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Mechanical performance of asphaltic concrete incorporating untreated and treated waste cooking oil

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HIGHLIGHTS

- Treated WCO into hot mix asphalt mixture increased the stability, modulus stiffness and tensile strength.
- Treated WCO can provide highest creep stiffness to resist rutting deformation.
- Treated WCO highly improve the inter-molecular adhesion bonding of asphalt mixture.

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ABSTRACT

In recent years, various oil-based modifications that involve the use of waste cooking oil (WCO) have been applied to deliver obvious benefits to the pavement industry. This effort is in line with the response to the issue of waste management. The current constraint in dealing with WCO is its declining rutting resistance performance at high temperatures. This issue is observed globally and remains unresolved. Adverse rheological performance induces the rutting issue due to the high susceptibility of WCO toward temperature exposure. The pretreatment of WCO is proposed as an extensive research work that aims to produce treated WCO before its addition to HMA. However, the potential of treated WCO is still at the empirical stage and still questionable. Therefore, a mechanical test was performed on the control, 5% untreated WCO, and 5% treated WCO mixtures to evaluate any improvement in the performance of the HMA incorporated with untreated and treated WCO. The mechanical test included the Marshall Stability, resilient modulus, creep stiffness, and indirect tensile strength (ITS) tests. Microstructure observation was performed using an atomic force microscope (AFM) to identify the surface roughness related to the adhesion properties. Results shows an improvement in Marshall Stability, resilient modulus, and ITS performance was recorded with the replacement of 5% treated WCO in bituminous mixture. In addition, the highest creep stiffness, with an enhancement of about 25% relative to the control mixture, was achieved with the 5% treated WCO mixture to resist permanent deformation. The microstructure observation revealed that the lowest surface roughness produced with the treated WCO in modified binder contributed to the improvement of adhesion bonding that increased the strength of the asphalt mixture.

1. Introduction

Rutting is recognized as one of the most common structural distresses in road pavement. This issue minimizes the service life of asphalt mixtures and directly increases maintenance costs [1]. According to Arabani et al. [2], the deterioration rate of asphalt pavements can be reduced by using a substitute modifier in the asphaltic concrete mixture as part of the modification of binders. Modifiers significantly improve the engineering value of asphalt mixtures in terms of resistance against rutting and thermal cracking [3]. Therefore, modifiers are recommended as an alternative solution to the service life issues in the asphalt industry. Oil-based modification, especially the use of waste cooking oil (WCO), has gained widespread attention in recent years as a response to waste management and environmental concerns.

Numerous studies reported the superior performance of WCO as a rejuvenator for aged binders. Zargar et al. [4] evaluated the potential of WCO as a rejuvenator for aged binders. Their finding indicates that 3% WCO is the optimum value that could help

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resemble control binder properties by yielding a high penetration value from the aged binder. Similar results were obtained by Asli and Karim [5], who found that WCO can be applied as a regenerative agent for aged binders to resemble the physical and rheological properties of original binders. Wen et al. [6] and Maharaj et al. [7] investigated the performance of WCO as a modifier for asphalt binders. The authors recorded similar rheological results, which indicate the superior resistance of asphalt binders to thermal cracking at low temperature as the WCO content increases. By contrast, they found that the rutting resistance of asphalt binders at high temperatures weakens as the WCO dosage increases. WCO can be characterized according to its source or feedstock, that is, from either plant-based lipids or animal-based lipids [8]. Plant-based lipids are derived from palm oil, olive oil, sunflower oil, rapeseed oil, corn oil, soybean oil, canola oil, and so on. Animal-based lipids include fish oil, butter, ghee, and kermanshahi oil. The usage of various sources of edible animal and vegetable oils produces WCO after the frying process [9]. WCO can also be differentiated on the basis of the physical and chemical properties of the oil. Physical quality is identified in terms of color, viscosity, density, foaming, and flavor. Chemical quality includes acid value, water content, and antioxidant property. The degradation of WCO quality differs depending on the rate of frying activity [10]. According to Asli et al. [11], the major chemical compounds found in WCO are oleic acid (43.67%), palmitic acid (38.35%), and linoleic acid (11.39%) (Table 1). The other compounds identified in WCO are minor compounds. The acid compounds in WCO can be divided into saturated, monounsaturated, and polyunsaturated compounds. Saturated fatty acids include stearic acid, palmitic acid, lauric acid, and myristic acid. Monounsaturated fatty acids include oleic acid and *cis*-11-eicosenoic. Polyunsaturated fatty acids include linolenic acid, γ linolenic acid, and linoleic acid [12]. The frying process degrades the WCO by altering its acid compositions.

