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Effect of Coarse Aggregate Shape on Engineering Properties of Stone Mastic Asphalt Applied to Airport Pavements

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Abstract: Stone mastic asphalt (SMA) was developed in Germany during the 1960's as a durable asphalt mixture. In late 1990's, the Construction and Planning Agency brought the German asphalt mix technology to Taiwan. The initial interest in the use of SMA on highway pavements continued with the application to airport pavements. Laboratory work was conducted to refine the SMA design procedure in terms of coarse aggregate shape. Image evaluation provided quantitative indices such as geometric measurement and angle rotation of granular materials. The change in rotation angle of coarse aggregate was found to correlate well with the internal resistance of a SMA mix. SMA was shown to possess improved resistance to rutting and moisture damage if the engineering properties of coarse aggregate were under control. The requirements for flat and elongated particle were crucial to the engineering properties of SMA applied to airport pavements. Cubical particles were desirable for increased aggregate internal friction and improved rutting resistance. The particle index (PI) value of coarse aggregate significantly affected the engineering properties of a SMA mix. A high PI value indicated that the aggregate shape is likely to be cubical. The particle shape determined how aggregate was packed into a dense configuration and also determined the internal resistance of a mix. Of the four particle shapes evaluated, the cubical aggregate demonstrated the best rutting resistance. Flaky and/or elongated aggregate was shown to have lower compactibility and higher breakage.

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***Key words**: Aggregate shape; Stone mastic asphalt; Rutting resistance.*

Introduction

Stone Matrix Asphalt (SMA) was developed in Germany over 30 years ago. Its success has led to its usage throughout Europe, U.S. and Asia on both highway and airfield pavements. In 1999, the Construction and Planning Agency, Ministry of Interior, led an Experimental Test Road Study introduced SMA to Taiwan [1]. SMA has demonstrated good performance on highway pavements [2], but has seen little use on airfields in Taiwan. Recently, there has been resurgence in interest in SMA in Taiwan as a more durable paving option than traditional hot-mix asphalt (HMA) mixes.

SMA is a gap-graded asphalt mixture with a high percentage (> 70 percent) of coarse aggregate. Gap-graded refers to the fact that SMA mixtures typically have very little material retained on the sand size sieves (e.g. between 2.36 mm and 0.075 mm). SMA is differentiated from dense-graded mixes by its coarse aggregate skeleton, consisting of a limited number of particle sizes, which carries the load. Mastic, consisting of mineral filler, fibers, and asphalt binder, fills the voids between the coarse aggregate skeleton. The percentage by weight passing the 0.075 mm sieve is typically greater than 8 percent. Asphalt contents range from 6 to 7.5 percent by weight of total mix. Fiber, either cellulose or mineral, is generally added to prevent draindown of the binder during construction.

Aggregate morphological characteristics are very complex and cannot be characterized adequately by any single test. As a result, conflicting results have been reported on how aggregate shape influences the quality of SMA mixtures. For example, Prowell et al. [3] concluded that replacing uncrushed coarse aggregate with crushed coarse material did not significantly improve the asphalt mix properties. Gatchalian et al. [4] found a direct correlation between the rutting potential of HMA mixtures and the shape and texture of coarse aggregate particles. Brown et al. [5] concluded in their study that flat and elongated particles could be permitted in a mixture without adverse effect on its strength. Some mixes with flaky aggregates have been found to exhibit higher fatigue life than mixes with nonflaky aggregates. Cooley et al. [6] showed that the percentage of crushed coarse particles had a significant effect on laboratory permanent deformation properties. As the percentage of crushed coarse particles decreased, the rutting potential of the HMA mixtures increased. Clark et al. [7] found that crushed aggregate containing 19% flat and elongated particles did not adversely affect the volumetric properties of HMA mixtures. West et al. [8] presented data on the effect of aggregate shape, and recommended blends of regular particles, flat particles, and rod-like particles to achieve optimum strength.

In Germany, aggregates for SMA are tested to ensure that not more than 20 percent of the particles exceed a length to thickness ratio of 3:1. Stuart [9] noted that the German's indicated that some elongated or other irregularly shaped particles are desirable to improve aggregate interlock. Flat and elongated particles are considered undesirable because they can lead to variability in volumetric properties in the laboratory (particularly if the percentage of flat and elongated particle varies), can break during compaction exposing uncoated faces, and may align themselves during compaction, possible altering stability or causing bleeding.

