



Effects of Compactor Types on Aggregate Orientation of Asphalt Mixtures

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PAPER INFO

Paper history:

Received 28 December 2012

Received in revised form 08 February 2013

Accepted 28 February 2013

Keywords:

Digital Image Processing

Aggregate Orientation

Geometrically Cubical Shape Aggregate

ABSTRACT

More than 90% of Malaysian roads are constructed using asphaltic concrete. However, previous investigations of asphaltic concrete have mainly concentrated on the macroscopic properties of the composite materials based on the assumption that the mixtures are homogeneous and isotropic. This paper applies a digital image processing technique to compare the orientations of coarse aggregate particles in asphaltic concrete compacted using Marshall, Servopac and Presbox compactors. Aggregate orientation was measured in terms of a vector magnitude and the average major axis angle. The average major axis angle of all compactors are less than 45° indicating that aggregate orientation in all of the prepared specimens have the preferential orientation along the horizontal plane. The vector magnitude results of the Presbox compacted sample is the least, indicating the presence of the most randomly oriented aggregate. However, the Servopac specimens have more randomly oriented aggregate compared to Marshall specimens. An ANOVA analysis for vector magnitude indicates that only compaction method, not Geometrically Cubical Shaped (GCS) proportion, has a significant impact on aggregate orientation randomness.

doi: 10.5829/idosi.ije.2013.26.07a.01

1. INTRODUCTION

More than 90% of Malaysian roads are constructed using asphaltic concrete. However, previous investigations of asphaltic concrete have mainly concentrated on the macroscopic properties of the composite materials based on the assumption that the mixtures are homogeneous and isotropic. Some studies have used digital image technique to analyze the microstructure of engineering materials. Asphalt, air voids and aggregate can be distinguished and identified by image processing based on their different colors. Masad et al. and Wang et al. [1, 2] have used 3-dimension computed tomography (CT) and 2-dimension image processing technique to analyze air voids and asphalt mixtures' microstructure.

The inherent anisotropy of asphaltic concrete was quantified by using the inclination angles of the coarse aggregate particles and fine aggregates in the asphaltic concrete [3]. The contribution to the inherent anisotropy of each aggregate may not be the same but depends on the size, orientation, and sphericity of the aggregate

particle. Hence, aggregate characteristics such as angularity, flakiness and elongation indexes significantly influence the performance of asphaltic concrete. The presence of flaky and elongated aggregates in large proportion might reduce the fracture toughness of the asphaltic concrete since these aggregates are prone to break during mixing, construction and while in-service.

However, Geometrically Cubical Shaped (GCS) aggregate could lead to better aggregate interlocking than normal shape aggregates. The proper bonding between the adjacent spaces ensures better pavement performance but it is not always achieved due to poor interlocking of the normal shape aggregates. The use of GCS aggregate can improve the strength of the road as it is not easily breakable when exposed to continuous compressive loading [3].

Yue and Morin [4] applied an innovative digital image processing technique to quantify the orientations of coarse aggregate particles (> 2 mm) in asphaltic concrete. Digital image processing is the term used to convert video images into digital form, and applying various mathematical procedures to extract significant information from the picture. Digital image processing

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has been applied by examining statistically the differences between the aggregate particles on horizontal and vertical cross sections of asphaltic concrete. The image editing software, named Picture Publisher (v.4.0) and image analysis statistics software, named MOCHA, have been used in digital image processing.

Kutay et al. [5] applied new 3D image processing and analysis methodologies to quantify the internal structure of asphalt mixtures using their X-ray Computed Tomography (CT) images. These techniques are crucial for proper utilization of X-ray CT for understanding the difference between the various compaction methods as well as to assess the relationship between laboratory and field compaction. The used X-ray CT device included a 420 keV continuous X-ray source and a linear array detector of 512 channels. The minimum aggregate size that can be measured using the X-ray CT technique is highly dependent on the spatial resolution of the images.

This paper presents the results from the 2-dimension digital image that was scanned from the surface of the hot-mix asphalt in an attempt to present the microstructure of hot-mix asphalt. The main objective of this study is to compare the aggregate orientation of asphalt specimens prepared by the Marshall, Servopac and Presbox compactors.

