

PAPER

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Voids Characteristic of Hot Mix Asphalt Containing Waste Cooking Oil

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Abstract. Pure bitumen production through crude oil petroleum refining process is not desirable in road pavement application. The asphalt binder exhibits insufficient properties for pavement construction and need to be modified with various additives. In this study, the effect of untreated and treated waste cooking oil (WCO) on voids properties of hot mix asphalt was evaluated. A 5% of WCO (by weight of binder) was selected and replaced into the modified binder before being mixed with the aggregates in asphalt mixture. The voids characteristic of hot mix asphalt was determined based on Marshall Mix design test. Five different content of bitumen i.e. 4%, 4.5%, 5%, 5.5% and 6% was chosen on the basis of min and max value as required by Malaysia public work department. Test results show that the voids filled with bitumen and density was increase as the bitumen content increases from 4% to 6% for untreated and treated WCO mixes. Furthermore, the result also indicates that the void in total mix was linearly decreased when the bitumen content increased from 4% to 6%.

1. Introduction

Waste cooking oil (WCO) is non-edible oil and can be recognised as a by-product of fresh oil produced during food frying [1]. Fresh cooking oil is physically light yellow in color with low viscosity [2], while used cooking oil has high viscosity [3] and dark brown in color [4]. WCO source is collected from food industries, household disposables, restaurants and recycling centre by authorised companies [5,6,7]. The modification of binder with WCO for paving materials indicates the implementation of recycling practice with environmental issues concern, thus improving the proper management of this waste product. A laboratory evaluation conducted by Wen et al. [8] reported that the addition of waste cooking oil based bio-asphalt to produce alternative binder for hot mix asphalt (HMA) reduced the dynamic modulus and high-temperature performance, decreased the stiffness and flow value with increasing amount of bio-asphalt. A significant and noticeable finding reported by previous researchers indicating that the WCO application is recorded as a superior improvement for HMA. The superior performance of the modified binder incorporating WCO is attributed to the natural fluidity characteristic of WCO. The WCO fluidity properties in binder facilitates high flow rate and



decreases the viscosity of modified binder within the mix, thereby assisting the reduction in induced stress or cracking existence. From the review presented, it can be noticed that WCO can be categorised as one waste material that is mostly utilised for partial substitution as a modifier in binder modification. Oil-based modification by using WCO is expected to improve the engineering value of modified asphalt binder in comparison with the conventional binder. Apart from that, waste disposal problem could be solved and also promotes environmental preservation. For this reason, it is vital to evaluate the voids characteristic of hot mix asphalt containing untreated and treated waste cooking oil.

2. Materials and method

2.1. Bitumen

The bitumen with a penetration grade of 60/70 was used in this investigation as recommended in the new Malaysian Public Works specification [9] for road works based on tropical climate. From laboratory test, the physical properties of bitumen was 68 dmm penetration at 25°C with softening point was about 52°C. On the other hand, the relative density of bitumen is 1.03 while the viscosity at temperature of 135°C was 600cp.

2.2. Aggregate

Crushed granite aggregates were used to prepare hot mix asphalt. The physical and mechanical properties of aggregates were tested according to the appropriate standard method. Results proved that all the aggregate properties met the relevant standard specification as summarised in Table 1 and the aggregates were approved to be used for asphalt mixture preparation.

Table 1: Granite aggregates properties

Descriptions	Water Absorption (WA)		Aggregate Impact Value (AIV)	Aggregate Crushing Value (ACV)
	Fine	Coarse		
Standard	ASTM C 128 [10]	ASTM C 127 [11]	BS-EN 1097-2 [12]	
Requirements	<2%		<30%	
Test result	1.05 %	0.62 %	14%	17%

2.3. Gradation

In this study, the gradation of asphaltic concrete 14 (AC14) was selected for mix design purpose as listed in Table 2. It can be seen that the aggregate grading for AC14 conformed the gradation limit requirement specified in the Malaysian Public Works [9] specification.