Campbell [10] reported that while SMA had been used on roadways in 25 countries around the world, its usage on airfields

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Table 1. Physical Properties and Aggregate Gradation for SMA and Dense Mixes.

Type	Specific Gravity	L.A. Abras. (%)	Size Distribution (% Passing by Weight)										
			25 mm	19 mm	12.5 mm	9.5 mm	4.75 mm	2.36 mm	1.18 mm	0.6 mm	0.3 mm	0.15 mm	0.075 mm
SMA	2.62	19.8	100	92.3	47.1	39.5	24.6	18.5	14.5	17.2	13.9	11.8	10.2
Dense	2.62	19.8	100	91.5	81.2	74.2	55.2	43	-	26.1	18.2	12.2	5.1

was limited to 15 countries. Aggregate durability, or hardness, is an important consideration in the design of SMA for airfield pavements. Excessive aggregate breakdown during mixing and compaction could alter the SMA gradation, potentially causing a loss of stone-on-stone contact between the coarse aggregate particles. Secondly, the contact points between the coarse aggregate particles provide stability to the mixture. If the aggregate is too soft or brittle, these points could break down under load. The Los Angeles (L.A.) Abrasion Test, ASTM C131, is typically used to characterize aggregate breakdown during construction in the U. S.[11]. However, the L.A. test cannot be not used to characterize aggregate breakdown. Therefore, the objectives of this paper are (1) to quantify the morphological characteristics of coarse aggregate, (2) to evaluate the engineering properties of SMA mixtures made of different aggregate shapes, and (3) to characterize the aggregate orientation during traffic loading.

Materials and Methods

Aggregate

Crushed limestone was used for aggregate gradations listed in Table 1. Gap- and dense-graded gradations were two examples of the influence of aggregate shape on engineering properties of hot-mix asphalt mixtures. The stone-mastic asphalt mixture is a gap gradation supposed to provide a high interlocking mechanism through coarse aggregate. The dense gradation is a typical gradation employed by highway agencies in Taiwan. Coarse and fine aggregate refers to materials retained on and passing through the 4.75-mm sieve, respectively. The coarse aggregate was sieved and partitioned into four size fractions, namely, 25 to 19 mm, 19 to 12.5 mm, 12.5 to 9.5 mm, and 9.5 to 4.75 mm (3/4 to 1/2 in., 1/2 to 3/8 in., and 3/8 in. to #4). The fine aggregate was sieved and partitioned into seven size fractions as in Table 1.

SMA was evaluated for the influence of coarse aggregate shape on engineering properties of a HMA mix. The particle longest diameter (d_L), the intermediate diameter (d_I), and the shortest diameter (d_S) of an aggregate size was measured to differentiate the aggregate shape [12]. The selection process was carefully conducted by an image analyzer, as discussed in the next section. The flat and elongation ratios were used to define the aggregate shape as shown in Fig. 1. The ratio of d_I to d_L is related to aggregate elongation, and the aggregate flatness is represented by the ratio of d_S to d_I. Disk, blade, rod, and cube are four different aggregate shapes selected for comparison. As both ratios are equal to or larger than 2/3, the cubical aggregate was selected for the SMA mix in order to contrast it with the mixes consisting of other shapes. The disk-shaped aggregate is flaky and oblate, the rod-shaped is elongated, and the blade-shaped is both flaky and elongated.

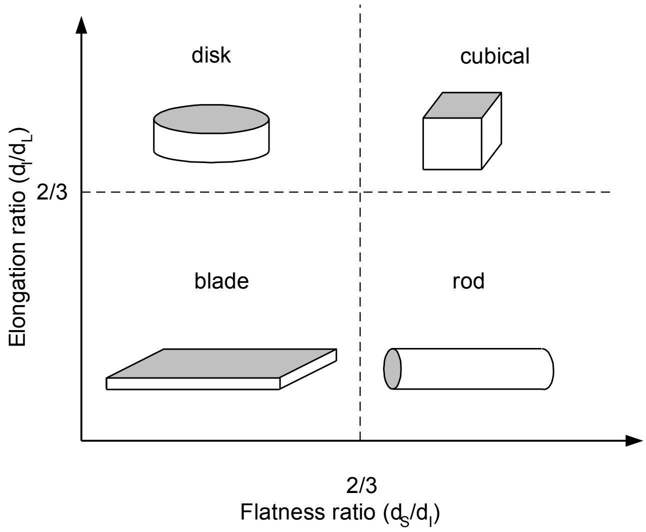

Fig. 1. Classification of Aggregate Shapes.