2. MATERIALS AND MIX GRADATION

Normal shaped aggregates and GCS aggregates were used in this study. In the laboratory, the GCS aggregate was crushed using a Barmac rock-on-rock vertical shaft impactor crusher marketed by Metso. The aggregates were crushed by means of impact, cleavage, attrition and abrasion. The crushing work allowed the aggregates to crush itself rather than relying on breaker bars, hammers or cones. There are four basic ways to obtain processed aggregate including impact, cleavage, attrition and abrasion. Fracture took place along the rock's natural grain, producing the characteristic cubical shape and surface texture. The physical properties of the coarse aggregates affect significantly the properties of the asphaltic concrete. The homogeneity of the mixture is better if the roughness of the aggregates' surfaces is greater in the binding mechanism. The aggregates produced were geometrically cubical in shape and this can be seen from the aggregate flakiness and elongation indices shown in Table 1.

A conventional bitumen grade 80/100 supplied by PETRONAS was used as a binder for the specimens. The filler used in this study was hydrated lime.

The aggregate gradation used conformed the particle size distribution given in the Malaysian Public Works Department for mix type AC14 [6]. The median gradation served as the target gradation as shown in

Figure 1. The used binder contents were 5.3, 5.2, 5.1, 5.0, 4.9% for 0, 25, 50, 75 and 100% of GCS aggregate, respectively. The test parameters are shown in Table 2. Table 3 shows the proportion of aggregate and the binder contents used in this study.

TABLE 1. Aggregate properties

Property	Type of Aggregate Shape	
	GCS	Normal
Flakiness Index (%)	6.0	21.3
Elongation Index (%)	10.1	23.7
Aggregate Crushing Value, ACV (%)	16.2	20.4
Aggregate Impact Value, AIV (%)	17.4	20.5

TABLE 2. Test parameters

Test Parameters	Data
Geometrically Cubical Aggregate	0, 25, 50, 75 and 100%
Compactors	Marshall, Servopac and Presbox

TABLE 3. Proportion of aggregate and binders contents

Proportion of Aggregates (%)		Used Binder Content (%)
Normal	GCS	
100	0	5.3
75	25	5.2
50	50	5.1
25	75	5.0
0	100	4.9

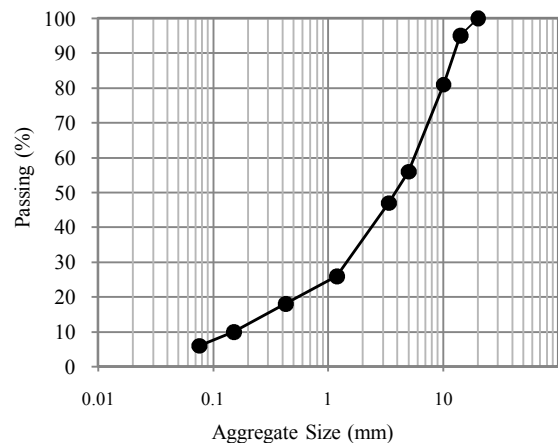


Figure 1. Aggregate gradation

3. DIGITAL IMAGE AND EXPERIMENTAL PROCEDURES

According to the procedure stated by Lv et al. [7], the aggregate orientation test was conducted using digital image processing and analysis. Specimens compacted by the Marshall Hammer, Servopac and Presbox compactors were used for aggregate orientation test. A total of 20 specimens were produced from the Marshall hammer and Servopac machine with two replicates for all five GCS aggregate content. However, there were only two specimens prepared using the Presbox machine. The specimens represent 0 and 100% GCS aggregates each weighing 25 kg.

Laboratory prepared specimens produced from the Marshall and Servopac compactor had a diameter of 100 mm. The specimens were cut vertically into two halves as shown in Figure 2. The beams were cut vertically into 4 and horizontally into 2 as shown in Figure 3. The distance between the new cut section and the previous cut section cannot be less than 50 mm. The image of the cut cross section was scanned using a scanning machine. The photographs were converted into digital files for analysis. The major axis of the aggregates were then determined. Each measurement was labeled. Figure 4 shows a typical example of scanned image of a sliced HMA.