Table 2: Gradation of hot mix asphalt

Sieve size (mm)	Lower limit	Upper Limit
20	100	100
14	90	100
10	76	86
5	50	62
3.35	40	54
1.18	18	34
0.425	12	24
0.15	6	14
0.075	4	8

2.4. WCO

The WCO were collected from a food restaurant. At laboratory, raw WCO sample was first filtered by placing a filter paper of 45 micron pore size in a beaker to remove food, dirt, and impurities. This filtering process took approximately 1 h to complete before the filtered WCO was obtained. At the end of process, impurities remained on the filter paper, while residues of filtered WCO were collected for further testing. During frying, the WCO deteriorated, hence, affecting the WCO quality. WCO quality was assessed based on its acid value content. Initially, the acid value in the WCO sample was determined by using the titration method in accordance with the ASTM D1980 [13]. On the other hand, the pretreatment method for untreated WCO was used the single-step transesterification reaction via alkali catalysts. This process was proposed to minimize the presence of high acid value in the WCO and improve WCO performance. After the chemical treatment process, the original of the WCO (untreated) changed into treated WCO.

2.5. Hot mix preparation

A typical 101.6 mm inner diameter steel Marshall mold was used in conjunction with a Marshall hammer. An electrically heated paddle mixer was used to blend the aggregates and bitumen. In the laboratory, the dry aggregates were mixed in less than 30 s. Subsequently, the correct amount of binder was poured into the dry mix, and 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 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.

2.6. Volumetric properties test

The void in total mix (VTM) and void filled with bitumen (VFB) were examined as volumetric properties. 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). VFB is the percent of the volume of the VMA that filled with bitumen. The test was carried out in accordance with ASTM D 6927 [14].

3. Results and discussion

3.1. Density

The density was performed on the three types of asphalt mixture, which can be denoted as the control mixture and modified asphalt mixture incorporating untreated and treated WCO. In all cases, a density increase was linearly recorded with the higher bitumen content between 4% - 6% for untreated and treated WCO mixes, as illustrated in Fig. 1. In contrary, the control mixture presented an inconsistency trend for density as the bitumen content was increased. On the other hand, the density showed an increasing trend between the different types of asphalt mixture starting from the control, untreated and treated WCO mixture. The results also indicated that the density for control mixture was recorded lower from untreated WCO at 4% - 5% of bitumen content. It was higher at 5.5% - 6% in comparison with untreated WCO. The density was in a range of 2.30 - 2.41 g/cm³ (control) and 2.31 - 2.40 g/cm³ (untreated WCO) for 4% - 6% of bitumen content, respectively. Meanwhile, the treated WCO mixture recorded a higher density as compared to the untreated WCO mixture, which was represented in a range of 2.33 to 2.41 g/cm³ for 4% - 6% of bitumen content. It can be noticed that the treated WCO mixture exhibited the highest density followed by untreated WCO mixture while the lowest density was recorded by control mixture. This implied that the modified mixture containing untreated and treated WCO improved density as compared to the conventional mixture. This due to the WCO has fluidity and lubricant effects, either untreated or treated, in which it enhances the high flow rate. When the WCO was added into the binder to produce a modified binder, it increased the tendency rate of lubrication effect on binder, which became prone to flow easily. Due to high flow rate properties possessed by modified binder with WCO, the soft and less viscous binder has potential to slide into spaces between the aggregates particles and enable them to fill up the voids in the asphalt mixtures

composition. Once the voids were filled with binder, it made the mixture more compact and hence increased the density as well. As the increasing available voids were increasingly filled with binder, a high density was achieved. It can be seen that a higher density was recorded by asphalt mixture containing 5% of untreated and 5% treated WCO as compared to the control mixture.