Image Measurements of Coarse Aggregate

Image analysis techniques were used in this study to characterize the morphological characteristics of coarse aggregate particles. The system consists of two major assemblies – a microscope with a scanner, and a rack of modules – basic, display, control, and measurement. The device, called Optimas image analyzer, is versatile software capable of providing full measurements of coarse aggregate. Aggregate particles were attached to adhesive clear plastic trays with two perpendicular faces; then, the sample tray was rotated 90 to establish two orthogonal planes of measurement. Particles were placed on a light box that illuminated the sample and made definite contact between aggregate and background. The parameters of length, width, and thickness were obtained by measuring the two orthogonal planes. These parameters provided a direct method for determining the flatness and the elongation ratios of the particles. Additionally, the image analysis method provided other shape indices that could be related to the effects of aggregates on the properties of a SMA mix. This image analysis method was more time-efficient than the ASTM Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate (D 4791). The imaging processing technique also provided more information.

Particle Index of Coarse Aggregate

The combined effects of particle shape and surface texture of an aggregate were determined in accordance with ASTM Test Method for Index of Aggregate Particle Shape and Texture (D 3398). The equipment required for this test consists basically of a cylindrical steel mold 152 mm (6 in.) in diameter by 178 mm (7 in.) high, and a steel rod 16 mm (5/8 in.) in diameter by 610 mm (24 in.) long with the tamping end rounded to a hemispherical tip. A clean, washed, oven-dried, single-size aggregate fraction was used for this test. The mold was filled in three equal layers, with each layer compacted with 10 well-distributed blows of the tamping rod. Each tamp consisted of a drop with the tamping rod from 51 mm (2 in.) above the surface of the layer being compacted. This procedure was repeated using the same material but applying 50 blows on each of the three layers. The weight of the contents of the mold in each case was determined and the corresponding percentage of voids was calculated using the bulk specific gravity of each aggregate fraction. The particle index (PI) is derived using the following equation:

$$PI = 1.25V_{10} - 0.25V_{50} - 32 \quad (1)$$

where,
V_{10} = percent voids in the aggregate compacted with 10 blows per layer;
V_{50} = percent voids in the aggregate compacted with 50 blows per layer.

Mixture Design

Mixture designs were performed using the Marshall method by preparing and compacting samples with asphalt content varied in 0.5% increments according to ASTM Test Method for Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus (D 1559). Grade AC-20 asphalt binder from the Chinese Petroleum Corporation was used in this study. Specimens were compacted with 50 blows on each side. Three samples were made for each asphalt content. Approximately 0.3% cellulose fiber was added to the SMA mixture to prevent draining down. The optimum asphalt content was chosen as the asphalt content that produced 4% air voids. Further, two types of void were calculated for the compacted samples: the void in mineral aggregate (VMA), and the void space in coarse aggregate (VCA). The VCA's were calculated in a way similar to the VMA's by replacing percent of aggregate in the mix with percent of coarse aggregate in the calculation. The equations used for calculating VMA and VCA are as follows:

$$VMA = 1 - \frac{V_{agg}}{V_T} \quad (2)$$

$$VCA = 1 - \frac{V_{ca}}{V_T} \quad (3)$$

where,
V_{agg} = volume of aggregate,
V_T = total volume of compacted mixture,
V_{ca} = volume of coarse aggregate

Indirect Tension Test

The resilient modulus and the indirect tensile strength of SMA are used often to evaluate the relative quality of materials. The repeated-load indirect tension test for determining the resilient modulus was conducted by applying compressive loads with a haversine waveform according to ASTM Test Method for Indirect Tension Test for Resilient Modulus of Bituminous Mixtures (D 4123). The load was applied vertically in the vertical diameter plane of a cylindrical specimen of asphalt concrete through a curved loading strip. The resulting horizontal deformation was measured and used to calculate the total resilient modulus (Mr) as follows:

$$M_r = \frac{P \cdot (\nu + 0.27)}{t \cdot H} \quad (4)$$

where
P = repeated load,
ν = Poisson's ratio,
t = thickness of specimen,
H = total recoverable horizontal deformation.

