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Conventional physical and microwave properties of bitumen modified with waste cooking oil (WCO)

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Abstract:
Bitumen is a rheological, viscoelastic, thermoplastic and extremely complex material that has hydrocarbons as its predominant molecules with slight traces of others. Bitumen is semi solid at room temperature, liquid at high temperature and solid at very low temperature. Due to its complexity, till date complete understanding of its properties have not been fully known. Various techniques/methods have been developed by many researchers in order to study the behavior of this complex material. This research is aimed at developing another method of determining the properties of bitumen using microwave technology by way of examining the performance of bitumen PG 76 and PEN 60 – 70 modified with Waste Cooking Oil (WCO) using the conventional tests, dielectric constant (DC) and loss factor (LF). The modification was done by replacing neat bitumen with WCO at 0%, 1.5%, 3.0% and 4.5% by weight of the neat bitumen. The conventional tests conducted were penetration, softening point and viscosity, all in accordance with ASTM standards. The DC measurement was carried out at 2.45 GHz (ISM Band) while the LF was measured at 500 MHz frequencies. The results of the conventional tests showed that increasing the percentage of WCO has effect on the bitumen binders by increasing their penetration values and at the same time decreasing their softening point and viscosity. Also based on the DC value, the performance of PG 76 bitumen binder reduced with the increment in the WCO percentage. However, the results of the LF for two modified bitumen binders were illogical. Comparatively, it is the conclusion of this study that, the modified PG 76 bitumen binder will perform better than the modified PEN 60 – 70 bitumen. The result further reveals that the modified binders can only be used in temperate regions.

Keywords: *Bitumen, Microwave, Dielectric constant, Loss factor, Waste Cooking Oil*

1. Introduction

Flexible pavement consists of aggregate particles (coarse and fine) that are glued together by bitumen binder at high temperatures. Traditional bitumen binder is a residue found through the crude petroleum refining process. Due to the improvement in environmental regulations for new drilling, declining existing resources and changes to the refining process that maximize the fuel quantity while curtailing bitumen residue have recently increased the cost of bitumen [1]. Thus, it becomes more imperative to explore the likely alternative binder material to completely or partially replace the petroleum-based bitumen for the sustainable developments of flexible pavements.

Bitumen has important role especially for coating in pavement construction. Bitumen functions as satisfactory binder in improving the physical interlocking of bituminous mixtures. However, its properties change as it ages. This is attributable to bulk storage, mixing, paving, transport and storage on site. Consequently, the aging bitumen then leads to deterioration and major distress of pavement such as fatigue, rutting and cracking [2].

According to Chebil et al. [3], bitumen binder which is produced through the refining process of crude oil petroleum generally does not exhibit the desired properties for application in road pavement. Fresh bitumen, which exhibits insufficient properties as binder in pavement construction needs to be modified with various types of additives including oils, fine minerals, carbonaceous materials and polymers. Therefore, significant amount of research should be conducted by using the approach through modification process on improving asphalt binder properties [4].

Modification of bitumen by additives can be considered as one of the effective engineering solutions that should be practiced nowadays [5] in order to reduce deterioration and increase the durability of a bituminous layer. The bituminous layer should be improved with regard to performance properties, such as resistance to permanent deformation, fatigue and so on. Bitumen binder can be modified with Waste Cooking Oil (WCO) by blending at different proportions of the oil contents. Modification of bitumen binder and blending recycled bituminous concrete with WCO showed improvement in the performance qualities of the resulting blends from previous research [1, 6, 7].

