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Effect of Aggregate Shape on the Properties of AsphalticConcrete AC14

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Graphical abstract

Abstract

The objective of this study is to evaluate the effects of aggregate shape on volumetric properties of asphaltic concrete mixtures. The aggregate gradation of AC14 was prepared using granite aggregates crushed via compression and impact crushers. In this study, compression crusher was used to produce aggregates with flaky and elongated shape while the impact crusher was used to produce aggregates with a cubical shape. Modified bitumen, Styrene-Butadiene-Styrene (SBS) was used in preparing the specimens. The stability, density, voids in total mix, voids filled with bitumen, and voids in mineral aggregate of asphalt mixture specimens was investigated. In addition, the resilient modulus test with temperature of 25ºC and stiffness modulus test with temperature of 40ºC was carried out using the Universal Testing Machine in accordance with ASTM D4123 standard. The test results showed that the volumetric properties improved when cubical aggregate was introduced to the asphalt mixture. Moreover, the incorporation of geometrically cubical aggregates in asphalt mixture causes an increase in resilient and stiffness modulus compared to asphalt mixture prepared with irregularly aggregates.

Keywords: *Asphaltic concrete; geometrically; cubical; resilient modulus, stiffness modulus*

■1.0 INTRODUCTION

The road construction industry constitutes an important sector of the Malaysian economy and highly depends on the quarrying sector for its aggregates. Demand for raw materials especially aggregate for road construction industries keeps on increasing. The properties of aggregate are very important to the performance of hot mix asphalt pavements particularly the aggregate shape properties. The aggregate shape properties i.e. rounded and angularity and its texture, substantially affect the overall performance of the pavement [1, 2]. A number of research reported that cubical and surface texture of aggregates have significant effect on the mechanical properties of bituminous mixes such as shear resistance, durability, stiffness, fatigue resistance, rutting resistance, workability, bitumen demand etc. [3, 4, 5]. Hot mix asphalt (HMA) mixtures containing different aggregates types has been studied by Ishai and Gelber for Marshall stability and flow, resilient modulus, and split tension strength [6]. The results showed that there was a significant increase in the stability with the increase in the geometric irregularities of the aggregates. In view of these consequences, the effect of cubical aggregates in the hot mix asphalt needs to be further investigated for obtaining more information regarding this matter. Therefore, in this study, the volumetric properties of asphaltic concrete AC14 containing geometrically cubical aggregate were examined.

■2.0 MATERIALS AND EXPERIMENTAL PROCEDURES

2.1 Aggregate

Aggregates were classified based on their particle size. Three common groups were obtained, coarse aggregate, fine aggregates and fillers. In this study, the granite aggregates used were supplied by Yen BumiSdn. Bhd, Penang. In the quarry, these aggregates were crushed via cone crusher that imparted a compression mode of crushing. The mode of crushing produces aggregates that are more flaky and elongated. The same aggregates were then re-crushed through the use of a Vertical Shaft Impact (VSI) crusher, as shown in Figure 1, available in the laboratory of the School of Materials and Mineral Resources Engineering, UniversitiSains Malaysia [7]. The resultant aggregates are more cubical in shape and extensive works on characterization of aggregate shape via this impact mode of crushing has been carried out by Khairun et al [7]and Hamzah et al [3]. In this study, the gradation of the granite aggregates met the requirements for the Malaysian Public Works Department AC14 [8] as depicted in Figure 2. The median gradation was selected as the target gradation.

Figure 1 VSI crusher used to produce geometrically cubical aggregates

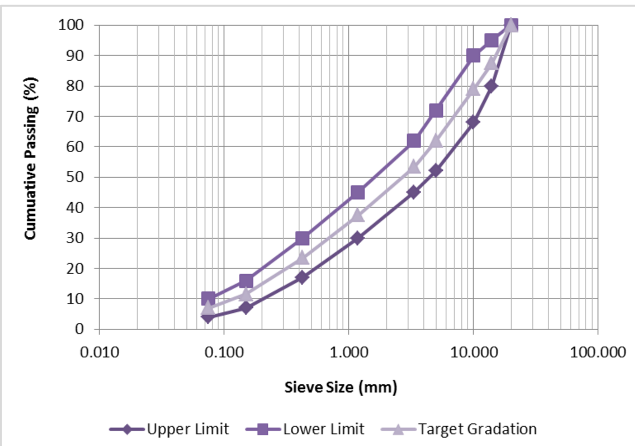

Figure 2 Plotted aggregate gradation for asphalt concrete (AC 14)

