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Stability and voids properties of hot mix asphalt containing black rice husk ash

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Abstract. Asphalt durability is often linked to the thickness of the asphalt coating on the aggregate particles. In order to have an adequate film thickness in asphaltic concrete, there must be sufficient space between the aggregate particles in the compacted pavement. This void space is referred to as voids properties. Hence, this study investigates the performance of black rice husk ash as (BRHA) modified binder on stability and voids characteristics of hot mix asphalt. Four BRHA were used as in this study namely 0%, 2%, 4%, and 6% (by weight binder). The stability and voids properties of asphalt mixture were determined based on Marshall Mix design test. Test results show that the stability of hot mix asphalt incorporating BRHA was higher than the controlled mixture. The results also indicate that the addition of BRHA causes an increasing or decreasing in voids properties.

1. Introduction

The use of industrial waste materials has been widely studied for seeking suitability utilized in road construction [1,2,3]. Black rice husk ash (BRHA) is one of the agro-waste that could be used to improve the properties of the asphalt mixture [4]. Rice husk can be found as natural materials; this material is also obtained with re-choiring low cost, energy and time. Unfortunately, BRHA waste material is dumped into the environment without any commercial return. The burning of rice husk under uncontrolled temperature produces a highly reactive black rice husk ash [5]. In general, the quality from BRHA depend on: (a) the content Silica achieved by complete combustion of rice husk, (b) an amorphous silica phase crystallization formed by the combustion of suitable rice husk on temperature control or un-control and treatment of BRHA, and (c) the size and surface area of the ash particles obtained by the grind-ing process. Utilization of agricultural waste such as BRHA as a modifier in asphalt mixture could solve the waste problem. If this material can suitably be used in road construction, the pollution and disposal problem can be reduced. The use of waste also at the same time may decrease the cost of construction and increase the quality of the pavement. Over the past decades, many studies explored the effects of natural additives on the properties of conventional bitumen [6,7]. The current use of coconut shell [8], kaolin clay [9], rice husk ash [4], palm oil fuel ash [10] and etc. as a modifier in bitumen or replacement of aggregate in asphalt mixture has drawn considerable attention among researchers. However, the used of black rice husk ash (BRHA) from agricultural as a modifier in bitumen is uncommon in Malaysia. One possible reason is that only a few studies assessed the potential of rice husk ash as a bitumen modifier to improve pavement properties. For example, Romastarika et al. [4] investigated the black rice husk ash at different percentages to improve bitumen properties. They found that bitumen became more viscous when 6% BRHA was replaced, whereas the rate of penetration decreased when the replacement amount of BRHA increased. Therefore, the usage of BRHA could help improve the performance of road pavement and reduce the rutting effect. Previous studies focused on the use of BRHA as binder modifier. However, the use of BRHA in hot mix asphalt has yet to be reported. In this study, the usability of BRHA in asphalt mixture was investigated in term of stability and air voids properties.

2. Materials and method

2.1. Aggregate and gradation

The aggregates were supplied in one batch for the entire experimental program. In order to obtain the final blend in the mixture proportioning, the aggregates were washed, dried, and then sieved into their respective size ranges. The size required would depend on the kind of gradation used. The gradation of aggregates used in this study is tabulated in Table 1. It showed that they complied with the requirement of the Malaysian Public Works Department [11].

Table 1: Gradation of aggregate used in this study

Sieve Size (mm)	Percentage Passing (%)
20.0	100
14.0	90 – 100
10.0	76 – 86
5.0	50 – 62
3.35	40 – 54
1.18	18 – 34
0.425	12 – 24
0.15	6 – 14
0.075	4 – 8

2.2. Bitumen

Bitumen with the penetration grade 60/70 was used through this study. The physical properties of bitumen60/70 are in the standard range as shown in Table 2.

Table 2: Physical properties of 60/70 bitumen

Physical properties	Values
Penetration (dmm)	65
Softening point (°C)	51
Relative density	1.03
Viscosity at 135 °C (cp)	600

2.3. Black rice husk ash

The black rice husk ash (BRHA) was collected from a rice mill in Johor Bahru. Malaysia. In the production process, the rice husk was burned at a temperature of 850 °C with short residential time (10–15 min). After incineration, BRHA was left to cool and then collected the following day. The burned ash was then ground to obtain the required particles size less than 75 μm. Silicon dioxide was identified as the main component of BRHA. On the other hand, silicon dioxide, aluminium oxide and iron oxide comprised 90% of the material in accordance with ASTM C618-15 [12], and those three main oxides make up no less than 70% of the pozzolanic material.

