) The 5 to 1 flat and elongated particle content criteria appear to be too liberal. It appears that the 2 to 1 or 3 to 1 flat and elongated particles criterion will provide a much better separation between the various aggregates than the 5 to 1 ratio.

(3) The flat and elongated particle content shows excellent correlation with aggregate breakdown. Aggregate breakdown increased with an increase in flat and elongated particle content.

(4) In a SMA mix, the percent passing 4.75 mm sieve must be below 30 percent to ensure proper stone-on-stone contact. Stone-on-stone contact can be evaluated by plotting VMA or VCA versus the percent passing the 4.75 mm sieve. The dry rodded test, as outlined in AASHTO T19 can be used to determine the limiting VCA for a SMA mixture.

(5) The percent of filler finer than 0.02 mm did not correlate with mortar stiffness. Hence, the criterion for limiting the percent finer than 0.02 mm should be removed from the guidelines. The dry-compacted volume as obtained from the Penn State test method showed a better correlation with mortar stiffness and can be utilized to characterize the shape of filler. Generally, a more angular filler tends to produce a higher air voids result in this test.

(6) A field study showed that rutting has been negligible in SMA pavements constructed in the United States since 1991. However, for the pavements with air voids falling

below the 3 percent range, some rutting has been observed.

(7) The VMA of a SMA mixture can be significantly lowered due to aggregate breakdown. Hence, the mix designer must consider aggregate type, compactor type, and compactive effort along with the gradation when attempting to design SMA and meet the required VMA criterion. Specifying a minimum asphalt content can result in significant differences in optimum asphalt binder content due to different aggregate specific gravities. Even with sufficiently high VMA values, the optimum asphalt content by weight may be relatively low when using aggregates with high specific gravities.

(8) Fifty blows of the Marshall hammer is approximately equal to 100 revolutions of the Superpave gyratory compacter in terms of resultant SMA density. The Superpave gyratory compacter produces less aggregate breakdown than the Marshall hammer. However, for both compactors, the amount of breakdown is affected by aggregate type and compactive effort.

(9) Fiber stabilizers are found to be more effective in reducing draindown than polymer stabilizers. However, mixtures modified with polymers show better resistance to rutting in laboratory wheel tracking tests.

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