2.2 Bitumen

Throughout this investigation, base bitumen modified with styrene-butadiene-styrene (SBS) was used. The relative density value of modified SBS binder was 1.01. The bitumen was supplied by PPMS Technologies Sdn. Bhd.

2.3 Mix Design

The volumetric properties of asphaltic concrete AC14 was determined based on Marshall Mix design as outlined in JKR SPJ/1988 [8]. The procedure aimed at determining a number of parameters including stability, density, voids in total mix, voids filled with bitumen, and voids in mineral aggregate. An additional parameter, resilient modulus was incorporated. For this purpose, the specimens were prepared at binder contents ranging from 4.0 to 6.0% by weight in 0.50% increment. According to Samat [9], for the modified SBS mixtures, the mixing and compaction temperatures used were 180ºC and 165ºC respectively.The geometrically cubical aggregate mixed with styrene-butadiene-styrene modified bitumen was generally designated as CS whereas irregularly aggregate (contain flaky and elongated shape) as IS.

2.4 Marshall Stability Test

In the stability test, the specimens were prepared with the specified temperature by immersing in a water bath at a temperature of 60°C±1°C for a period of 45 minutes. It was then placed in the Marshall Stability testing machine and loaded at a constant rate of deformation of 50.8 mm/minute until the maximum load was reached [9]. The stability result was recorded on the Marshall testing machine in kN.

2.5 Resilient Modulus Test

The resilient modulus test can be a used to assess pavement mix response to traffic loading. The test was conducted by measuring the indirect tensile strength in repeated loading or pulse using Universal Material Testing Apparatus (UMATTA). Each specimen was tested at 25ºC after 4 hours conditioning, while the test procedures conformed to those stipulated in ASTM D4123 [10]. Initially, the samples were subjected to 5 condition pulses; beyond which a 1200N peak load was applied along the vertical diameter of the sample [11]. The pulse period and pulse width applied for this test were 3000ms and 100ms respectively with 50ms rise time.

2.6 Dynamic Creep Test

The dynamic creep test was developed to estimate the rutting potential of asphalt mixes. This test was conducted using the Asphalt Universal Testing Machine, MATTA in accordance with the procedures outlined in ASTM D4123 [10]. Actual dynamic creep test was conducted at 40°C, 1 hour loading time and 0.1MPa applied stress.

■3.0 RESULTS AND DISCUSSION

3.1 Volumetric Properties

3.1.1 Stability

From the experiment conducted, a quadratic shaped curve and a maximum point of stability can be identified from Figure 3. It can be observed that the stability of the specimens increases to maximum and then decrease with the increase in the bitumen content. Both asphalt mix concrete specimens that consist IS and CS are found to achieve the maximum stability of 15.8kN and 17.2kN at 4.8% and 4.6% bitumen content respectively. It is understood that as the value of stability increases, the specimen will be able to cater more loading imposed to it. Malaysia Public Works Department specification [8] recommends that, for a wearing course layer, the value of stability should be more than 5.0kN. Therefore, the values obtained for both mixture types satisfy the JKR Specifications. The use of cubical aggregates enhances the mixture stability as a result of good aggregate interlocks and internal friction which is the main source of stability compared to flaky and elongated aggregates (irregular shape) that is more susceptible to breaking. In addition, the results show that specimen with irregular aggregate shape needs more bitumen to achieve maximum stability compared to specimen with cubical aggregate shape. This is because aggregates with irregular shape have a relatively high surface area and more bitumen is required to coat the aggregate particles.