Currently, microwave and radio-frequency signals are employed for a wide variety of applications. This comprises of wireless communication systems, mobile phone, radar, telemetry, medicine, biology, agriculture, industrial process control, etc. Significant efforts have also been dedicated toward the development of electromagnetic application in highway engineering [8]. According to Ma, et al. [9], microwave measurement methods are dynamic and their parameters can be measured instantaneously, and the waves have no effect on the Material Under Test (MUT) in any way [10]. According to Jilani et al. [11], every material have different electrical characteristics and these characteristics are dependent on the material dielectric properties. Valuable information is provided by these properties which helps engineers and researchers in utilizing such information in design, material characterization or for monitoring process quality. Thus, in this study, conventional physical and microwave tests (Dielectric Constant and Loss Factor) were used to determine the properties of PG 76 and PEN 60 – 70 bitumen modified with WCO.

2. Materials and Test Methods

In this study, PG 76 and PEN 60 – 70 grades bitumen binders were used as control binders, and the WCO was collected from a restaurant. The particles and impurities in the WCO were removed through filtering using cotton cloth. First, the two bitumen binders, PG 76 and PEN 60 – 70, were uniformly heated separately in an oven at 130° C to obtain their liquid form, making it easily pourable in a container. Modified asphalt binder was prepared by replacing the WCO sample at different percentages, namely, 0.0%, 1.5% 3.0%, and 4.5%, from the weight of bitumen and then mixed into the control bitumen binders. These materials were blended using a high shear mixer at a constant speed of 1000 rpm for 1 h at 185º C and 165º C respectively [12]. Thereafter, the prepared samples were tested to determine the change in their properties.

2.1 Conventional Tests

2.1.1 Penetration Test

The purpose of this test is to examine the consistency of a sample of bitumen by determining the distance in tenths of a millimeter that a standard needle vertically penetrates the bitumen specimen under known conditions of loading, time and temperature. The penetration test is simply a means for grading bitumen at ambient temperature. This test is carried out under a laboratory condition at 25°C, and the purpose of this experiment is to determine the depth that a weighted needle sinks into a bitumen specimen within 5 seconds [13].

2.1.2 Softening Point Test

Two horizontal disks of bitumen cast in shouldered brass rings are heated at a controlled rate in a liquid bath while each supports a steel ball. The softening point is reported as the mean of the temperatures at which the two disks soften enough to allow each ball, enveloped in bitumen, to fall at certain distance. This test was conducted according ASTM D36-95 [14] and aims to evaluate the softening point of bitumen binder, which allows for the classification of the behavior of bitumen at increased temperatures. In this test, as the temperature rises, the bitumen binder slowly changes from brittle to softer and less viscous liquid.

2.1.3 Brookfield Viscosity Test

The Brookfield viscosity test was conducted according to ASTM D 4402 [15]. The Brookfield thermosel, sample chamber, and spindle were preheated at 135° C. The blended sample of bitumen was poured into three sample chambers and then each of the sample chamber together with the blended sample were inserted into the rotational viscometer (RV) temperature controller unit. The spindle was lowered into the sample carefully and thereafter, the sample temperature was brought to the desired temperature (first at 135° C and later at 165° C) and allowed to equilibrate at that temperature for 15 minutes. The spindle was then rotated at 20 rpm. Five different viscosity readings from RV display were taken for the three samples poured into the sample chamber, allowing one minutes between each reading. The viscosity result is reported as the average of the three readings obtained from the three samples poured into the sample chamber.

Viscosity is used to determine the flow resistance and internal friction of the asphalt binder. The sample with low friction will record low viscosity reading in units of centipoise (cP). The viscosity value is measured for determination of mixing and compaction temperature during hot mix bitumen production.

2.1.4 Microwave Test

A Keysight E5071C network analyzer (ENA) was connected to a PC and control using USB key KT-85070E/20/22/30/UL software. The ENA has a wide frequency range from 300 KHz to 20 GHz. It was observed that most of the previous researchers used frequency range from 1 MHz to 20 GHz to determine properties of various materials. All dielectric data measurements were taken at room temperature (25 ± 1º C). Figure 1a and b show the ENA with two cables connected to it, core axial probe, and shorted kit. In order to avoid errors before the measurement, three standard calibrations at the tip of the probe were made in air, short and water [16].