The particle orientation was measured as the angle between the major axis of the particle and the horizontal line. This is termed as the major axis angle. The major axis was defined as the longest distance between two points in the particle as shown in Figure 5. The major axis angle was measured manually using a protractor.

The orientation was measured by a vector magnitude (Δ) and the average major axis angle (θ). The vector magnitude varied between 0 and 100%. Complete random distribution of the orientation would give a 0% vector magnitude. A 100% vector magnitude implies that all observed orientation have the same direction. The vector magnitude and average major axis angle were calculated using Equations (1) and (2), respectively [7]:

$$\Delta = \frac{100}{N} \sqrt{(\sum \sin 2\theta_k)^2 + (\sum \cos 2\theta_k)^2} \tag{1}$$

$$\theta = \frac{\sum |\theta_k|}{N} \tag{2}$$

where θ is the average of major axis angle, θ_k is the major axis angle of a particle, and N is the number of particles in an image.

4. RESULTS AND DISCUSSION

4. 1. Consistency of Compactors The average major axis angles of two replicate cylindrical specimens produced by Marshall and Servopac compactors are

tabulated in Table 4. The major axis angles observed are generally consistent between the two specimens for Marshall and Servopac compactors. This can be observed by the small difference between the two replicate specimens. This indicates that the Marshall and Servopac compactor produce consistent replicate specimens.

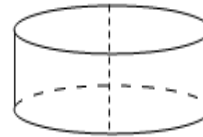


Figure 2. Marshall and Servopac specimens

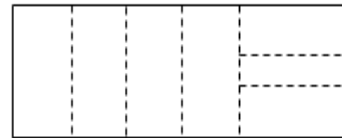


Figure 3. Presbox specimens

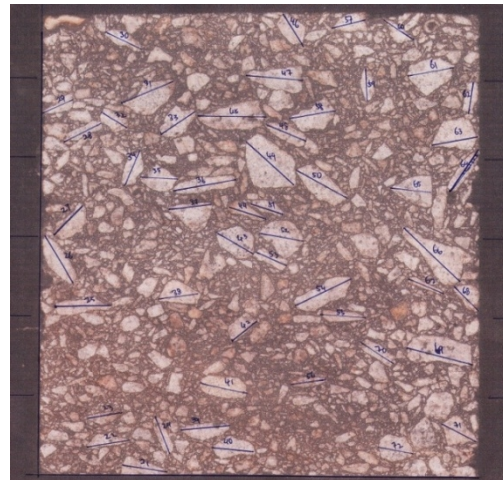


Figure 4. Example of scanned image of HMA

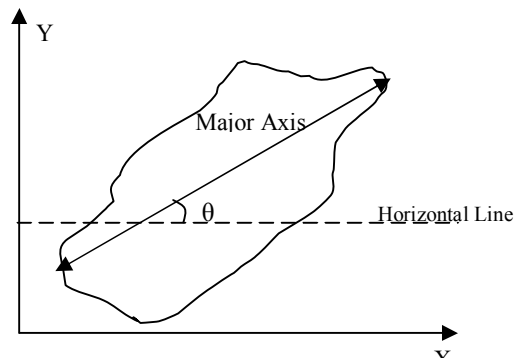


Figure 5. Geometric definition of an aggregate cross section

The average major axis angle for Presbox specimens are shown in Table 5. The average major axis angle for 0 and 100% GCS aggregate vary from 27.9° to 32.7° and 29.5° to 33.1°, respectively. The variations are quite small considering that the specimen weighs 25 kg each. This indicates that the Presbox machine also produces consistent aggregate orientation distribution throughout the specimen.

TABLE 4. Average major axis angles for cylindrical specimens

GCS (%)	Average Major Axis Angles (°)					
	Marshall			Servopac		
	S1	S2	Difference	S1	S2	Difference
0	30.2	32.4	2.2	34.4	28.3	6.1
25	32.6	31.3	1.3	32.4	35.9	3.5
50	37.4	35.5	1.9	29.4	33.1	3.7
75	41.4	35.8	5.6	32.3	34.5	2.2
100	40.5	33.0	7.5	31.5	42.0	10.5