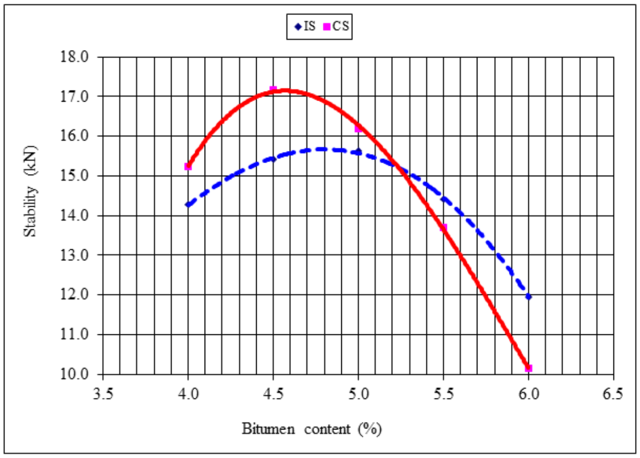

Figure 3 Stability against bitumen content

3.1.2 Density

Bulk specific gravity is one of the indicators that are used in determining the optimum bitumen content [12]. From Figure 4, the curve shows that the density increased until a maximum value and then decreases as the bitumen content increases. From the figure, it can be seen that mixture produced with irregular aggregate shape has lower density compared to the one with cubical shape. This could be affected by improper compaction due to less aggregate interlock within the IS mixture which determines the effectiveness of bitumen to fill up the voids between aggregate particles. This phenomenon will provide lower workability and tends to impede compaction.

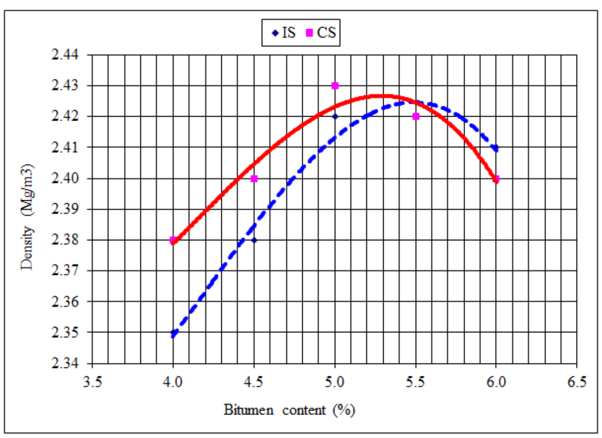

Figure 4 Density against bitumen content

3.1.3 Voids Total Mix (VTM)

Figure 5 shows the relationship between VTM and bitumen content. The percentage of air voids decrease exponentially with increasing bitumen content. At higher bitumen content, mixture produced with irregular aggregate shape (flaky and elongated) exhibits less air voids content compared to the one with cubical shape. During production and compaction, the flaky and elongated aggregates are able to break off which can cause an

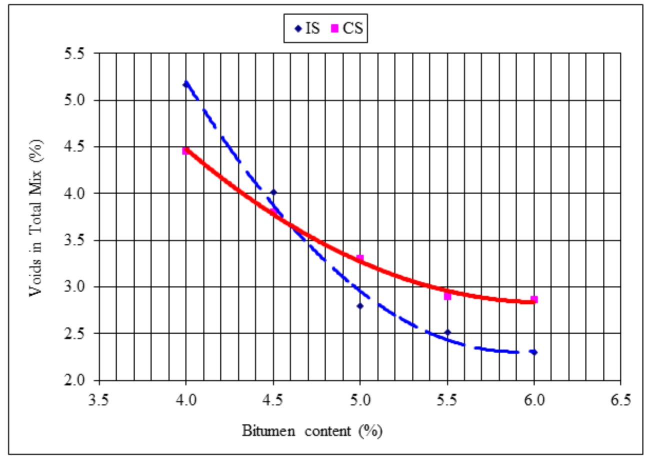

Figure 5 VTM against bitumen content

increase in fines and consequently lowering the air void content as the fines fill up the void. According to Malaysia Public Works Department specification [8], the percentage of air voids in asphalt concrete mixture is controlled between 3 and 5%. Therefore, based on the figure, it can be concluded that CS mixture gives least variation in the air void content compared to IS mixture.

