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Laboratory Investigation on the Effects of Flaky Aggregates on Dynamic Creep and Resilient Modulus of Asphalt Mixtures

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Graphical abstract

Abstract

This paper presents an investigation on the effects of flaky aggregates in asphalt mixture. In general, aggregate characteristics are critical to the performance of asphalt mixture. Therefore, flaky aggregate is normally avoided simply because it has significant contribution towards the gradation and reduces the interlocking characteristics of aggregates within asphalt mixture. In practice, it is recommended that the amount of flakiness aggregate should be limited to 25% or less. This study evaluates the mechanical properties of asphalt mixture specimens prepared with various percentages of flaky aggregates particularly 10%, 20% and 30% by the total weight of the mixture. Several laboratory tests were conducted including Marshall properties test, Indirect Tensile Modulus test and Dynamic Creep test. The results show that higher bitumen content is required with the increased in the amount of flaky aggregates added to mixture. Furthermore, greater amount of flaky aggregates tends to reduce the mixture's resilient modulus and its resistance against permanent deformation.

Keywords: Flaky Aggregates; resilient modulus; dynamic creep

1.0 INTRODUCTION

Aggregate acts as an organised skeleton structured in asphalt mixture that support the stability of the pavement. Kandhal and Parker [1] stated that asphalt mixture consists of 94 percent aggregates by weight of the asphalt mixture and its performance is highly depends on the properties of the coarse and fine aggregate used. Generally, the property of aggregates is one of the major concerns in asphalt industry because it represents or reflects the average quality of the entire mass of the asphalt mixtures. The shapes of the aggregates play a significant role on the performance of asphalt pavements. The shapes can be rounded, irregular, angular, flaky, and elongated. Sterling [2] explained that a coarse aggregate is naturally made up of rounded particles and this is not suitable for a good performance and strength of asphalt mixture due to weak interlocking bonding between the aggregates. Therefore, the aggregate needs to be well crushed to avoid this problem. Basically, coarse aggregates that undergo mechanical crushing tend to have more angularity and cubicle in shape, thus they are suitable to be used in asphalt mixture production. One of the major concerns during the process of aggregate crushing is when the aggregate shapes of the crushed aggregate form into flaky, elongated or both. The aggregate particles are considered as flaky shape aggregate when they have a thickness (smallest dimension) less than 0.6 of their mean sieve size [3].

For road construction, it is understood that the flaky aggregates are commonly undesirable and their amount should be limited. Kandhal and Parker [1] stated that the presence of flaky and elongated aggregate shapes are expected to break during the production (i.e. stockpiling, handling and mixing) and construction (i.e. transport, layout and compaction). These broken aggregates will create more uncoated aggregate in the pavement, causing the pavement to be exposed to moisture damage and leads to pavement distress [2]. Aggregates with good quality are expected to be hard and able to withstand abrasion. Previous researchers had also revealed that the performance in terms of resistance against permanent deformation depends on the shapes and surface texture of aggregates. Neglecting to measure these properties can lead to inconsistent interpretation of the asphalt mixtures performance [4, 5]. Oduroh [6] mentioned that due to the orientation of the flaky and elongated shapes of aggregate in bituminous mixture, it will reduce the mixture resistance against shear deformation and thus, create problems like premature failure. In Malaysia, the Malaysian Standards (MS 30) manual specifies that the maximum allowable flakiness index is approximately 25 to 30% depending on the type of road layers and also the type of aggregate gradations used in the road construction [7, 8]. For an asphalt mixture used for wearing course, the maximum amount of flakiness index shall not be more than 25 %. The presence of excessive amount of flaky aggregates may lead to higher tendency of pavement distress (i.e., cracks, surface deformation and surface defects). As a consequence, it will not only reduce the performance of asphalt pavement but also reduces the riding quality and the safety of road users. Therefore, it is important to evaluate the effects of shape characteristics of aggregate in asphalt mixture. This study investigates the influence of flaky aggregate on asphalt mixtures performance.

2.0 MATERIALS AND METHODS

2.1 Mixture Design

The type of aggregates used is crushed granite aggregate. The aggregates were obtained from Malaysian Rock Product (MRP) quarry located at Ulu Choh, Pulai, Johor. They were sieved and blended in accordance to Malaysian Standards gradation of Asphaltic Concrete Wearing Course 20 or ACW 20 [7] as shown in Table 1. The gradation for ACW 20 is available in Malaysian PWD 1988 [7] specification and the latest Malaysian PWD 2008 [8] specifications only provide the gradations for ACW 10 and ACW 14. In this study, the compacted specimens were prepared to achieve the middle of the aggregate envelope for ACW 20 gradation (mid-range) as plotted in Figure 1. Hydrated lime was used as filler. The addition of flaky aggregates in the mixture was done for the coarse aggregates portion (for the size of 20 mm, 14 mm and 10 mm). The gradation is based on a typical dense graded wearing course that satisfies the Malaysian PWD [7] specification with 20 mm is the nominal maximum aggregate size. The blended gradation consists of different proportion of flaky aggregates and non-flaky aggregates are added at fixed proportion to obtain the designed amount of 10%, 20% and 30% by weight of the mixture. The type of binder used in this study is 80/100 PEN. The bitumen was supplied by Shell Malaysia with the specific gravity is 1.03 g/cm^3. The targeted binder content for this particular mixture is between 4.5 to 6.5% and the air voids content is between 3.0 to 5.0%. The Marshall mix design was conducted at the increment of 0.5% of the binder content with three replicates for each binder content. The optimum binder content (OBC) for each mixture type is determined at their respective amount of flaky aggregates.