Poisson's ratio was calculated using the measured recoverable vertical and horizontal deformation. The tensile strength (ST) is calculated as follows:

$$S_T = \frac{1.96 \cdot P_{ult}}{\pi \cdot t \cdot D} \quad (5)$$

where
P_{ult} = ultimate applied load required to cause to the specimen to fail,
t = thickness of specimen,
D = diameter of specimen.

Wheel-Tracking Test

A wheel-tracking test was performed to evaluate the susceptibility of a mixture to permanent deformation. This equipment is similar to the Hamburg Wheel-Tracking Device. Mixture samples of different binders were carefully controlled to have the same binder content, air void content, gradation, and aggregate type. The test was conducted at the mean highest weekly average temperature, which was set at temperature 60 C under dry conditions. A smooth solid-steel wheel traveling at a speed of 1.4 km/h was used to correlate with rutting. Rut depths were measured every 200 wheel passes on 300 mm x 300 mm x 70 mm samples.

Results and Discussion

Particle Shape Analysis

Particle shape analysis was carried out in terms of elongation ratio, flatness ratio, shape factor, and sphericity using an image analyzer. The mean value for each aggregate size is listed in Table 2. The results show that there exist distinct morphological characteristics for different particle shapes. The differentiation of different aggregate shapes agrees well with the definition in Fig. 1 according to flatness and elongation ratios. For cubical particles, the flatness ratio is 0.80 and elongation 0.81, and both values are larger than 2/3. Note that, in cubical limestone, particles in the size range 25 to 19 mm are the most spherical, and those in the size range 9.5 to 4.75 mm are relatively flat and elongated. The dense gradation appears to be the combination of four different shapes since both ratios approach 2/3. Data in Table 2 indicate that the higher the shape

Table 2. Coarse Aggregate Shape Characteristics.

Shape	Size (mm)	d_L (mm)	d_I (mm)	d_S (mm)	Elong.[1]	Flat.[2]	Shape[3]	Spher.[4]
Cubical	25-19	23.38	19.77	17.90	0.85	0.91	0.83	0.87
	19-12.5	18.45	15.83	11.29	0.86	0.71	0.66	0.81
	12.7-9.5	14.35	11.77	9.99	0.82	0.85	0.77	0.83
	9.5-4.75	9.73	8.05	6.67	0.83	0.83	0.75	0.83
Avg.					0.84	0.82	0.75	0.83
Rod	25-19	30.23	16.60	15.44	0.55	0.93	0.69	0.65
	19-12.5	27.45	14.76	12.28	0.54	0.83	0.61	0.62
	12.7-9.5	19.44	11.09	8.93	0.57	0.80	0.61	0.64
	9.5-4.75	14.66	9.11	8.12	0.62	0.89	0.70	0.70
Avg.					0.55	0.86	0.64	0.64
Disk	25-19	25.36	23.75	14.82	0.94	0.62	0.60	0.82
	19-12.5	21.49	17.99	10.69	0.84	0.59	0.54	0.75
	12.7-9.5	16.15	13.37	8.26	0.83	0.62	0.56	0.75
	9.5-4.75	11.33	9.08	5.97	0.80	0.66	0.59	0.75
Avg.					0.87	0.61	0.57	0.77
Blade	25-19	38.06	22.99	15.01	0.60	0.65	0.51	0.62
	19-12.5	30.02	17.75	11.92	0.59	0.67	0.52	0.62
	12.7-9.5	21.47	13.63	6.27	0.64	0.46	0.37	0.57
	9.5-4.75	16.38	8.31	3.82	0.51	0.46	0.33	0.49
Avg.					0.61	0.59	0.46	0.60
Dense	25-19	30.84	23.05	13.93	0.75	0.60	0.52	0.70
	19-12.5	28.42	18.11	11.42	0.64	0.63	0.50	0.63
	12.7-9.5	18.81	12.11	6.76	0.64	0.56	0.45	0.61
	9.5-4.75	10.41	6.38	4.95	0.61	0.78	0.61	0.66
Avg.					0.68	0.60	0.49	0.65

1: Elongation ratio = d_I / d_L 2: Flatness ratio = d_S / d_I

3: Shape factor = $d_S / \sqrt{d_I \cdot d_L}$ 4: Sphericity = $\sqrt[3]{d_S \cdot d_I / d_L^2}$

factor, the more nearly cubical the aggregate. For aggregate used in pavement construction, the shape factor is generally between 0.3 and 0.8. Aggregate used in this study falls within this range. The sphericity value represents the roundness of an aggregate regardless of its thickness. Cubical particles possess a higher sphericity value than do the others. The typical sphericity value is between 0.5 and 0.9, which corresponds well with the description of each aggregate shape.

