Investigation on rheology and physical properties of asphalt binder blended with waste cooking oil

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Abstract. The service life of the concrete pavement is more than 20 years. While the service life of asphalt pavement is about ten years. The service life cannot be achieved due to pavement damage and increase the cost of road maintenance. The waste cooking oil gives a solution to soften the asphalt binder. The idea of using WCO is the possibility of transferring the aged asphalt binder condition from stiff to soft and reuse it for a new construction road. In this study, the bitumen grade 60/70 blended with 0, 2, 4, 6% of waste cooking oil by the weight of the bitumen. In this study, the bitumen prepared with various waste cooking oil percentage evaluated in terms of their properties such as Softening point, Penetration, penetration index, Penetration-Viscosity number, Viscosity, and Dynamic Shear Rheometer. The test result indicates that the penetration values increased with rising the content of the waste cooking oil and the softening point result decreased related to the quantity of the waste cooking oil. The viscosity of the binder reduced when increased the content of WCO. The strength of the binder (G*) will decrease, and the elasticity of the binder (&) will grow when increased the content of the oil. The rutting parameter decreased with increased WCO. From this finding, it concluded that the waste cooking oil has a potential impact on soft the asphalt binder and can be used to produce a soft asphalt binder. Moreover, the 60/70 grade asphalt binder can be 80/100 after adding 2% of waste cooking oil.

1. Introduction
The asphalt binder price is increased due to the high desire of it from the infrastructure companies and try to find alternative materials to replace it. Many studies search that the possibility of using waste materials as modified or replace the asphalt binder [1]. In Malaysia, one of the largest production material is waste cooking oil. The waste cooking oil comes from frying process which requires a high temperature to frying the food. Based on the analysis report that showed on [2], stated that the approximate amount reported is 15 million tons annually. However, the percentage of waste cooking oils that have been collected and recycled is only in the small amount which these entities are normally processed with the treatment stage and released into the river [3]. Waste oil recycling is considered manageable to alleviate these matters with the concerned or practiced of "high cost and natural resource conservation." Waste cooking oil as a modified in the bitumen, it can be less the cost and the demand for the bitumen. Other than that, the utilized cooking oil is as often as possible found as some garbage
materials in the landfill from the restaurants and houses [4]. Likewise, WCO utilized as a fuel in biodiesel [5]. Examinations demonstrated that utilizing of 19% oil by weight of the bitumen in the Reclaimed Asphalt Pavement (RAP), whenever planned and appropriately utilized, made utilization of reused blends containing 80% RAP conceivable [6]. Through restoration the properties of the aged bitumen asphalt especially the bitumen properties can be enhanced to re-establish the first proportion of asphaltenes to maltenes and recompense this hardness impact [7,8]. It is to give adequate coverage to new aggregate from the reclaimed pavement to deliver asphalt with reliable execution [9]. One previous study concluded that the penetration values increased with rising the quantity of waste cooking oil [10].

It observed by the previous study that the high quantity of WCO leads to an increase in the penetration outcome. On the other hand, increased the percentages of the WCO cause lowering the softening point values. The viscosity result was decreased linear with adding the WCO which is improved the workability of the asphalt binder [11]. Another researcher is concluding that the WCO has a strong effect on the penetration and softening point results [12,13]. The parameter of therutting $G'/\sin \delta$ observed that decreased with adding the high quantity of oil [14]. The addendum of WCO with virgin binder minimize the PG of the asphalt binder, indicating growing resistance to thermal cracking parameter but decreased resistance to rutting parameter [15]. Asphalt Binder modified by adding the WCO has indicated the softening point, viscosity and penetration value changes for binder asphalt [16]. The addition of waste frying oil in the bitumen binder can be growing the penetration value and reduced the softening point [17]. The main objective of this study to investigate the effect the waste cooking oil on the asphalt binder and it could change the physical and rheology properties from stiff to soft asphalt binder.