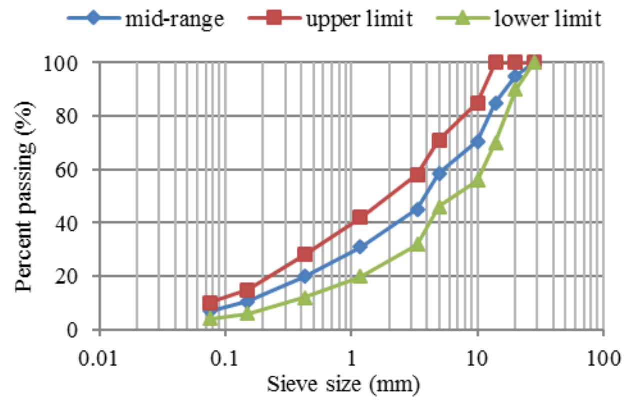

Figure 1 Plotted aggregate gradation for asphalt concrete wearing course (AC 20)

The investigations to determine the OBC a mixtures using Marshall mix design method developed by Bruce Marshall [9] in 1939. Two types of tests used to predict the performance of in Marshall mix design are Marshall stability and flow. These tests are conducted simultaneously. Marshall stability is used an indicator to the maximum loading for the specimen can support before failure occurs. The rate of loading acted on the specimen is 50.8 mm/minute. While flow test is used to calculate the resistivity of the specimens to plastic flow as the specimens experience loading on the lateral surface due to Marshall stability test. The investigation on flow test is recorded using a dial gauge.

2.2 Mechanical Properties Tests

In this study, resilient modulus test and dynamic creep test were conducted to investigate the performance in terms of mixture's recovery and mixture's potential for permanent deformation. This is important in order to understand the influence of excessive flaky aggregate towards the recovery properties and rutting potential of asphalt mixtures.

2.2.1 Resilient Modulus Test

Resilient Modulus (M_R) test measures time dependent deformation under constant compressive stress to evaluate the capacity of laboratory compacted specimen to recover from repeated load cycles without reaching the failure limit. Resilient modulus test was performed in accordance with ASTM D 4123 – 82 [10] under the indirect tensile mode as shown in Figure 2 using a Universal Testing Machine (UTM) at a controlled temperature of 25 and 40°C (± 1°C) [11]. The loading frequencies of 0.5 and 1 Hz for each test temperature were used and the load duration of this test was 0.1 second. The peak load of 1000 N was applied vertically in the diametral plane of a cylindrical specimen and the horizontal deformation was measured. For this test, the specimens were tested in two orientations, 0˚ and 90˚ and the average resilient modulus is presented. The total resilient modulus (M_R) is calculated using Equation 1 [12].

$$M_R = \frac{\mathrm{P(v+0.27)}}{\mathrm{t\,x\,H}} \qquad (1)$$

where:

P = Repeated load,
V = Poisson's Ratio,
t = Thickness of specimen,
H = Total recoverable horizontal deformation.

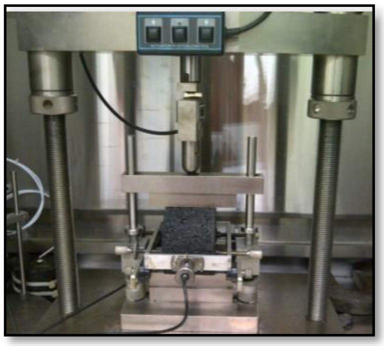

Figure 2 Resilient modulus test

2.2.2 Dynamic Creep Test

The creep test can provide sufficient information to determine current elasticity (recoverable) and plastic (irrecoverable) components for the type of materials used which is necessary to understand its stress–strain behaviour. Dynamic creep test was performed using Universal Testing Machine (UTM) according to BS EN 12697-25 [13] as shown in Figure 3. This test applies 0.3 MPa repeated pulses of uniaxial stress parallel to the specimen with 3600 recovery cycles and measures the deformation in the same direction using Linear Variable Differential Transducers (LVDT). In this study, this test was conducted at the temperature of 40°C (± 1°C) for different mixture types with different percentages of flaky aggregates.