Particle Index (PI)

The particle index of an aggregate containing several sizes is weighted on the basis of the percentage of the factions in the original grading of the aggregate. Table 3 lists the procedure to calculate the PI value for each aggregate shape. The weighted value is the product of the aggregate grading times the corresponding particle index of each size group. The PI is the summation of the weighted values, which are 17.0, 15.8, 14.8, 12.7, and 15.2 for cubical, rod, disk, blade, and dense aggregate, respectively. A higher PI value implies that the particle shape is closer to cubical. The flat and elongated aggregate is associated with a lower PI. For the dense gradation conventionally used, the PI value is 15.2.

Four aggregate characteristics (elongation ratio, flatness ratio, shape factor, and sphericity) in Table 2 were correlated with the particle index. The relationship between predicted PI and measured PI is shown in Fig. 2. Aggregate composed of flat and elongated particles may have a low particle index of 10 or less, while aggregate consisting of highly cubical particles can have a particle index of 18 or more. The coefficient of determination (R^2) is 0.85, indicating that there exists a strong correlation between measured PI and the PI calculated using the aggregate geometric characteristics. The calculation of the PI value is presented in equation (1).

Marshall Design Values

The Marshall test is a routine test that enables one to determine strength indexes such as stability and flow for the design of a SMA mixture. Other mixture design criteria such as asphalt content and air void content are also obtained from this test. Table 4 lists the mixture characteristics of different aggregate shapes. Statistical analysis with the significance level $\alpha = 0.05$ for flow and asphalt content shows no statistically significant differences among the mixes in Table 4. The p-value is the probability of obtaining a test statistic at least as extreme as the one that was actually observed. These results give an indication that these properties of the mixes made of different particle shapes are equal. A p-value less than 0.05, however, indicates statistical significance in which the aggregate shape affects the behavior of a SMA mix. SMA mixtures containing

Table 3. Particle Index (PI) for Various Aggregate Shapes.

Shape	Size (mm)	Retained (%)	PI For each Size	Weighted PI
Block	25-19	12.5	17.9	2.2
	19-12.7	58.9	18.0	10.6
	12.7-9.5	10.9	17.1	1.9
	9.5-4.75	18.7	16.7	3.1
Sum		100.0		17.8
Rod	25-19	10.2	16.2	1.7
	19-12.7	59.1	16.0	9.5
	12.7-9.5	11.6	16.0	1.8
	9.5-4.75	19.1	16.8	3.2
Sum		100.0		16.2
Disk	25-19	10.8	14.3	1.5
	19-12.7	59.7	15.1	9.0
	12.7-9.5	10.9	14.5	1.6
	9.5-4.75	19.5	13.6	2.7
Sum		100.0		14.8
Blade	25-19	10.9	12.8	1.4
	19-12.7	59.8	11.7	7.0
	12.7-9.5	10.3	12.1	1.2
	9.5-4.75	19.0	11.9	2.3
Sum		100.0		11.9
Dense	25-19	23.7	17.8	4.2
	19-12.7	23.7	15.9	3.8
	12.7-9.5	22.6	15.4	3.5
	9.5-4.75	30.0	13.6	4.1
sum		100.0		15.5

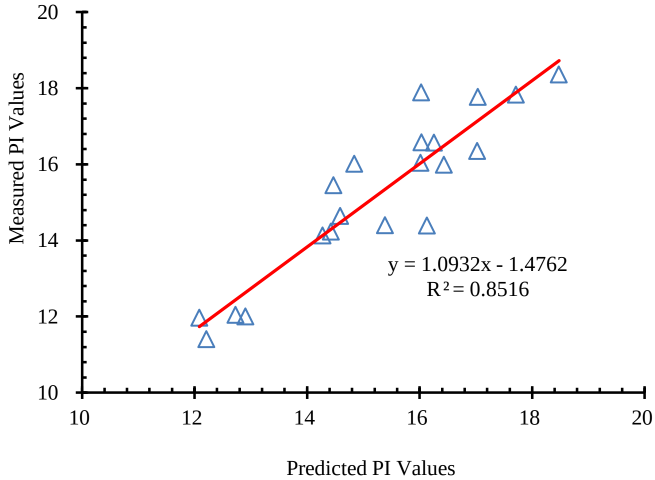

Fig. 2. Measured PI versus Predicted PI.

