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Rutting resistance of untreated and treated waste cooking oil in bitumen after aging condition

M Nordiana[1], W A Wan Nur Aifa[1], M R Hainin[1], M W Muhammad Naqiuddin[1], A H Norhidayah[1], Y Haryati[1], A Juraidah[2] and P J Ramadhansyah[3]

[1]Faculty of Engineering, School of Civil Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor Bahru, Malaysia
[2]Faculty of Civil Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
[3]Faculty of Civil Engineering and Earth Resources, Universiti Malaysia Pahang, 26300 Gambang, Pahang, Malaysia
Corresponding author: ramadhansyah@ump.edu.my

Abstract. Waste cooking oil (WCO) is identified as a valuable potential waste material that can enhance the performance of conventional asphalt binder for road pavement construction. This study aims to evaluate the rutting resistance of bitumen incorporating untreated and treated WCO. Waste cooking oil dosage of 0%, 3%, 4%, and 5% by weight of binder was used throughout the experiments. The dynamic shear rheometer test was conducted to determine the performance of rutting resistance test. In addition, one way analysis of variance (ANOVA) was used to determined correlation of the sample. It was found that the rutting resistance performance was decreased as the test temperature increased. The results also indicated that modified binder with treated WCO exhibited the highest rutting resistance as compared to the untreated WCO. Based on analysis of variance it show that there are a significant difference in G*/sin δ for different untreated and treated WCO in modified binder.

1. Introduction

Bitumen is recognised as an essential coating material in bituminous pavements composition apart from the aggregates skeleton for pavement construction. In asphalt mixture composition, the binder functions as an adhesive agent for coating process and bind the aggregate particles together. Generally, 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 types such as carbonaceous materials, fine minerals and polymers [1,2]. An improvement of engineering properties for asphalt binder can be achieved with the application of a modifier by reducing temperature susceptibility and enhancing the rheological performance to withstand the environmental and traffic loading. Currently, a number of notable studies are being conducted worldwide to explore valuable resources from waste materials as a modifier for asphalt binder modification. In recent years, a wide range of oil-based modifications have been introduced, especially involving WCO. The WCO is also recognised as waste grease oil which is characterised as the by-product of fresh cooking oil produced during cooking and food processing. This oil source has recently gained widespread attention because of its satisfactory achievement as a potential waste material to enhance the physical and rheological performance of modified binder. Abundant of WCO production can cause prominent adverse impact and threat to the environment if not properly managed and disposed. Therefore, recycling or reusing WCO in modified asphalt binder is considered as an effective utilisation and management of this waste while at the same time ensuring economic and environmental benefits [3]. It is noteworthy that, most researchers have focused on the superior performance of WCO as a rejuvenator for aged binder [4-10], apart from substituting WCO in modified binder to improve rheological performance. The WCO performance as a modifier at high and low temperatures was evaluated by Wen et al. [11]. The rheological findings indicate declination of the complex modulus (G*), which resulted in a low rutting resistance at high temperature. On the contrary, an increment in thermal cracking resistance performance at low-temperature was observed to occur linearly with the addition of WCO content. Hence, there is the issue on rutting resistance performance that should be further clarified and investigated.

2. Materials and experimental methods

2.1. Asphalt binder
60/70 penetration grade bitumen was used as control sample through this study. According to Raissa et al. [12] reported that the penetration value of the binder was 69 dmm at 25°C and the softening point of approximately 52°C. The physical properties bitumen 60/70 was met the requirements of the Jabatan Kerja Raya (JKR) specification for Road Works [13].

2.2. Waste cooking oil and preparation
WCO was collected from a restaurant. At the field, the raw sample of WCO was filtered first by placing filter paper in a beaker to remove food, dirt, and impurities. The filtering process took approximately 1 h to complete before the filtered WCO was obtained. After the process, the impure particles remained on the filter paper, while the residues of the filtered WCO were collected for further testing. At laboratory, modified asphalt binder was prepared by replacing the WCO at different percentages i.e. 0%, 3%, 4%, and 5% (by weight of bitumen) and then these materials were blended using a high shear mixer at a constant speed of 1000 rpm for 1 h at 160 °C. Duration time (1 h) mixing was chosen to achieve a homogeneous mixing state. Thereafter, the samples were used for performance tests.

2.3. DSR and aging test
The dynamic shear rheometer (DSR) was used to characterize the viscous and elastic behavior of asphalt binders at medium to high temperatures. According to ASTM D7175 [14], DSR determines the complex shear modulus (G*) and phase angle of a specimen. G* is the total resistance to deformation during shear loading, and d is the time lag between shear strain and shear stress. Rutting resistance was determined by using a 1 mm-thick spindle 25 mm in diameter. In addition, short-term aging of asphalt binders was simulated in the laboratory by using an RTFO based on ASTM D2872 [15]. Short-term aging simulated the aging during hot-mix production and construction.