TABLE 5. Aggregate major axis angles for Presbox compactor

Average Major Axis Angles (°)	GCS (%)			
	0	Average	100	Average
H1	32.4	27.9	34.8	32.7
H2	23.4		30.5	
V1	24.6	29.5	27.8	33.1
V2	28.2		32.3	
V3	33.6		39.3	
V4	31.5		32.9	

4. 2. Effects of Geometrically Cubical Shape Aggregate on Aggregate Orientation

The effects of GCS aggregate on aggregate orientation were evaluated for both Marshall and Servopac compactors. The test results are shown in Figure 6. The results imply that there is no clear trend that how the CGS aggregate content affects the aggregate orientation. Similar pattern is found in Servopac specimens shown in Figure 7. The experimental data from Marshall specimens range from 10.2° to 32.9° as indicated by the hatched area. The Servopac data were found to range from 9.4° to 21.3°. Further investigation should be carried out to improve fundamental understanding on the relationship between GCS aggregate content and aggregate orientation.

The influence of the GCS aggregate content on the aggregate structure was also investigated by measuring the change in aggregate orientation as shown in Figure

8. It is evident that the vector magnitude changes as the GCS aggregate content changes. The changes are larger for Marshall specimens. An increase in GCS aggregate content causes more changes in the vector magnitude but the pattern is different for all three compactors. The Presbox compactor experience a negative change in vector magnitude indicating that the aggregate orientation becomes more random when 100% GCS aggregate was incorporated.