Table 4. Marshal Mix Design Properties for SMA Mixtures.

	Blade	Disk	Rod	Cubical	Dense	*p*-value
Stability (kN)	7.6	7.8	9.7	11.2	8.6	0.003
Flow (0.25 mm)	15.0	15.1	14.4	13.3	15.2	0.663
Asphalt Content (%)	6.8	6.7	6.6	6.9	6.0	0.295
VMA (%)	18.9	19.0	18.1	17.5	14.1	0.005
VCA (%)	17.3	16.7	16.1	16.3	12.5	0.024

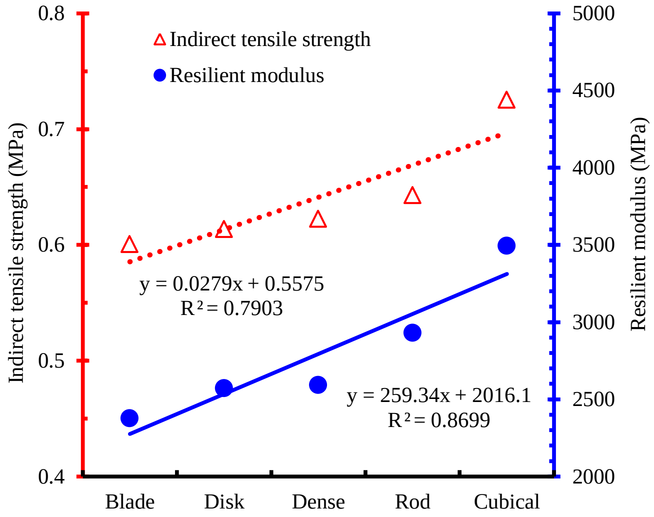

Fig. 3. Indirect Tensile Strength and Resilient Modulus of SAM Mixtures by Different Aggregate Shapes.

flaky aggregate have a significantly higher void percentage than similar mixtures containing cubical aggregate. Flaky particles produce a lower Marshall stability. This implies that blade and disk aggregates have low compatibility, thus contributing to lower stability values.

Indirect Tensile Test and Resilient Modulus

Conventionally, the indirect tensile test and resilient modulus test are conducted to indicate the internal resistance in a mix. Mixes were prepared to observe the effect of aggregate shape on the strength of the mixes. Fig. 3 shows the test results for different aggregate shapes. The resilient modulus is observed to increase with increasing PI value. A similar trend was also observed for indirect tensile strength. Coarse aggregate with lower PI provides lower stiffness than one with higher PI. Blade and disk particles impede compaction and thus may prevent the development of satisfactory properties in SMA. In compacted mixtures, cubical particles exhibit interlock and internal friction, and hence result in greater mechanical stability than do flat, thin, and/or elongated particles. The PI value is a quantitative measure of the aggregate shape that influences the characteristics of SMA mixtures. Test method ASTM D 3398 provides an adequate index to indicate the effects of the aggregate shape on the engineering properties of a SMA mix.

Rutting Resistance

Fig. 4 shows the results obtained from the wheel-tracking test for different aggregate shapes. Mixtures with cubical aggregate clearly show better rutting resistance than do the others. As aggregate shape becomes cubical, the internal resistance appears to initiate at an early stage, i.e., around 300 s after loading. When cubical coarse aggregates make contact, stone-on-stone interlocking inside the SMA mix takes place. Conversely, the skeleton of elongated and/or flaky aggregate remains relatively unstable. Note that flat and elongated particles are more difficult to compact, tend to produce higher void contents and, therefore, may result in a weak aggregate structure.