3. Results and discussions

3.1. Rutting resistance
A higher rutting resistance was achieved for untreated and treated WCO after aged condition as presented in Figure 1 and Figure 2. The rutting resistance performance was linearly decreased as the test temperature was increased and higher WCO content was replaced in the binder. The result indicated that the higher rutting resistance was achieved with control binder, according to the highest failure temperature at 76 °C as compared to the untreated WCO. The lower rutting resistance recorded by untreated WCO, based on lower failure temperature, was attained by this sample at 58 °C for 5%, 58 °C for 10%, 46 °C for 15% and 46 °C for 20% of untreated WCO replacement as shown in Figure 1. Meanwhile, the treated WCO recorded a higher rutting resistance performance in Figure 2 by increasing the failure temperature at 76 °C, 76 °C, 70 °C, 70 °C for 5%, 10%, 15% and 20% of treated WCO replacement, respectively as compared to the untreated WCO, as expected. It can be noticed that the failure temperature for control and modified binder with 5% and 10% of treated WCO was

increased after aged condition, thereby indicated a rutting resistance performance improvement. Besides, the increment of failure temperature was observed from untreated to treated WCO, which indicated an improvement of rutting resistance for the binder incorporated with treated WCO after chemical treatment as compared with untreated WCO.

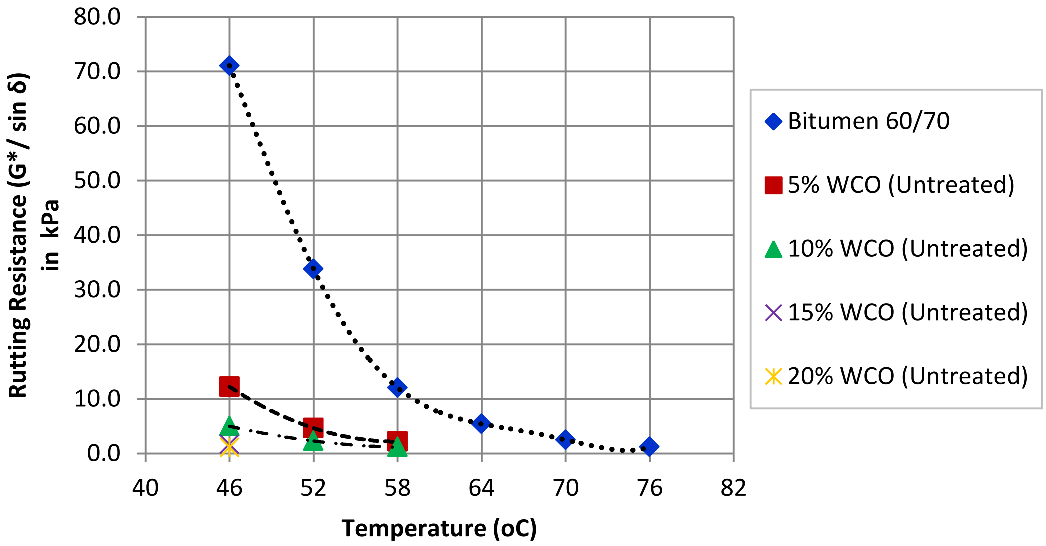

Figure 1. Rutting performance of WCO at untreated condition

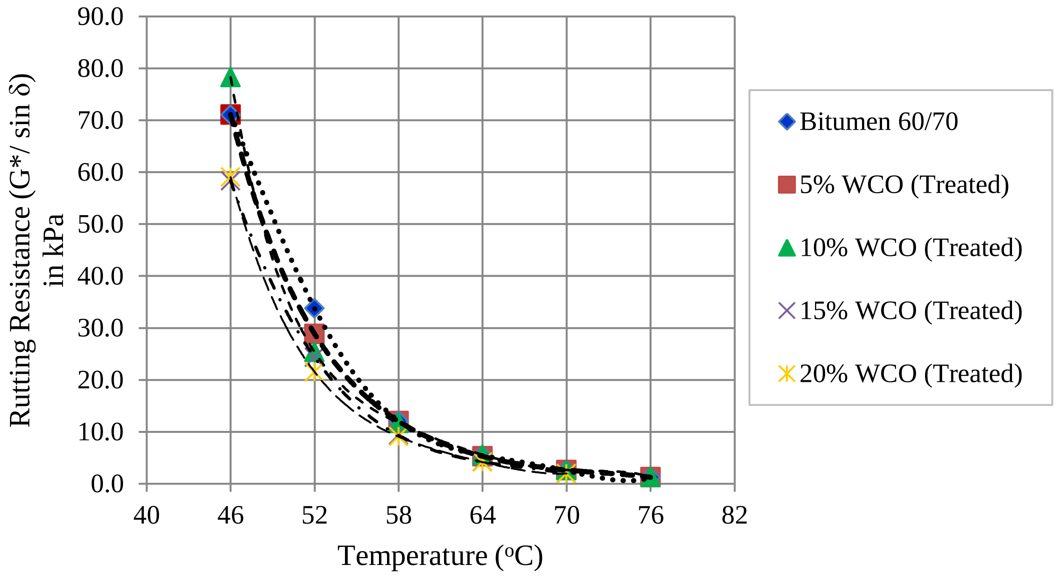

Figure 2. Rutting performance of WCO at treated condition

3.2. Failure temperature

The value at failure temperature as shown in Table 1 was compared between control and modified binder with untreated and treated WCO. The lower G*/sin δ was presented by untreated WCO as compared to the control binder for 1.18 kPa failed at 76 °C. An improvement of rutting resistance by the increasing of failure temperature at 76 °C, 76 °C, 70 °C, 70 °C was achieved with 5%, 10%, 15% and 20% of treated WCO, which presented as 1.23 kPa, 1.30 kPa, 1.95 kPa and 1.95 kPa. It indicated that, the modified binder, with treated WCO, exhibited the highest rutting resistance as compared to the untreated WCO and the performance reported was comparable with the control binder. A higher rutting resistance was achieved at aged condition due to the mechanical properties of binder become harder and more elastic solid-like as the formation of carbonyl, sulfoxides and asphaltenes fraction

[16]. The hard binder with high stiffness possessed in aged binder sample was able to withstand against permanent deformation at high temperature exposure, thereby had increased the rutting resistance performance. Therefore, the higher rutting resistance was achieved after aged condition. From Table 1, the difference in decrement from control to untreated WCO was recorded higher, this was attributed to the noticeable reduction of G*/sin δ for untreated WCO as compared to the control binder. Meanwhile, the difference in increment was observed from control to 5% and 10% of treated WCO, which were recorded as 4.2% and 10.2%. A lower