3.1.4 Voids in Mineral Aggregate (VMA)

VMA is referred as the total volume of void space between the aggregate particles and the volume of effective asphalt (asphalt not absorbed into the aggregate). Figure 6 shows the relationship of VMA against bitumen content. Overall, voids in mineral aggregate decreases to a minimum value and then it increases with the addition of bitumen content. At the beginning, IS mixture tends to have higher air voids compared to CS mixture. This is because aggregate with a cubical shape is much easier to be compacted compared to the irregular shape which could create an improper aggregate interlock. However, with the increase in the bitumen content, the mixtures become more workable, and they can be compacted easily. As a result, the VMA for CS mixture begins to increase higher than IS mixture due to the greater aggregate displacement (aggregates are pushed apart by the bitumen). Whereas for IS mixture, the aggregate particles tend to break and the gradation might become finer, thus densify during compaction. This will reduce the void spaces and more bitumen is needed to coat the fines (due to the increase in the surface area) which ultimately lead to a reduction in VMA.

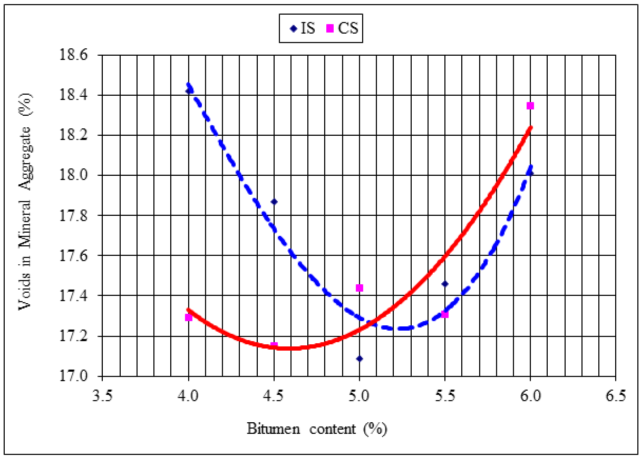

Figure 6 VMA against bitumen content

3.1.5 Voids Filled Bitumen (VFB)

VFB is referred to the void spaces that exist between the aggregate particles in the compacted mixture that are filled with bitumen. The relationship of VFB against bitumen content is shown in Figure 7. In general, the VFB increased with the increase of the bitumen content. Based on the figure, it can be seen that the IS mixture contains higher VFB than the CS mixture. The thicker film thickness observed for the IS mixture could be due to the less sharp edges and fractured faces of the aggregates used which reduced the absorbed bitumen compared to the one offered by the cubical aggregates. Malaysia Public Works Department specification [8] has recommended that the percentage of voids filled with bitumen must be controlled between 75 and 85%. Based on the result, CS mixture achieves the allowable range, whereas IS mixture tends to be out of range at high bitumen content which could result in a tendency to bleed or exhibit plastic flow.