After completing all connections, an operating frequency range of 1 MHz to 20 GHz was set. Then, the probe aperture was pressed firmly on the surface of the sample as indicated in Figure 2, and Transverse Electromagnetic wave (TE) was transmitted to the sample through the probe aperture. The wave was reflected back together with the material information to the ENA. The reflected signals were then converted to Dielectric Constant (DC) and Loss Factor (LF) using a built-in software manufactured from Keysight technology. The relationship between DC and percentage increment of WCO was determined at an Industrial, Scientific and Medical Radio Band (ISM Band), 2.45 GHz.

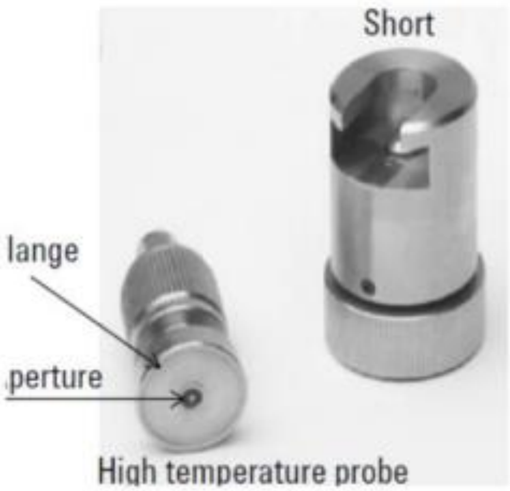

Figure 1a: Details of probe and calibration

Figure 1b: Economy Network Analyzer (ENA)

Figure 2: Bitumen testing by Coaxial probe

3 Results and Discussion

3.1 The Effects of WCO on Penetration

Figure 3 shows clearly the effect of WCO on penetration value of the modified PG 76 and PEN 60 – 70 bitumen binders. As the percentage of WCO increases, the penetration value also increases which shows that WCO has significant effect on penetration value. Similar trend was reported by Asli [2], Al-Omari et al. [17] and Asli et al. [18]. From the figure, it can also be seen that the effect of the modifier is more pronounced on PEN 60 – 70 as compared to PG 76. This is because the raw PG 76 bitumen is stiffer than PEN 60 – 70 bitumen.

3.2 The Effects of WCO on Softening Point

As shown in Figure 4, the softening point of PG 76 decreases from 60.8º C to 53.8º C while that of PEN 60 – 70 decrease from 47.5º C to 42º C as the percentage of WCO increases. The decrease in phase change of temperature among the bitumen grades indicates that PEN 60 – 70 bitumen binder has less resistance to high temperature. Higher softening point value of bitumen binder is an indication that the binder is less susceptible to temperature.

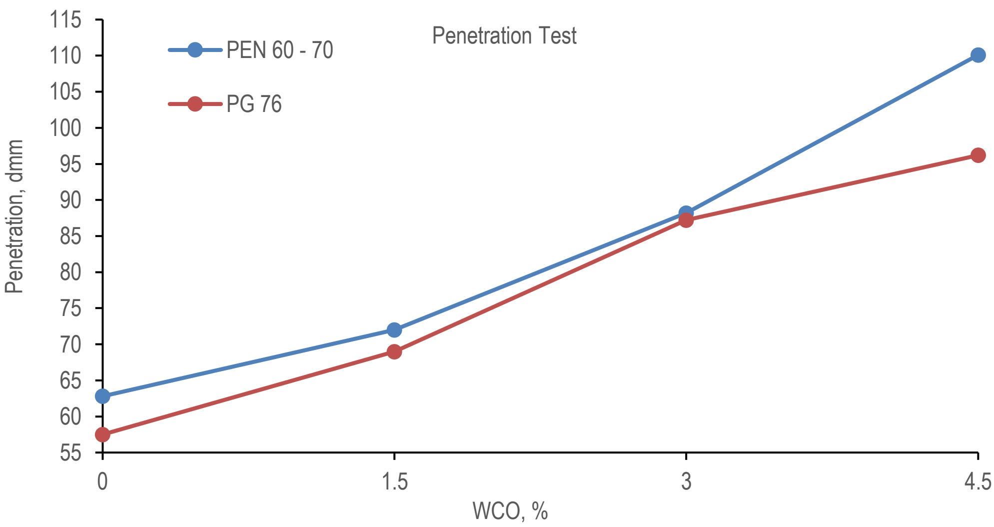

Figure 3: Penetration value of PG 76 and PEN 60 – 70 at various percentages of WCO