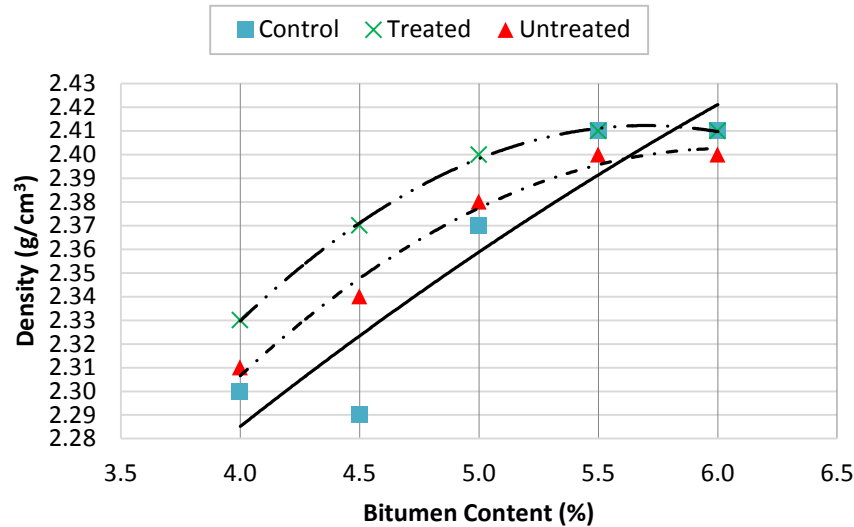


Fig. 1: The density of asphalt mixture containing untreated and treated WCO

3.2. VTM

The results of VTM for control, untreated and treated WCO mixtures are showed in Fig. 2. It was observed that an inversely proportional relationship with the VFB result was recorded by this test, in which the VTM was linearly decreased when the bitumen content was increased from 4% - 6%. The similar decreasing trend of VTM was displayed by control and both modified mixtures with untreated and treated WCO. The highest VTM was recorded at 4% bitumen content while the lowest VTM was presented at 6% of bitumen dosage. The higher VTM indicated a high amount of voids. The asphalt mixture that contained 6% of bitumen content exhibited the lowest VTM due to the high amount of bitumen which filled the voids, and thus reduced the remaining available voids in the total mixture composition. Generally, an excessive void is prone to poor durability while insufficient voids lead to bleeding problem. This was because the residual voids were required for bitumen expansion, which softened and occupied the voids space between aggregates under hot weather condition. Therefore, it is essential to determine an optimum VTM for sufficient voids in the mix design. Based on Fig. 2, the control mixture achieved a higher VTM percentage in a range of 4.14 - 11.34% when compared to the untreated WCO mixture. The VTM attained for untreated WCO mixture was recorded in a range of 1.48 - 8.26%. In contrast, the VTM for treated WCO mixture was found to range at 1.21 - 7.12%, which was lower as compared to the untreated WCO mixture. It indicated that the treated WCO mixture exhibited the lowest VTM as compared to the control and untreated WCO mixture. Based on the result, they are not much significant difference when the VTM was slightly decreased from untreated to treated WCO mixture. The VTM result was related with the fluidity properties of WCO, which enhanced the flow rate performance of the modified binder. The high flow rate facilitated the uniform distribution movement of binder containing untreated and treated WCO around the aggregates particles, thus directly filled the available voids content in the asphalt mixtures composition. Eventually, it reduced the VTM as well. It can be said that the modified binder with untreated and treated WCO in asphalt mixture reduced the voids content in the bituminous mixture as compared to the conventional asphalt mixture.