Figure 3 Dynamic creep test

■3.0 RESULTS AND DISCUSSION

3.1 Optimum Binder Content

The optimum binder content (OBC) was determined before preparing samples for the mechanical tests using Marshall mix design. The trial bitumen contents used were 4.5%, 5.0%, 5.5%, 6.0% and 6.5% with three specimens produced for each. For this study, there are three different proportions of flaky aggregates, 10%, 20% and 30% which make up a total of 45 specimens for the OBC determination. Table 1 presents the result for the verification samples for different percentages of flaky aggregates. Based on the results obtained, the OBC for the mixture increases with the increase in the flaky aggregates content. By adding higher content of flaky aggregates in the asphalt mixture, more binder is needed to fill up the voids or gaps formed due to improper aggregate interlocking or aggregate arrangement within the mixture. In addition, the breaking of flaky aggregates during mixing provides higher aggregate surface area thus more binder is required to coat the aggregate particles. Overall, mixtures with 10% and 20% flaky aggregates satisfy the Malaysia PWD [8]. Whereas mixture with 30% flaky aggregates does not fulfil the specification with the value of flow and voids filled with bitumen (VFB) exceed the limit. In terms of stability, mixture with 10% flaky aggregate has higher stability compared to the other two mixture types. This shows that improper aggregates arrangement within the asphalt mixture could reduce its stability and strength as the flaky aggregate particles tend to break during compaction and under the loading action.

Table 1 Verification sample for different percentage of flaky aggregates

Parameter	JKR/SPJ/ 2008-S4	Flaky aggregates (%)		
		10%	20%	30%
Stability, S	>8000 N	13072	12442	12438
Flow, F	2.0 – 4.0 mm	3.96	3.88	4.08
Stiffness, S/F	>2000 N/mm	3300.9	3206.7	3046.1
Voids in total mix (VTM)	3.0 – 5.0 %	4.0	3.8	3.5
Voids filled with bitumen (VFB)	70 – 80 %	76.0	78.5	83.0
Optimum bitumen content (OBC)	4.5 – 6.5%	5.6	5.7	5.8

3.2 Resilient Modulus

Table 2 shows the result for resilient modulus performed at the temperature of 25˚C and 40˚C. It can be clearly seen that the resilient modulus values are affected by the different proportions of flaky aggregates added to the mixture. For both test conditions, the resilient modulus obtained for mixture added with 10% flaky aggregates is higher compared to the mixtures added with 20 and 30% flaky aggregates. By testing the specimens at high temperature (40˚C), the resilient modulus was reduced at approximately 87%. The higher content of flaky aggregates in the aggregate gradation reduces the ability of the mixture to recover under the loading action because the particles tend to break and provide 'weaker transition zones' within the mixture. In other words, the weaker transition zones describe the inability of the aggregate structure to properly distribute or transfer the stress applied to the specimen and recover as soon as it is unloaded.

Table 2 Resilient modulus at different percentage of flaky aggregates tested at 25 and 40°C

Flaky aggregates (%)	Resilient modulus (MPa)	
	25°C	40°C
10	2444	324
20	2353	305
30	2278	298

3.3 Dynamic Creep

Figure 4 shows the results of stiffness modulus obtained from dynamic creep test. The highest value of stiffness modulus was obtained at 10% of flaky aggregate with the value of 20 MPa. By adding an additional 10% of flaky aggregate, the value of stiffness modulus reduced to 15 MPa. It is well established that the stiffness modulus reflects the resistance of asphalt mixture towards permanent deformation. From the result, it can be observed that, the addition of flaky aggregates in the mixture reduces the ability of the asphalt mixture to withstand the repeated load and thus provide less resistance against rutting. In this case, the breaking of aggregate particles under the repeated loading can be a significant mechanism contributing to the reduction in the rutting resistance as a result of poor aggregate interlocking and aggregate embedment and also minimal texture depth due to the flat surface.

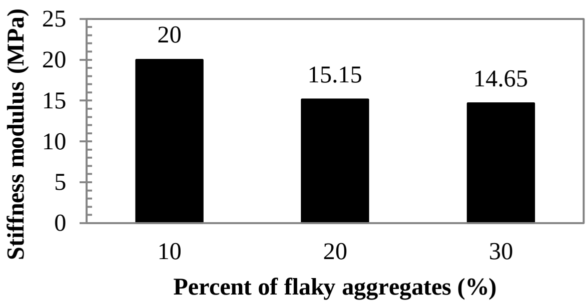

Figure 4 Stiffness modulus at different percentage of flaky aggregates

■4.0 CONCLUSION

From the study, it can be concluded that the shape of aggregates has a significant effect on the performance of asphalt mixture. The values of resilient modulus and stiffness modulus under the creep loading decrease with the increase flaky aggregate contents in the mixture indicating that asphalt mixture with fewer flaky aggregates has better recovery properties and resistance towards the deformation compared to other mixture types. This indicates that aggregate shape could affect the aggregate arrangement within the mixture and thus the mixture properties. Therefore the amount of flaky aggregates used in asphalt mixture should be limited in order to achieve consistent and standardised quality of asphalt mixture.

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