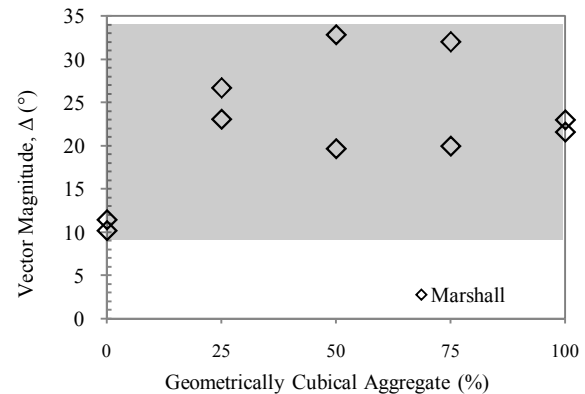


Figure 6. Vector magnitude of Marshall specimen

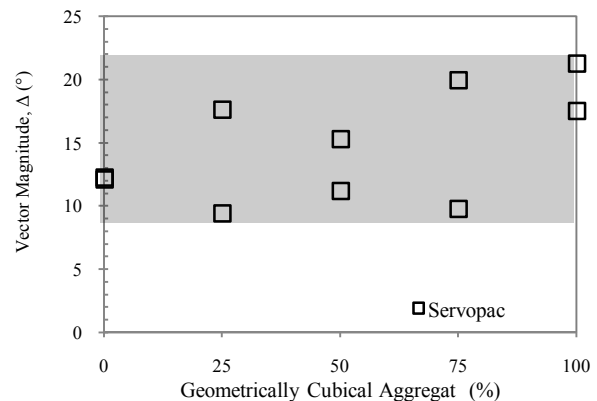


Figure 7. Vector magnitude of Servopac specimen

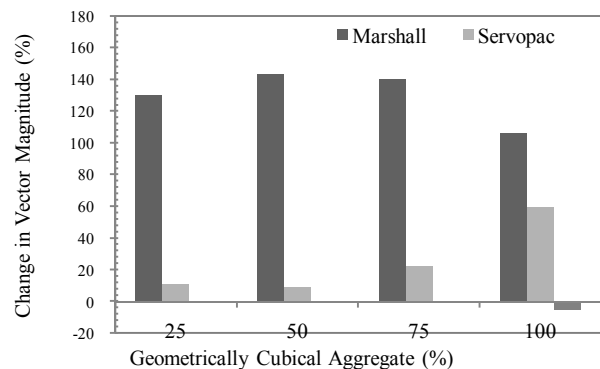


Figure 8. Change in vector magnitude

4. 3. Effects of Compactor Type on Aggregate Orientation

The average major axis angle (θ) and vector magnitude (Δ) of specimens from the Marshall, Servopac and Presbox compactors are shown in Figures 9 and 10. The result shows that the angle inclination of Marshall, Servopac and Presbox are less than 45° . These indicate that particles orientation in all of the prepared specimens tend to be on the horizontal plane. Zhang [3] also indicated that the aggregates in an asphalt mixture have the preferential orientation along the horizontal direction. In general, the vector magnitude is consistently smaller for Servopac specimens compared to Marshall specimens. This indicates that the Servopac specimens appear to have more randomly oriented aggregate compared to Marshall specimens. However, the Presbox specimen at both 0% and 100% GCS aggregate has the smallest vector magnitude. This indicates the most randomly oriented aggregate in the specimen. Yue and Morin [4] found in their study that the aggregate particles may be more randomly oriented in mixes compacted with Marshall compactor compared to gyratory compactor. From a study done by Lv et al. [7], different compaction methods affect the vector magnitude of aggregates in the specimen.

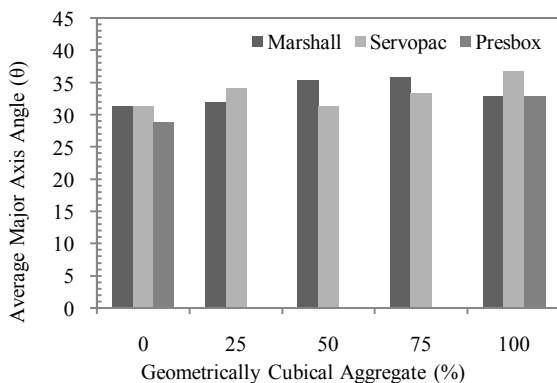


Figure 9. Average major axis angle for different compactors

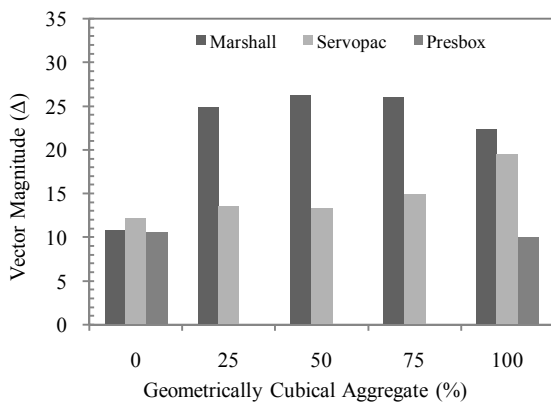


Figure 10. Vector magnitude for different compactors

The digital image processing results for Marshall, Servopac and Presbox specimens are illustrated in Figures 11 to 13. Segregation is visible in Presbox specimen. This may be due to the large amount of materials to be handled at once.

Further analyses are carried out using a two-way analysis of variance (ANOVA). Five GCS aggregate contents ranging from 0 to 100%, and compaction method between Marshall and Servopac compactor, at 95% confidence level were analyzed. The results for average major axis angle of the mixes are shown in Table 6. The p-value of more than 0.05 implies that the compaction method, GCS aggregate content and the interaction factor do not significantly affect the aggregate angles in the asphalt mix.



Figure 11. Vertically sliced Marshall hammer compacted specimen

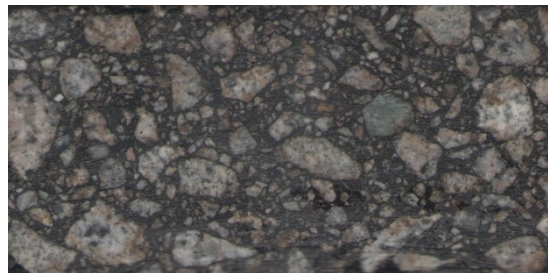


Figure 12. Vertically sliced Servopac compacted specimen



Figure 13. Vertically sliced Presbox compacted specimen

Table 7 shows the two-way ANOVA analysis for vector magnitude of asphalt mix. The results indicate that only compaction method has significant impact on aggregate orientation randomness. This is indicated by the p-value of less than 0.05. The GCS content does not seem to give any significant effect on the vector magnitude of dense asphalt. Furthermore, the interaction factor also indicates that the effect is not significant.