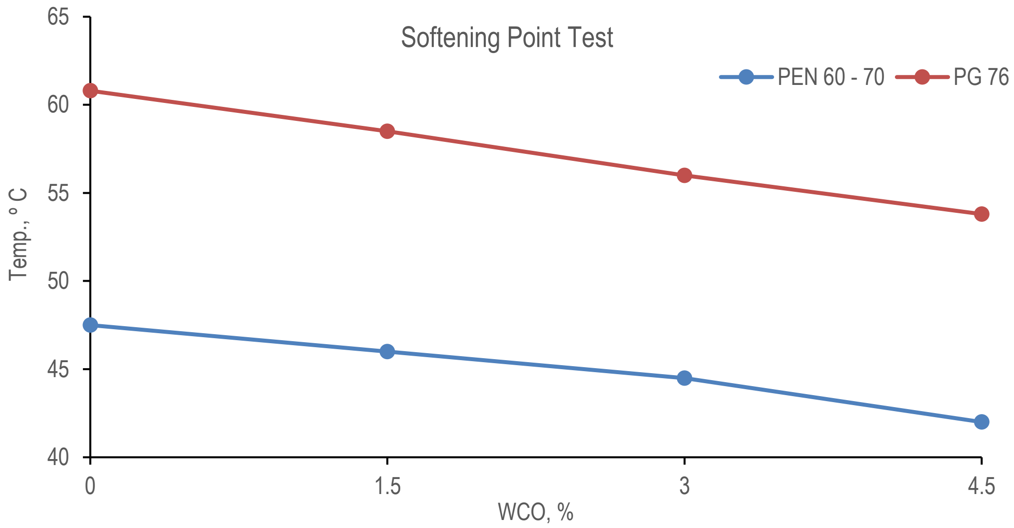

Figure 4: Softening point of PG 76 and PEN 60 – 70.

3.3 The Effects of WCO on Viscosity

The rotational viscosity test results at 135° C are shown in Figure 5. The results presented decreasing trends of viscosity values for both modified PG 76 and PEN 60 – 70 bitumen with the addition of WCO. For PEN 60 – 70, two different spindles, S27 and S21, were used for 0 and 1.5 % WCO and 3.0 and 4.5 % WCO respectively. This further revealed the softness of PEN 60 – 70 when compare with PG 76. The viscosity was consistently reduced from the control sample, which was 1500 cP for PG 76 and 700 cP for PEN 60 – 70, at 1.5, 3.0 and 4.5% replacement of WCO. This shows that the modified binders will have a good workability with low rutting resistance. On the other hand, it can increase fatigue cracking resistance at high temperature.