2. The Materials and Method Used

2.1 Materials Used

In this study, conventional bitumen 60/70 pen grade used for the whole sample preparations as well as a waste cooking oil in quantities of 0, 2, 4, 6% from the weight of the binder mix, respectively. Petronas Sdn supplied the bitumen. Bhd and waste cooking oil were collected from a local restaurant at Batu Pahat town in Johor, correspondingly. The waste cooking that blended with bitumen filtered by filtration papers with diameters 150mm for further investigation.

2.2 Method Used

The wet method used in this study to blend the waste cooking oil. Table 1, shows the Binder Identity and materials used. The virgin bitumen heated at the temperature not more than 110°C. Then, the bitumen poured in the aluminium cup. An additive used in this experiment was waste cooking oil (WCO), it was adding by a small amount during 20 min of mix time, and shear mix rate was 1500rpm with temperature 150°C. Figure 1. display the high mixer shear device.

| Binder Identity | Materials used (%) |
|-----------------|-------------------|
|                 | Asphalt binder 60/70 | Waste cooking oil |
| M               | 100                | 0                |
| N               | 98                 | 2                |
| U               | 96                 | 4                |
| Z               | 94                 | 6                |
Figure 1. High Mixer Shear Device.

It investigated the physical and rheology properties, and it conducted tests such as penetration, viscosity, softening point, Penetration index, penetration-viscosity number, and dynamic shear rheometer. Table 2, shows the number of tests, physical properties test names and the standard specification used.

| Number of tests | Test name                         | The specification of the test          |
|-----------------|-----------------------------------|----------------------------------------|
| 1               | Penetration                       | ASTM D5                                |
| 2               | Softening point                   | ASTM D36                               |
| 3               | Viscosity                         | AASHTO T136                            |
| 4               | Dynamic shear rheometer           | AASHTO T315                            |
| 5               | Penetration-viscosity number      | -                                      |

3. Result and discussion

3.1 Penetration test result
The result of the penetration test shown the effect of waste cooking oil on the stiffness of the bitumen. Besides, the penetration increased with rising the percentages of waste cooking oil. From the graph, it can conclude that each one percent of oil increases the penetration value nearly to 10mm. The penetration values of the binder with 2%, 4%, 6% WCO are 86.2mm, 108.33mm, and 156mm Respectively. It noticed that the binder with 6% of WCO is the highest penetration result related to the high quantity of the waste cooking oil. Figure 1, shows the penetration result.
3.2 Softening points result

The result for the softening point shown in figure 3; It noticed from the results values that the modification binders have lower softening points than the (virgin) unmodified binder. The softening point of the virgin binder obtained as 48.5°C. The softening values for hot mix asphalt binder with 2% WCO are 44°C, with 4% WCO is 39.75°C, and with 6% WCO is 36.35°C. As a result, adding WCO lead to decrease in the softening point which makes the binder softer than the virgin binder.

Figure 2. Show the penetration result.

Figure 3. Display the softening point result.

3.3 Penetration index PI

The penetration index used to identify the type of bitumen, and it can be classification to three groups blown bitumen, conventional paving bitumen and temperature susceptible bitumen (tar). The penetration index also can be used to measure temperature susceptibility. The results indicate that adding the waste cooking oil to the bitumen, it makes the penetration index decreased and change the type of bitumen
from conventional to tar. The WCO of 2% modification can give a result similar to the 80/100 grade and can use as conventional paving bitumen. Table 3, summarized the value of PI for virgin and modified bitumen at different percentages of waste cooking oil.

Table 3. PI at different percentages of waste cooking oil.

| Oil content (%) | Softening point (°C) | Penetration (mm) | Penetration index | Bitumen type          |
|-----------------|----------------------|------------------|------------------|-----------------------|
| 0%              | 50.5                 | 62.96            | -0.53            | Conventional paving bitumen |
| 2%              | 44                   | 86.2             | -1.55            | Conventional paving bitumen |
| 4%              | 39.75                | 108.3            | -2.4             | Tar                   |
| 6%              | 36.65                | 156              | -2.6             | Tar                   |

3.4 Penetration-viscosity number PVN

The PVN can be calculated based on viscosity at 135°C and penetration at 25°C which are the criterion specifications for the paving asphalt. Table 4, shows the effect of WCO on the PVN. The rise of the waste cooking oil was increasing the PVN values. The PVN value increased from -0.25 to 0.16 which have a percentage of 0% and 6% respectively. This high of PVN outcome shows the signs of the WCO addition in the bitumen to improve the temperature susceptibility of bitumen.