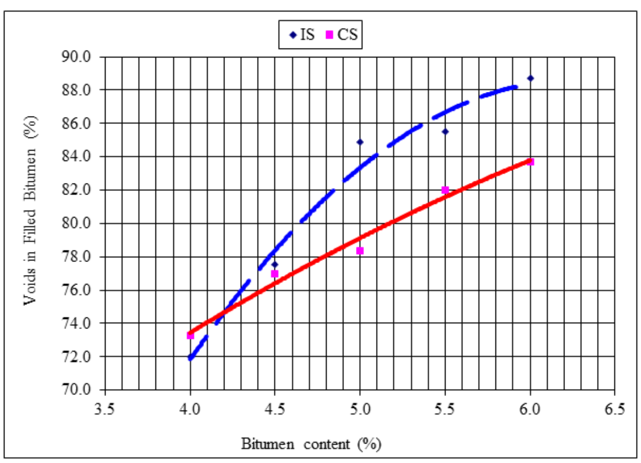

Figure 7 VFB against bitumen content

3.2 Mechanical Properties

3.2.1 Resilient Modulus

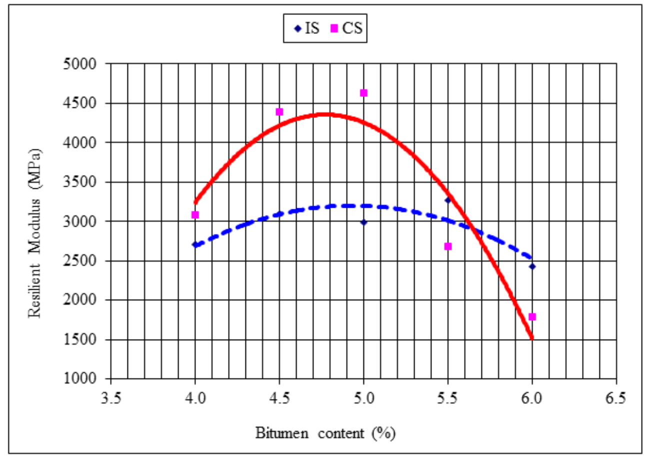

Figure 8 Resilient modulus against bitumen content

Figure 8 shows the relationship between resilient modulus and bitumen content. Overall, the resilient modulus increased to maximum and then decreases with the increase in the bitumen content. The maximum resilient modulus of IS and CS mixtures are observed at 3500 and 4550MPa with the bitumen content of 4.8 and 4.9% respectively. High resilient modulus obtained for the CS mixture with the increase in bitumen content, exhibits the greater recoverable strain or the elastic behaviour of the mixture [13]. It also shows the capability of the mixture to withstand against imposed deformation without creating a permanent distortion. In other words, the mixture is able to return to the original state after it is no longer subjected to the applied load. This is more likely to occur within the CS mixture compared to IS mixture due to the proper aggregate interlocks and less aggregate breaking that prevent the mixture from plastic flow.

3.2.2 Dynamic Creep

Generally, the dynamic creep of CS mix is much higher compared to the IS mix. The positive effects of using geometrically cubical shaped aggregates can be seen from the overall results presented in Figure 9. The figure also indicates that there is a general tendency for the stiffness to increase as binder content increases but reduces beyond the maximum value. It also can be seen that mixes incorporating geometrically cubical shaped aggregates perform better than mixes with aggregates crushed using the conventional compression crusher. The percentage increase in creep stiffness is more pronounced with conventional mixes tested at different binder content. For instance, at binder content 4.5%, the creep stiffness of IS mix is 19.5MPa but the stiffness modulus of HMA mixtures with CS mix is 26.2MPa which represents a 34.3% increase. Therefore, the CS mix can be improved the stiffness modulus of asphaltic concrete AC14.

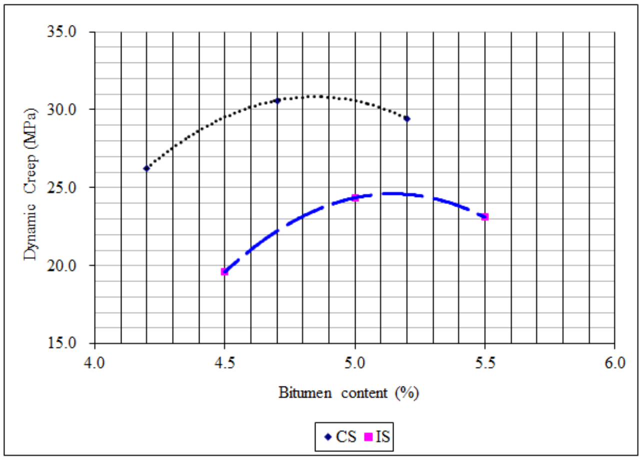

Figure 9 Dynamic creeps against bitumen content

■4.0 CONCLUSION

Based on the volumetric properties and resilient data obtained from the investigation, the following conclusions can be made:

a. An improvement in volumetric properties values is observed when geometrically cubical aggregates and SBS modified binder is used.
b. The use of geometrically cubical re-crushed aggregates in asphalt mixture can increase the resilient and stiffness modulus compared to the mixture contains uncrushed irregularly shaped aggregates.

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