Stone-on-stone contact for the blade aggregate is shown to begin at much later time. The results shown in Fig. 4 validate the internal resistance as discussed in Fig. 3. As the shape of coarse aggregate changes to be more cubical, the internal resistance increases and the SMA mix improves its capability of carrying traffic load. The cubical particles possess the highest rutting resistance, following by rod, dense, disk, and blade particles. It appears that a SMA mix can be made more stable and resistant to rutting by specifying the coarse aggregate shape, i.e., by specifying the flatness ratio, the elongation ratio, and the aggregate angularity.

Samples after the wheel-tracking test were studied to determine if their gradations changed with the application of traffic loading. Fig. 5 shows a higher breaking percentage in SMA mixes containing the blade aggregate than the cubical aggregate. This breakage favors the formation of voids free of asphalt binder and fines, which causes the specimen to weaken. It is shown in Fig. 5 that blade particles increase the breakage percentages between sieve sizes 12.5 mm and 4.75 mm (#4 sieve). Flat particles, thin particles, or long, needle-shaped particles break more easily than do cubical particles. The degradation of flaky aggregate also leads to poorer mechanical properties.

Aggregate Orientation

Utilizing the image processing technique makes it possible to observe the internal resistance in a SMA mix during the wheel-tracking test. A cross-section is cut and the rotation change of coarse aggregates examined after loading is applied. Images of cross sections are taken and analyzed before and after testing.

The rest angle is measured to examine how the internal resistance develops in a mix. The angle between the long axis of a coarse aggregate particle and the horizontal line is defined as the rest angle. Figs. 6 and 7 illustrate the change in rest angle before and after the wheel-tracking test for cubical and blade aggregates, respectively. The rest angle is divided into three groups: 0° to 30°, 31° to 60°, and 61° to 90°, representing the degree of coarse aggregates settling down in a mix. A higher portion of 0° to 30° rest angles indicates a stable mix in which internal resistance is ready to mobilize once external loading is applied, whereas the 61° to 90° range is a sign of an unstable condition. The intermediate range of 31° to 60° is a transition area either from unstable to stable conditions or vice versa.

Mixtures with cubical particles show more stable rest angles (0° to 30°) than do blade ones. Especially after the test, the former mix becomes more stable with more than 56% of coarse aggregates settling within the 0° to 30° range, whereas the latter one results in the reduction of stable rest angles. Fig. 6 shows that the cubical particles are in greater contact with each other, a sign of developing internal resistance to rutting. The transition range 31°-60° significantly increases for mixtures with blade particles. The decrease in 0° to 30° and the increase in 31° to 60° rest angles may lead to an unstable skeleton inside mixtures with blade particles. Image evaluation of aggregate rotation is in good agreement with previous results on the determination of internal resistance.

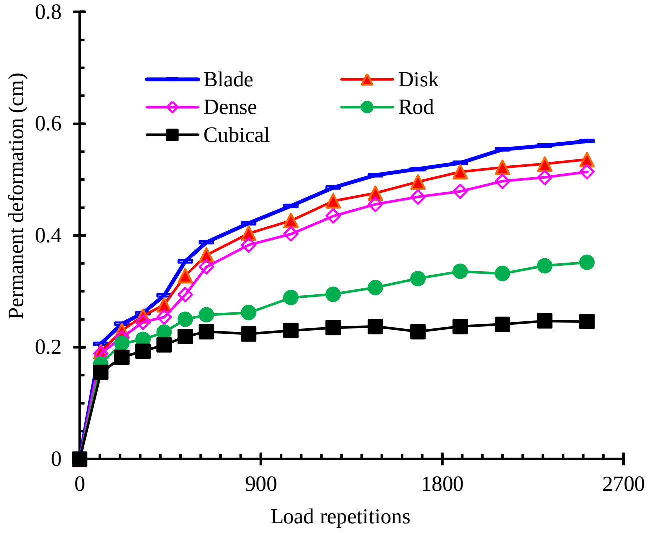

Fig. 4. Permanent Deformation Curves of SMA Mixtures.

