Voids characteristics of asphaltic concrete containing coconut shell

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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 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 in total mix (VTM), voids with filled bitumen (VFB), and voids in mineral aggregate (VMA). Hence, this study investigates the performance of coconut shell (CS) as coarse aggregate replacement on voids characteristics of asphaltic concrete. Four CS were used as coarse aggregates replacement in asphalt mixture namely 0%, 10%, 20%, 30%, and 40% (by weight volume). The voids properties of asphalt mixture were determined based on Marshall Mix design test. Test results show that VTM and VMA values were decrease with the increasing bitumen content where VFB was increase with increasing bitumen content. Furthermore, increasing the percentage of coconut shell in asphalt mixture was found to increases the voids value up to a peak level and then decreases with further additions of CS.

1. Introduction

Conventional aggregates sources in Malaysia are depleting fast due to speedy growth of construction activities [1]. Currently, transportation industry is under pressure to use alternative materials due to high consumption of aggregates in road construction [2]. In order to move towards sustainable development, these materials should be used wisely. A large number of researches have been done in order to search for a possible material as aggregates replacement in road conductions [3,4,5]. Currently, using agricultural waste materials as an aggregates replacement becomes trends in construction industry [6,7]. The aim of using agricultural waste is to minimize the production of waste, reserve the environment and improve the pavement durability [8]. Durability refers to the ability of the mixture to resist abrasion of the surface due to the voids content is high allowing air and water to prematurely harden the asphalt. Coconut shell is one of the agricultural wastes that can be used to durability resistance [9]. Several of research has been done by using coconut shell as coarse aggregates
in lightweight concrete [10,11]. Yet, the usage of coconut shell in hot mix asphalt has never been extensively studied. Therefore, this study presents the effects of coconut shell on the voids characteristics of hot mix asphalt (HMA). This investigation focused on using the variation of coconut shell from 0% to 40% as aggregate replacement in the HMA.

2. Materials and methods

2.1. Binder
The bitumen used in this study was a 60/70 PEN supplied by Chevron Malaysia. This grade bitumen is widely used in Malaysia and other countries. According to the manufacturer’s specification, the relative density value of the 60/70 binder was 1.03. The softening point and penetration was 52°C and 65dmm, respectively.

2.2. Aggregate and gradation
Granite aggregates supplied by Kuad Quarry Sdn. Bhd. was used throughout this investigation. Prior to aggregate batching, the aggregates were washed, dried and sieved into their respective size ranges. The granite aggregate had a specific gravity of 2.65 g/cm³, while the ACV and water absorption was 26.1% and 0.48%, respectively. In addition, the aggregate gradation used in this study conformed to JKR/SPJ/2008-S4 [12] specifications for asphaltic concrete AC14.

2.3. Mix preparation
Ordinary Portland cement and hydrated lime were used as filler in this investigation. The 60/70 PEN bitumen was used as binder for mix preparation. The aggregates were first mixed into batches according to the designated gradations and weight. These batches were then heated in an oven at the designated mixing temperature for at least 4 hours before the mixing process. The heated aggregate batches were then mixed with a specified amount of bitumen. The mixes were compacted with 75 blows on each side with the standard Marshall hammer. After compaction, the specimens were removed from the molds and allowed to cool overnight.

2.4. Voids characteristics
The air voids characteristics of asphaltic concrete AC14 was determined based on Marshall Mix design as outlined in ASTM D6927-15 [13]. The procedure aimed at determining a number of parameters including voids in total mix, voids filled with bitumen, and voids in mineral aggregate. For this purpose, the specimens were prepared at binder contents ranging from 4.0 to 6.0% by weight in 1.0% increment.

3. Results and discussion

3.1. Voids in total mix
VTM is the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as a percent of the compacted mixture. The effects of asphaltic concrete incorporating coconut shell on VTM are presented in figure 1. Generally, voids in total mix decrease gradually with the increasing of bitumen content. For instance, at 0% coconut shell mix, the VTM value of 8.5 to 2.8% was achieved when the bitumen content was increased from 4.0 to 6.0%. On the other hand, increasing the percentage of coconut shell in asphalt mixture was found to increases the VTM values up to a peak level and then decreases with further additions of CS. For example, the VTM value of 8.5 to 13.6% was achieved at 4% bitumen content when the coconut shell level was increased from 0 to 40%. Based on JKR specification [12], the VTM for wearing course should range from 3.0% to 5.0%. However, the requirement does not specify limitation values for asphalt mixture incorporated waste agriculture materials, especially coconut shell. At all VTM investigated, the 0% CS content mixes record the lowest voids in total mix. Hassan et al. [14] reported
that lower air void contents minimize the aging of the asphalt cement films within the aggregate mass and also minimize the possibility of moisture penetrating the thin asphalt cement film and strip the asphalt cement off aggregates. In this investigation, the lowest VTM value of asphaltic concrete incorporating coconut shell was recorded at 10% and 40%, respectively.

![Figure 1. VTM vs. coconut shell at varying bitumen content](image)

3.2. Voids in mineral aggregates

The VMA values of asphaltic concrete at varying percentage coconut shell are illustrated in figure 2. It can be seen that the VMA values of specimens are decrease by increasing bitumen content. For instance, at 20% CS, the VMA value of 20 to 14% was achieved when the bitumen content was increased from 4.0 to 6.0%. The CS had a lower specific gravity due to lightweight material but higher water absorption, indicating that it absorbs more bitumen content during the mixing process. Similar findings were also reported by another investigation [7,9,15]. The results also indicated that the VMA of controlled specimen is lowest than VMA of asphaltic concrete containing 10, 20, 30, 40% coconut shell, respectively. There are no specifying limitation values for VMA in JKR standard for asphaltic concrete containing waste materials. The VMA value was found to range from 13 to 19% when the coconut shell content was increased from 0 to 40%.

![Figure 2. VMA vs. coconut shell at varying bitumen content](image)
3.3. Voids filled with bitumen
Voids filled bitumen (VFB) is the percentage of the volume of the VMA that is filled with bitumen. The VFB is inversely related to the air voids. As the percentage of air voids approaches zero, the VFB approaches 100 [7]. The general effect of asphaltic concrete containing coconut shell on VFB at different bitumen content is illustrated in figure 3. It can be seen that the VFB decreases as the coconut shell quantity increases. The VFB reduces from 54% to 44% as the coconut shell content increases from 0% to 40%. JKR specification [16] stated that the VFB value of specimen should range from 75% to 85%. However, these specifications do not specify limiting values for agriculture waste materials, specifically for coconut shell. The results also show that the VFB values of specimens are increase by increasing bitumen content. For instance, at 0% CS, the VFB value of 54 to 79% was achieved when the bitumen content was increased from 4.0 to 6.0%. Compared with the study conducted by Jeffry et al. [12] reported that when the VFB exceeds approximately 80% to 85%, the asphaltic concrete mix typically becomes unstable and rutting is likely to occur. Hence, the VFB values are within 39% to 54%, 65% to 80%, and 79% to 97%, correspondingly for 4%, 5%, and 6% bitumen content. It can be concluded that the use of 0% to 40% CS in asphalt mixture at 4% bitumen content was more effective in enhancing rutting.

![Figure 3. VFB vs. coconut shell at varying bitumen content](image)

4. Conclusions
The effect of coconut shell on the voids properties of asphalt mixture was investigated. It can be seen that the addition of coconut shell as aggregate replacement materials was not enough improvement to the durability performance of asphaltic concrete. However, when compared among substitutes level, the use of 10% CS resulted in good resistance of mixtures.

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