TABLE 6. Two-way ANOVA on aggregate average major axis angle of asphalt mix

Source	DF	SS	MS	F	P
Compaction Method	1	0.072	0.0720	0.00	0.950
GCS Content	4	32.103	8.0258	0.46	0.762
Interaction	4	42.853	10.7132	0.62	0.660
Error	10	173.600	17.3600		
Total	19	248.628			

TABLE 7. Two-way ANOVA on aggregate vector magnitude of asphalt mix

Source	DF	SS	MS	F	P
Compaction Method	1	272.485	272.485	10.14	0.010
GCS Content	4	241.475	60.369	2.25	0.136
Interaction	4	157.911	39.478	1.47	0.282
Error	10	268.615	26.861		
Total	19	940.485			

5. CONCLUSIONS

The orientation angles of specimens compacted using both Servopac and Presbox compactors are more randomly oriented compared to Marshall specimens. However, the Presbox specimens were found to have the most randomly oriented aggregate at 0% and 100% GCS aggregate content. The aggregate angles tend to be more on the horizontal plane for all three compaction methods. Segregation is obviously seen to occur in the Presbox specimens, but the aggregates are the most randomly oriented. Great care must be exercised during specimen compaction as it will affect the aggregate distribution. Segregation may occur if the asphalt pre-

compaction stage is not well managed. Nevertheless, the Presbox compactor is ranked highest in producing specimens with randomly oriented aggregates while the Marshall compactor is ranked last out of the three compactors. In future tests, it is recommended to carry out a study that shows the comparison between Marshall, Servopac and Presbox compactors with more test specimens. It is also recommended that the specimens should be cut vertically and horizontally to obtain a better understanding of the influence of compactor types on aggregate orientation.

6. ACKNOWLEDGEMENT

The authors would like to acknowledge the Malaysia Ministry of Higher Education that funded this research grant through the Fundamental Research Grant Scheme that enables this paper to be written. Many thanks also due to the technicians of the Highway Engineering Laboratory at the University Sains Malaysia for their help. Authors acknowledged PETRONAS and Kuad Quarry Sdn Bhd, Penang for the supply of bitumen and aggregate.

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Paper history:

Received 28 December 2012

Received in revised form 08 February 2013

Accepted 28 February 2013

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مخلوط آسفالتی یکی از عمده ترین مواد استفاده شده در راهسازی است که بیش از ۹۰٪ راه های مالزی را می پوشانند. از آنجا که در بررسی های گذشته مخلوط آسفالتی به صورت همگن و ایزوتروپیک فرض شده است، عمده تحقیقات تنها خواص ماکروسکوپی مواد تشکیل دهنده مخلوط آسفالتی را بررسی کرده اند. در این مقاله با استفاده از تکنیک پردازش تصویر دیجیتال، نحوه جهت گیری سنگدانه ها در نمونه های مخلوط آسفالتی تهیه شده در دستگاه های تراکم مخلوط آسفالتی مارشال، سروپک و پرس باکس بررسی و مقایسه شده است. جهت گیری سنگدانه از نظر اندازه بردار برآیند و متوسط زاویه محور اصلی محاسبه گردیده است. متوسط زاویه محور اصلی در تمامی دستگاه های تراکم کمتر از ۴۵ درجه بوده و این نشان می دهد که همه نمونه های تهیه شده دارای جهت گیری به سمت محور افقی می باشند. با توجه به تمامی نمونه های تهیه شده، نمونه های متراکم شده در دستگاه پرس باکس کمترین میزان اندازه بردار برآیند را داشتند و این نمایانگر بیشترین احتمال تصادفی جهت گیری سنگدانه ها در این دستگاه می باشد. درحالی که نتیجه حاصل از جهت گیری تصادفی سنگدانه ها در نمونه های تهیه شده در دستگاه سروپک میزان بیشتری را در مقایسه با جهت گیری تصادفی سنگدانه های نمونه های تهیه شده در دستگاه مارشال نشان می دهد. تجزیه و تحلیل آماری بر اساس روش آنالیز واریانس (ANOVA) برای اندازه بردار برآیند نشان می دهد که روش متراکم سازی عمده ترین تاثیر را در جهت گیری تصادفی سنگدانه ها دارد در صورتی که شکل هندسی و مکعبی سنگدانه ها تاثیر قابل توجهی ندارد.

doi: 10.5829/idosi.ije.2013.26.07a.01