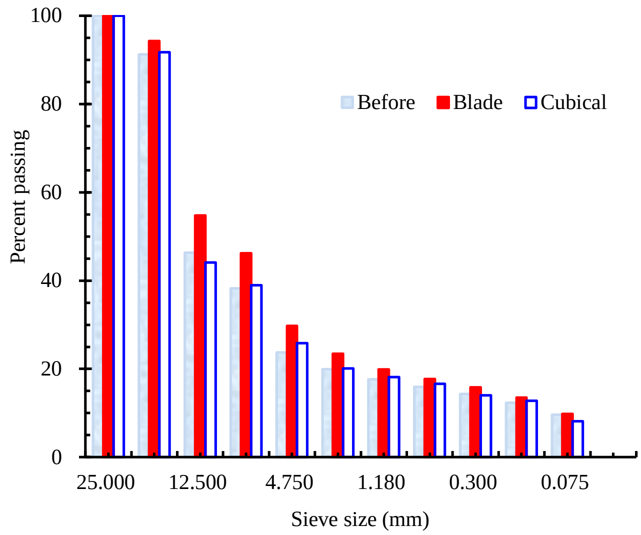

Fig. 5. Aggregate Gradations Before and After Wheel-tracking Test

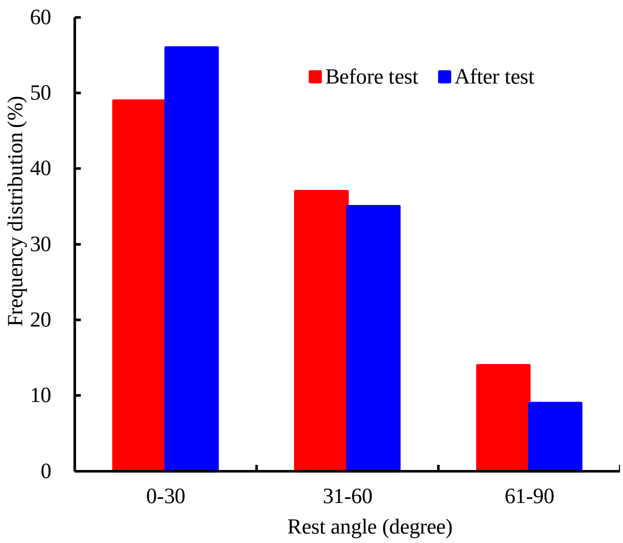

Fig. 6. Angle Distribution for SMA with Cubical Aggregate.

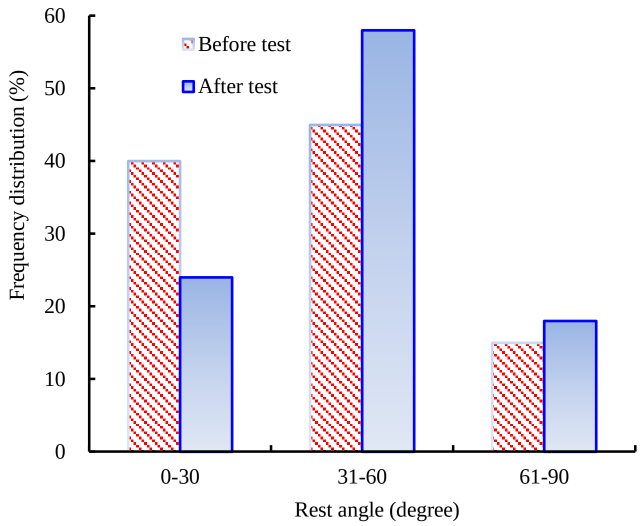

Fig. 7. Angle Distribution for SMA with Blade Aggregate.

Conclusions

A study was conducted to evaluate the potential of stone mastic asphalt for use as a surface course on airfield pavements. This paper is aimed at quantifying coarse aggregate shape in an efficient manner and relating aggregate characteristics to the engineering properties of SMA. Digital image analysis was used to evaluate aggregate characteristics such as elongation, flatness, and other shape indices. The following particle shapes were selected for this study: cubical, rod, disk, and blade. Data showed that the geometric characteristics of coarse aggregate correlated well with the results of other indirect tests such as the particle index. Cubical particles possessed the best rutting resistance over the other aggregate shapes for SMA mixtures. Flaky and/or elongated aggregate in a mixture resulted in a lower resistance to shear deformation. The morphological characteristics of coarse aggregates found from image analysis were in good agreement with the engineering properties of SMA. The particle index (PI) was shown to be an adequate measure of the combined contribution of particle shape, angularity, and surface texture to the stability of an aggregate. The PI value correlated well to aggregate geometric characteristics including elongation ratio, flatness ratio, shape factor, and sphericity. Based on the results of this study, SMA would offer good rutting performance, and improved resistance to cracking and moisture damage for airport pavements when the engineering properties of coarse aggregate are well controlled.

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