2.4. Mix preparation
A typical 101.6 mm inner diameter steel Marshall moulds were used in conjunction with the Marshall hammer. An electrically heated paddle mixer was used to blend the aggregates and bitumen. In the laboratory, mixing of dry aggregates was accomplished in less than 30 seconds. Then, the correct amount of binder was poured into the dry mix, and the wet mixing continued for another minute. The amount of binder required was calculated as a percentage of the total mix. Full compaction was then conducted by using the Marshall hammer with 75 blows on each side to account for the heavy traffic category. When compaction was completed, the specimens were allowed to cool to room temperature before testing.

2.5. Marshall stability test
The Marshall stability test was conducted in compliance with ASTM D 6927 [13]. In the laboratory, specimens were prepared with the specified temperature by immersion in a water bath at a temperature of 60°C±1°C for 45 minutes. Thereafter, specimens were placed in a Marshall stability machine and loaded at a constant deformation rate of 50.8mm/minute until the maximum load was reached. The maximum load in kN and flow in mm were recorded. The stability, voids in the total mix (VTM), voids in filled bitumen (VFB) and voids in mineral aggregate (VMA) were measured and documented.

3. Results and discussion

3.1. Stability
The stability of the hot mix asphalt containing black rice husk ash at different content is illustrated in Figure 1.The test results indicate that the stability of HMA containing BRHA was higher than the controlled mixes at all substitution. Clearly, the stability properties of HMA have increased significantly by the varying BRHA content. The carbon and amorphous silica of BRHA are the principal reasons for an increase in stability as described by Romastarika et al. [4]. The results also indicate that the stability of the HMA containing BRHA0 is lower than that of the BRHA2, BRHA4, and BRHA6 as shown in Figure 1. In general, the stability was found to range from 10.5 kN to 11.4 kN. The BRHA6 HMA mix exhibited the highest stability compared to others mixture. It can be said that the use of 6% adding BRHA in hot mix asphalt was more effective in enhancing stability.

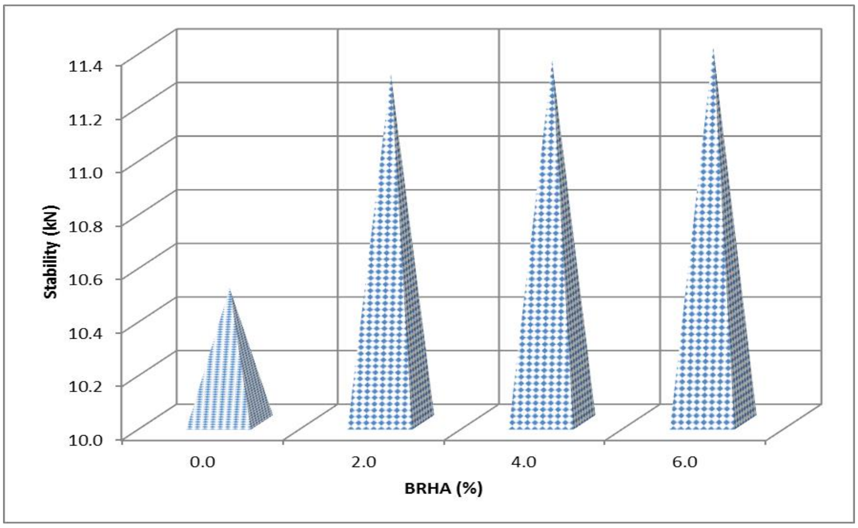

Figure 1. Stability of HMA at different black rice husk ash content

3.2. Voids in mineral aggregate

According to ASTM D6927 [13], voids in mineral aggregate is the volume of voids in the aggregates and is the sum of air voids and volume of bitumen. The VMA was calculated using Equation 1 as follows:

$$VMA = V_v + V_b \quad (1)$$

Where Va is the per cent air voids in the mix, and Vb is per cent bitumen content in the mix.

The voids in the mineral aggregate of asphalt mixture containing black rice husk ash at varying content are demonstrated in Figure 2.The highest VMA value was obtained using 0%black rice husk ash, where the lowest value of VMA was achieved at 6% BRHA. For instance, the value of VMA at BRHA0 is 17.08%, whereas the VMA value of BRHA6 is 15.10%. There is a difference of more than 12%. This indicates that the addition of BRHA causes a decreasing in VMA. The decreasing VMA is due to the filling up of pores by the BRHA. Lowest VMA values should be adhered to so that a durable asphalt film thickness can be achieved.