WCO is selected as a potential modifier because of its low-cost feedstock and excellent track record in improving binder performance, specifically at low service temperature [13]. The fluidity properties of WCO contribute toward enhancing cracking resistance performance, especially at low climatic change areas. On the contrary, an adverse finding is observed for rutting resistance at high temperatures, and it has become a debatable issue among researchers [14]. The addition of WCO softens the physical properties of modified asphalt binders and thus increases the sensitivity toward temperature exposure, which then increases the rutting tendency. WCO is not a suitable and applicable modifier in hot climatic regions, especially Malaysia, due to the high temperatures. Consequently, the usage of WCO in modifying binders is limited.

Numerous research findings related to WCO performance in asphalt mixture have been reviewed. For mechanical testing, asphalt mixture performance is evaluated on the basis of three major distress mechanisms of bituminous pavement, namely, stiffness, rutting resistance, and cracking resistance [15]. Wen et al. [6] conducted a laboratory evaluation for hot mix asphalt (HMA) that contained bioasphalt from the conversion of WCO through a thermochemical process. The bioasphalt in the HMA reduced the dynamic modulus by decreasing the stiffness linearly. In addition, the decreasing rutting resistance was proven by the reduction of the flow number with the addition of bioasphalt. This result implied that the resistance to rutting was reduced with the increasing of bioasphalt. This mechanical test performance is consistent with the studies conducted by Bailey and Zaroob [16], who recorded an increase in rut depth with the addition of used vegetable oil. On the contrary, the thermal cracking resistance of HMA at low temperatures improved with the addition of bioasphalt. Some et al. [17] revealed contradicting results, that is, the rutting depth of the binder modified with oil derived from sunflower and rapeseed (vegetable oil) was lower than that of the control mixture. Their result indicated that the resistance to permanent deformation improved with the addition of waste vegetable oil. Some et al. [18] investigated the effect of vegetable oil on the mixture performance. The decrease in the compression strength of warm mixed asphalt to resist stripping was recorded with the addition of 5% oil. Many researchers have explored vegetable oil as a rejuvenator for aged bitumen. For example, Bailey and Zaroob [16] discovered that adding 5% used vegetable oil can rejuvenate aged bitumen to its original condition in their research. No further extensive research has been conducted because of the unsatisfactory binder performance at high temperatures, which could be detrimental to the performance of asphalt mixtures and increase the rutting tendency. Owing to the insufficient review of available data, the performance of asphalt mixtures that are incorporated with WCO in the modified binder must be investigated comprehensively.

The present work highlights the important issue that no report has emphasized the fundamental factors that affect WCO performance. Theoretically, the performance of modified asphalt binders in HMA in terms of their rheological properties is affected by the variations in the quality of WCO, with the acid value identified as a parameter of quality measurement [19]. A high acid value leads to undesirable characteristics that could adversely affect asphalt mixture performance. Therefore, WCO should undergo pretreatment, which is the transesterification process, to reduce its high acid value.

The objective of the present study is to evaluate any improvement in the performance of HMA mixtures containing WCO after chemical treatment. Tests on resilient modulus, creep stiffness, and ITS for mechanical asphalt mixture evaluation were conducted in the laboratory to study the effect of untreated and treated WCO in modified asphalt binders on the performance of dense graded mixtures.

Table 1
Chemical properties of waste cooking oil (Asli et al. [11]).

Type of Free Fatty Acid	Waste Cooking Oil (%)
Oleic acid	43.67
Palmitic acid	38.35
Linoleic acid	11.39
Stearic acid	4.33
Myristic acid	1.03
γ-Linolenic acid	0.37
Lauric acid	0.34
Linolenic acid	0.29
cis-11-Eicosenoic acid	0.16
Heneicosanoic acid	0.08
TOTAL	100

2. Materials and preparation

2.1. Pretreatment of WCO

Initially, the acid value in the WCO sample was determined by using the titration method. An acid value test was conducted in accordance with the ASTM D1980 [20]. The single-step transesterification reaction via alkali catalysts was selected as the pretreatment method for untreated WCO. Pretreatment was conducted after the determination of acid value quality in the WCO sample. This process was proposed to minimize the presence of high acid value in the WCO and improve WCO performance. During the transesterification process, the reaction between WCO and methanol occurred in the presence of sodium hydroxide (NaOH) as catalyst (Fig. 1). Prior to this process, several optimum parameters were determined, such as the volume ratio (methanol:oil) of 6:1, the reaction time of 1 h at a temperature range of 60 –70 °C, and the catalyst concentration of 1% of the WCO volume [21,22]. The reaction was completed when the major layer was separated into the treated WCO (esters) at the upper phase and glycerol in the lower phase. The original dark brown color of the untreated WCO changed into light yellow (treated WCO) after the chemical treatment process (Fig. 2).