Table 4. PVN at different percentages of waste cooking oil.

| Oil content (%) | PVN value |
|-----------------|-----------|
| 0               | -0.25     |
| 2               | -0.13     |
| 4               | -0.02     |
| 6               | 0.16      |

3.5 Viscosity result

The viscosity of bitumen at compacting and mixing temperature supposed as a substantial factor in getting a good road pavement work. Because of the viscosity represent the ability of bitumen pumped through an asphalt plant and cover the aggregates in the asphalt cement mix, the viscosity result obtained for two temperature 135°C (compacting temperature) and 165°C (mixing temperature). Based on figure 4, it observed that the viscosity of virgin bitumen 60/70 is 628 cP at 135°C which is high viscous compared to the addition of 6% WCO which has the viscosity of 388.8 cP at the same temperature. However, at temperature 165°C the virgin binder record 170.4 cp and for the modified binder with 6% WCO the viscosity result was similar to the virgin binder with 115.2 cp. As a result, it concluded that by adding the waste cooking oil content, it would reduce the viscosity.
3.6 Dynamic Shear Rheometer (DSR)

The rheology properties of asphalt binders defined as two critical parameters which are complex modulus and phase angle. The G* consider as of the binder hardness at a different temperature, while δ is the phase angle between strain and stress. The value of the phase angle is between 0° to 90°. 0° means the materials consider as viscous and 90° means the materials considered as elastic [18]. Figure 3.4 display the result of the complex modulus and phase angle. The virgin binder gives the highest G* compare to the other modified binders. The virgin binders give 32.2 Kpa, and the 6% of WCO give 4.33 Kpa that because of the binder absorb the oily particulars from the waste cooking oil. The phase angle increased with higher content of the WCO and the δ° for the virgin binder was 80.65°, and for the modified binder with 6% of WCO, the δ° was 4.33°. The failure temperature for the virgin binder was 76C°, 2% of WCO is 70C° and for 4% and 6% of the WCO was the same temperature which is 64C°.

The G*\sinδ represent the rutting damage on the binder, figure 6, shows the effect of the WCO on the rutting parameter. From the graph, it concluded that when adding the waste cooking oil, it will reduce the rutting parameter. It is related to the properties of the WCO which make the binder softer and can
control the elastic of the binder by increased the content of the WCO. The $G^* \sin \delta$ for the virgin binder was 32.63 while the binder with 6% of WCO was 4.34.

Figure 6. Show the effect of the WCO on the rutting parameter.

4. Conclusions
Based on the outcome of the proposed characterization of laboratory tests, the important feedback and conclusions outlined below:

- The physical results were reasonable compared to the previous studies. Besides, the penetration result increased with the high content of WCO and softening point result; it reduced with raise the WCO percentages. The WCO effect the bitumen binder and reduce the viscosity to get better workability.
- From the penetration-viscosity number and penetration index results were concluded that the WCO has a significant effect on the binder by produce low-temperature susceptibility asphalt binders.
- The DSR outcome indicate that complex modulus is reducing, phase angles increased, and rutting resistance parameter of bitumen binder asphalt decreased with increased the content of WCO. For example, 60/70 bitumen grade transferred to 80/100 bitumen grade by adding 2% of the WCO.
- The outcome displays the benefits of waste cooking oil, and it can be used to soften the bitumen asphalt. The effect of the WCO will be more apparent with adding the WCO to the aged bitumen and investigate the chemical properties of it. This paper is the preliminary investigation of future work.

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