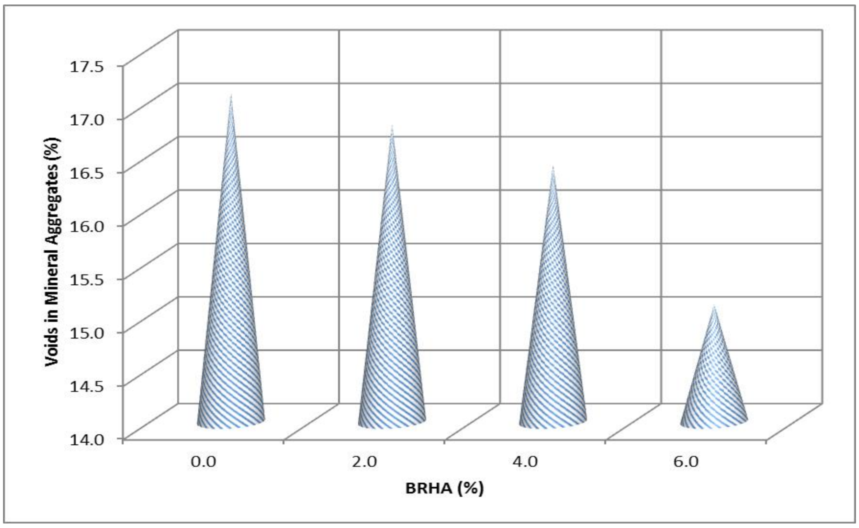

Figure 2. VMA of HMA at different black rice husk ash content

3.3. Voids filled with bitumen

As prescribed by ASTM D6927 [13], voids filled with bitumen are the void in the mineral aggregate frame work filled with the bitumen. The VFB of the specimens was calculated using Equation 2 as follows:

$$VFB = \frac{V_b \times 100}{VMA} \quad (2)$$

Where V_b is per cent bitumen content in the mix, and VMA is the per cent voids in the mineral aggregate.

The general effect of hot mix asphalt containing BRHA at the different percentage on VFB is presented in Figure 3.Three specimens were tested at each percentage BRHA, and the average value was reported. Based on the figure, it can be seen that conventional hot mix asphalt has the highest value of VFB. However, among the BRHA substitution, the VFB increase as increasing the percentage of BRHA. For instance, at 0% BRHA content, the VFB of HMA approximately 75%. Therefore, additions of 2% BRHA decrease the VFB by 66%.There is a difference of more than 12%.According to JKR specification [11], the VFB should range from 75% to 85%. However, these specifications do not specify limiting values for waste materials. Previously, Abdullah et al. [3] reported that if the VFB is too low, there is not enough asphalt to provide durability and to over-densify under traffic and bleed. Thus, in this study, the VFB of BRHA0 and BRHA6 was met to requirement range.

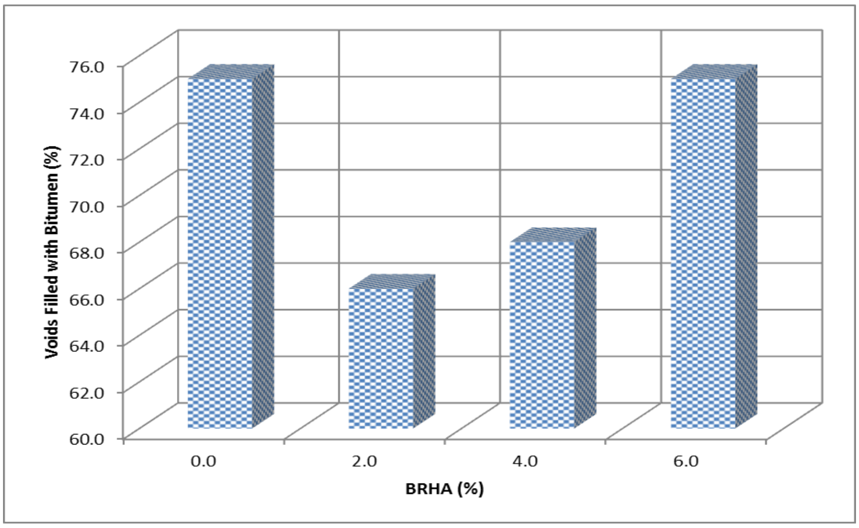

Figure 3. VFB of HMA at different black rice husk ash content

3.4. Voids in total mix

Voids in the total mix are small airspaces or pockets of air that occur between the coated aggregate particles in the final compacted mix [13]. Previously, Hassan et al. [14] reported that a certain percentage of air voids is necessary for asphalt mixture to allow for some additional pavement compaction under traffic. In this study, the values of air voids of specimens were calculated using Equation 3.

$$V_a = \left(1 - \frac{G_{mb}}{G_{mm}}\right) \times 100 \qquad (3)$$

Where V_a is air voids, G_{mb} is bulk specific gravity of the compacted mixture, and G_{mm} is maximum theoretical specific gravity of the mixture.