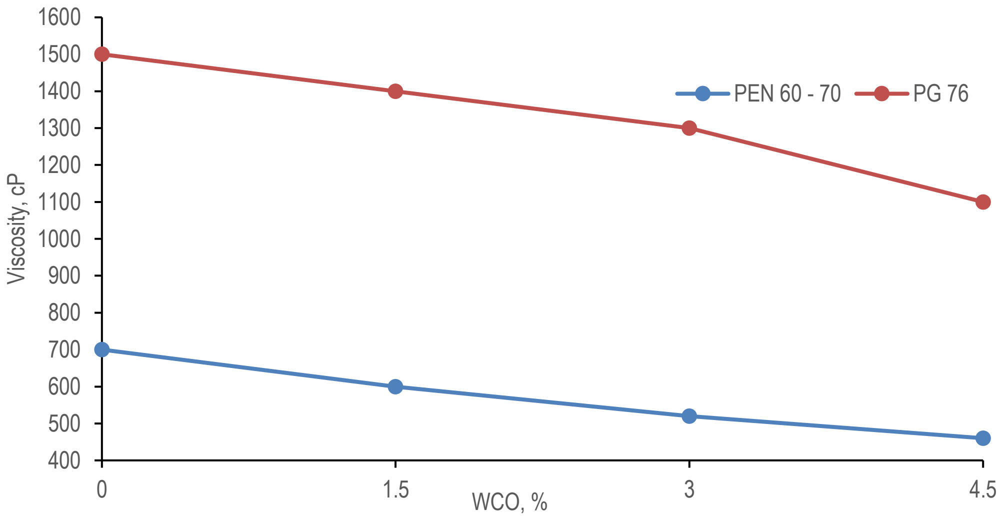

Figure 5: Viscosity of modified PG 76 and PEN 60 – 70 bitumen with WCO at135°C

3.4 The Effects of WCO on Dielectric Constant (DC)

According to Jilani et al. [11], every material have different electrical characteristics and these characteristics are dependent on the material dielectric properties. The higher the DC of a material, the better the isolation to conduct electricity and the better the material to store more electric charges. Thus, materials with high DC values are better in performance than those with lower DC values. From Figure 6, the DC of PG 76 at 0 % WCO was 3.0317, but decreased to 2.9127 at 4.5 % WCO. This shows that the performance of the binder decreased with increase in WCO content. However, for PEN 60 – 70, the DC increased from 2.9201 at 0 % WCO to 3.0286 at 4.5 % WCO. Although high DC was observed at 1.5 % WCO, the results show that increasing the percentage of WCO increases the performance of the binder.

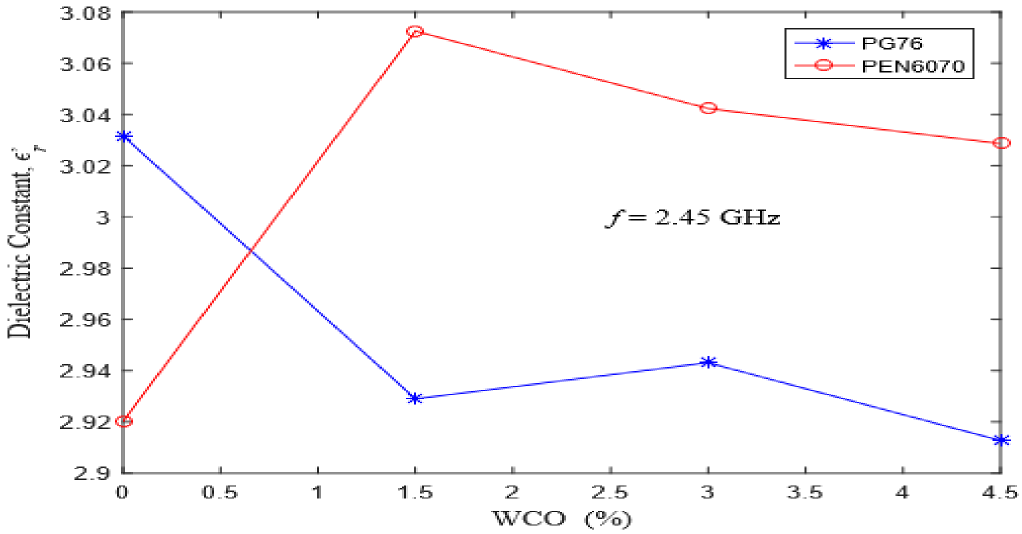

Figure 6: Relationship between DC and WCO modified PG 76 and PEN 60 – 70 at 2.45 GHz.