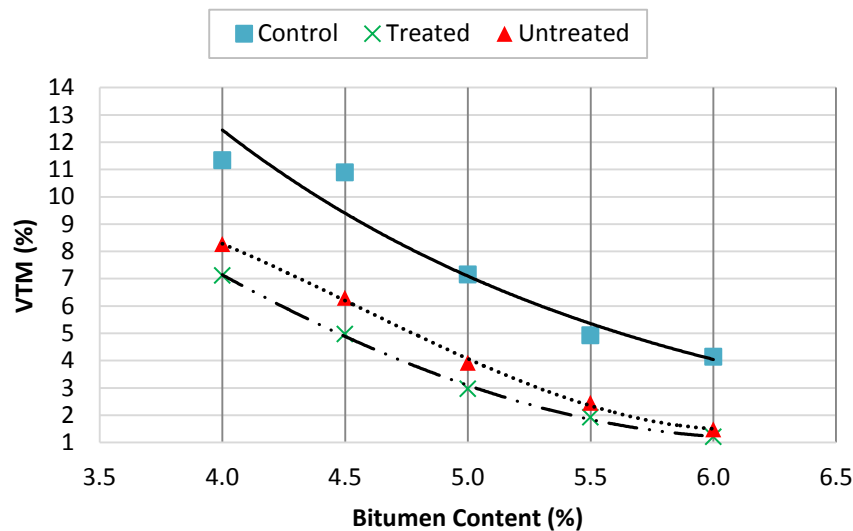


Fig. 2: The VTM of asphalt mixture containing untreated and treated WCO

3.3. VFB

The percentages of voids filled with bitumen can be described as VFB. Fig. 3 illustrates that the VFB was significantly increased and directly proportional with a higher addition of bitumen content from 4% - 6% in asphalt mixture. This trend was acceptable as the higher bitumen content was added hence resulted in the higher VFB. Therefore, it can be noticed that the highest VFB percentage was recorded at 6% of bitumen content. In comparison between different types of mixes, an increasing trend of VFB was observed from the control mixture, untreated and treated WCO mixture. Based on Fig. 3, the untreated WCO mixture achieved a higher VFB, which was in a range of 52.24 - 89.29% at 4% - 6% bitumen content when compared to the control mixture. In this study, the VFB attained for control mixture was found to range from 44.29 - 77.62% at 4% - 6% bitumen content. The VFB for treated WCO mixture represented a range of 55.96 - 92.75% at 4% - 6% of bitumen content, which was higher as compared to the untreated WCO mixture. Another interpretation from this VFB result indicated that the highest VFB percentages was achieved by treated WCO mixture followed by untreated WCO, while the control mixture recorded the lowest VFB percentages. This result was predicted based on the density values wherein the lower density attained by the control mixture attributed to the lower voids filled with the bitumen. Generally, the untreated and treated WCO mixture indicated better VFB percentages than control asphalt mixture. The findings in this study coincided with Borhan *et al.* [15] who discovered that the higher VFB was displayed by the modified mixture incorporated cylinder oil when compared to the control mixture. This is due to the fluid characteristic possessed by untreated and treated WCO that gave an advantage in terms of flow rate performance. The control binder with hard and high viscous characteristics affected the lower of VFB resulted in the lesser VFB percentage because the higher available voids were not filled with the binder. Comparing between the modified mixtures, the treated WCO achieved the highest VFB as compared to the untreated WCO. Finally it can be concluded that the asphalt mixture modified with WCO attained a higher VFB percentage as compared to the conventional mixture.

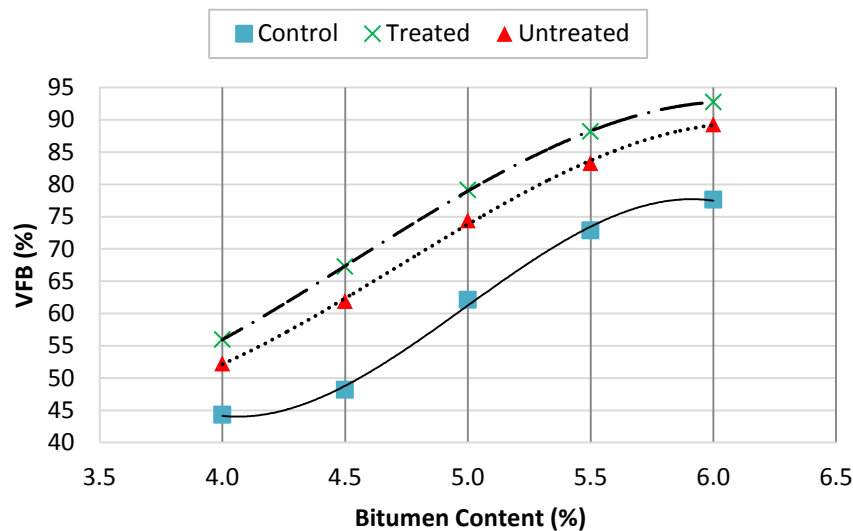


Fig. 3: The VFB of asphalt mixture containing untreated and treated WCO

4. Conclusions

The effect of waste cooking oil on voids of hot mix asphalt was evaluated in this study. It can be seen that the addition of waste cooking oil as binder replacement was improve the durability performance of asphalt mixture. The density and VFB showed an increasing trend between the asphalt mixture containing untreated and treated waste cooking oil. However, the VTM value was decreases as bitumen content increase between 4 to 6%.

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