Figure 4 illustrates the effect of black rice husk ash in HMA on air voids content. The figure exhibit that the air voids value of the hot mix asphalt varies from zero percentage BRHA to another. The test results also indicate that the air voids of HMA increase with increasing BRHA content up to a peak level and then decreases with further additions. Generally, the air voids value was found to range from 3.7% to 5.7%.The BRHA2 hot mix asphalt exhibited the highest air voids content compared to the controlled specimen, BRHA4, and RHA6.Too high air-void content provides passageways through the mix for the entrance of damaging air and water [15]. However, at all VTM investigated the 6% BRHA content mixes record the lowest voids in total mix. The lower the air-voids, the less permeable the mixture becomes [1].

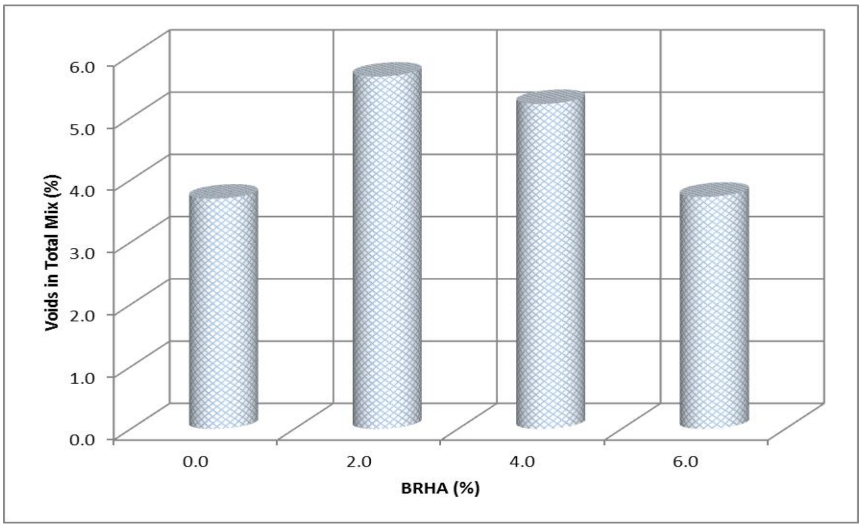

Figure 4. Air voids of HMA at different black rice husk ash content

3.5. Correlation between air voids and density

Figure 5 represents a graphical illustration of the relationship between air voids and density of asphalt mixture incorporating black rice husk ash. The plotted readings clearly show that the air voids reduces when the density value increases. It can be seen that the density and air voids content are directly related. Highest the density will result lower the percentage of voids in the mix [8]. The results also show that densities of the HMA increase with an increase in BRHA content as expected. Where the air voids value of the asphalt mixture decreases with BRHA percentage increased. For instance, the density of 2.29 g/cm^3 to 2.32 g/cm^3 was achieved when the BRHA content was increased from 0% to 6%. However, the air voids value reduces from 5.6% to 3.7% as the BRHA content increases from 0% to 6%.Generally, the air voids content (between 3–5% for the wearing course category) of all specimens is in the range recommended by the local specification JKR [11].

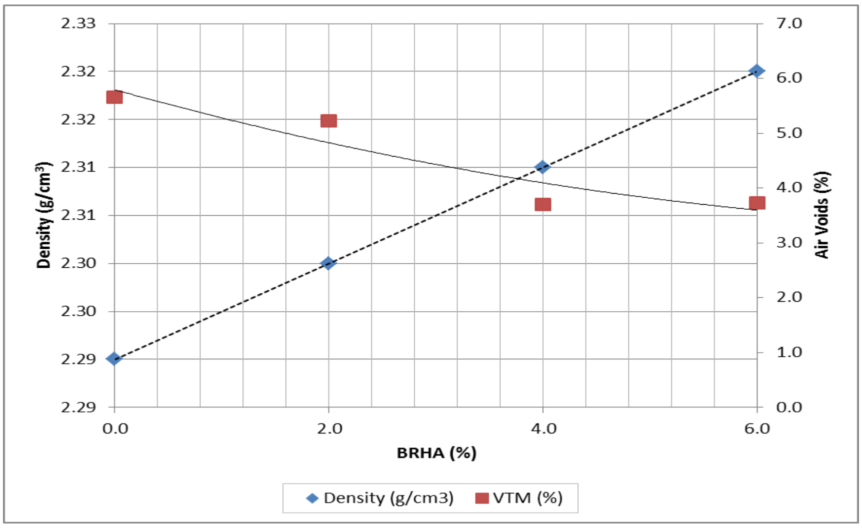

Figure 5. Density vs air voids of HMA at different BRHA content

4. Conclusions

From the laboratory tests results, asphalt mixtures incorporating black rice husk ash performed better than conventional asphalt mixtures. However, a balanced proportion of BRHA is needed to ensure the best performance obtained. Thus, 6% BRHA content is considered as the optimal limit. Black rice husk ash, when incorporated by a certain proportion to the asphalt mixture, exhibits higher stability and air voids.

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