3.5 The Effects of WCO on Loss Factor (LF)

Figure 7 shows the relationship between the LF and WCO modified PG 76 and PEN 60 – 70. This relationship was determined at 500 MHz because the noise produce by waves at that frequency is usually minimum. Material with low value of LF normally perform better. This is because LF value is determine by the presence of ion in a material. Thus, material with high ion content will have high LF value. The LF result of modified PG 76 bitumen binder shows that the material will still perform in service even after the modification. But in the case of modified PEN 60 – 70 bitumen binder, the result shows that the ion content in the binder increases with increase in WCO content, thereby increasing its LF.

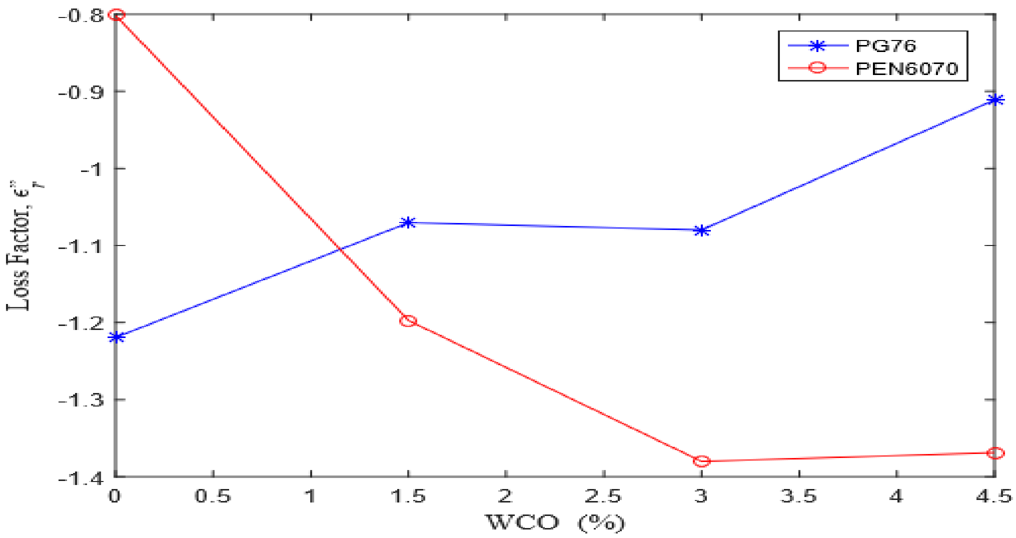

Figure 7: Relationship between LF and WCO modified PG 76 and PEN 60 – 70 at 500 MHz

4 Conclusions

Based on the experimental results from the two types of bitumen binders in terms of conventional and microwave tests, increase in penetration value was observed as a result of increasing the percentage of WCO to PG 76 and PEN 0 – 70 bitumen. This shows that addition of WCO has effect on the temperature susceptibility. Furthermore, the addition of the WCO made both the two bitumen samples to be softer by decreasing their softening point. This is an indication that the modified bitumen cannot be use in regions with high temperature. However, the minimum softening point of 53.8° C and 42° C obtained for the modified PG 76 and PEN 60 – 70, respectively, can still be acceptable for moderate weather regions. Similarly, the addition of WCO led to the decrease in the rotational viscosity of the modified bitumen samples. This can help in obtaining better bitumen workability at lower working temperatures. The DC result shows that PG 76 bitumen binder performance decreases with increase in WCO percentage, this result is similar to the result of the conventional tests conducted on the same material. But there was contradiction between the DC and conventional tests results in the case of PEN 60 – 70. Also, the results of LF for the two modified bitumen binders are not in agreement with that of DC of the same binders. The contradiction could be attributed to the type of core axial probe used in this research work.

Recommendation

In this study, commercial core axial probe which is sensitive to high frequency was used. Therefore, low frequency material like bitumen should be studied using a probe with high sensitivity to low frequency. Further study on bituminous materials using microwave should be conducted because it very simple (does not require complex set up), less time consuming and cost effective.

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