different increment shown between control and treated WCO as the G*/sin δ of treated WCO was slightly higher as compared to the control binder. Despite that, the little increment of G*/sin δ for treated WCO indicated the rutting resistance was improved from the control binder. In contrast, from control to 15% and 20% of treated WCO, the difference in decrement was recorded for 22% at both percentages as the lower value of G*/sin δ was attained for treated WCO as compared to the control binder. It can be said that the increment of failure temperature was identified in treated WCO which indicated an enhancement of rutting resistance performance as compared to the untreated WCO. Besides, the better value of G*/sin δ achieved in treated WCO was comparable with the control binder thus indicated the superior performance as a promising modifier in binder modification.

Table 1. G*/sin δ at failure temperature for aged sample

Designation	WCO Content (%)	G*/Sin δ (kPa)	Failure Temperature (°C)
Control (60/70)	0%	1.18	76
Untreated WCO	5%	2.17	58
	10%	1.16	58
	15%	1.68	46
	20%	1.14	46
Treated WCO	5%	1.23	76
	10%	1.30	76
	15%	1.95	70
	20%	1.95	70

3.3. Analysis of Variance

The effect for different untreated and treated WCO in modified binder on the rutting resistance (G*/sin δ) was evaluated by using one way Analysis of Variance (ANOVA), which is summarized in Table 2 and Table 3. The null hypothesis (H_o) for this analysis was that the G*/sin δ of untreated and treated WCO was equal. The data was analysed based on 95% confident interval. The result of ANOVA presents the p-value of 0.01 (untreated WCO) and 0.01 (treated WCO), respectively, which was less than 0.05. As the $p < 0.0.5$, it implied that the null hypothesis was rejected and indicated that there was a statistical significant difference in G*/sin δ for different untreated and treated WCO in modified binder. It can be summarised that that the untreated and treated WCO had a significant effect on the rutting resistance performance.

Table 2. One way ANOVA for G*/sin δ (untreated WCO)

Source	Sum of Squares	df	Mean Square	F	p
Between groups	0.066	3	0.022	221.00	p < 0.01
Within groups	0.001	8	0.000		
Total	0.067	11			

Table 3. One way ANOVA for G*/sin δ (treated WCO)

Source	Sum of Squares	df	Mean Square	F	p
Between groups	0.132	3	0.044	440.75	p < 0.01
Within groups	0.001	8	0.000		
Total	0.133	11			

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4. Conclusions

The test results revealed that that an enhancement of physical and rheological performance was recorded in modified binder incorporating treated WCO as compared to the untreated WCO. The lower penetration with higher softening point was reported by the modified binder with treated WCO as compared to the untreated WCO. The rheological test indicated a noticeable improvement in which the higher failure temperature at 70 °C was achieved by treated WCO for all percentages replacement relative with 5%, 10%, 15% and 20% of untreated WCO which was at 64 °C, 58 °C, 46 °C and 46 °C, accordingly. Besides, the superior failure temperature in modified binder with treated WCO was comparable with the control binder.

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