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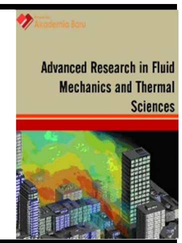

Effect of Viscoelastic Behaviour of Cellulose Oil Palm Fiber (COPF) Modified 60-70 Asphalt Binder for Deterioration for Roads and Highways

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ABSTRACT

This paper dealt with the viscoelastic behaviour of Cellulose Oil Palm Fiber (COPF) modified 60-70 penetration grade asphalt binder for the deterioration of roads. The main objective of this study is to investigate the effect of various COPF content on the physical and rheological properties of penetration grade 60-70 asphalt binder. Laboratory tests performed comprises of viscosity, penetration, softening point, short & long term ageing and complex shear modulus (G*). The COPF was blended in 0.2, 0.4, 0.6, 0.8 and 1.0% by weight of asphalt binder including 0% as control. The COPF modified asphalt binder showed an increasing viscosity and softening point with increase of COPF content, whereas penetration decreases as the COPF increases for the binder. The complex shear modulus (G*), rutting factor (G*/sin δ) and fatigue factor (G*sin δ) show significant improvement for the modified samples compared to unmodified samples. The results indicated that the COPF modified asphalt binder has high potential to resist permanent (rutting) deformation and fatigue cracking than the unmodified sample.

Keywords:
Cellulose oil palm fiber, rheological properties, deterioration, viscoelastic, complex shear modulus (G*), short and long term aging

1. Introduction

The main cause of premature failure of pavements is rutting due to uncontrolled large and heavy axle loads, increased traffic levels and higher tire pressures. As the viscoelastic properties of asphalt (bitumen) binder is temperature-dependent, asphalt binder becomes viscous and displays plastic flow when subjected to loads higher than its viscosity at a higher temperature. The plastic flow occurs due to lack of internal friction between aggregate particles and use of excess asphalt binder [1]. Some undesirable effects can occur mainly due to high number of vehicles imposing repetitive higher axle loads on roads, environmental condition and construction errors. These

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usually result in permanent deformation (rutting), fatigue and low temperature cracking. Consequently the service life of the road pavement is decreasing. Fatigue cracking and rutting deformation are the most common distresses in road pavement which result in the shortening of pavement life and increase maintenance cost as well as road user cost, vehicle operating cost, user delay cost etc. So, it is a vital to find out ways to reduce the asphalt pavement deterioration and increase its service life. Many studies have been conducted to improve road pavement characteristics which can provide a comfortable ride and to ensure greater durability and longer service life against climate changes and traffic loading [2].

To minimize the deterioration and, thereby, to increase the long-term durability of a flexible pavement, the bituminous layers should be improved with regard to performance-related properties, such as resistance to permanent deformation, low temperature cracking, load associated fatigue, wear and tear, stripping and ageing. One way of increasing the quality of a flexible binder courses is to use of high quality asphalt binder. Modification of asphalt binder is one of the approaches to improve its quality. A common method for asphalt binder modification is by adding polymer, although rubber and other oil based materials are being used to enhance the viscosity of the neat binder [3].

Cellulose fiber in general had been extensively investigated by various research groups in many countries to ascertain their suitability as substitutes for conventional synthetic fiber. The fibers from coconuts, sisal, jute, sugar cane, banana, wood, palm, flax and elephant grass are among the many studied by various investigators.

In Malaysia, oil palm is one of the most important commercial crops. Currently, there are about 3.6 million hectares of oil palm plantation producing annually over 10 million tonnes of crude palm oil (CPO), making Malaysia to be one of the major producer of palm oil. However, about 2.8 to 3.0 million tons of biomass wastes are produced per year in the process. This waste has been converted into reusable products such as particleboard, fiberboard, block board, solid fuel pellets, and pulp and papers. However, the conventional way of disposing most of these wastes is by burning [4].

The effect of cellulose oil palm fibers (COPF) in the fatigue performance of surface course other than the traditional drain down study is worth investigating [5]. From other studies also believed that the rheological properties of the PG 58 could be consolidated by utilizing natural cellulose fibers obtained from date or oil palm EFB [6-8]. Fiber content of 0.375% by the weight of total mix for the date palm fiber improved the blend up to PG 76 and as for the oil palm fiber; fiber content of 0.3% improved the blend up to PG 70. Therefore, in this study, the rheological properties of COPF modified 60-70 asphalt binder were investigated.

2. Materials

2.1 Bitumen (Asphalt) Binder 60-70 Penetration Grade

Asphalt binder is a lowloss material as loss tangent, tan δ ($\varepsilon''/\varepsilon'$) <0.5 and its microwave permittivity (real part, dielectric constant) value ranges from 2 to 7 depending on grade of bitumen and asphaltenes content [9]. The dielectric constant can be described in terms of the polarity and concentration of the various fractions of the bitumen [10]. Since the performance of the modifier is of concerned here, commonly use bituminous binder 60-70 was selected.

2.2 Cellulose Oil Palm Fiber

The cellulose oil palm fibers (COPF) were made from empty fruit bunch (EFB) by way of various methods of pulping. COPF are available in loose and pellet form. The cellulose fiber, which was used in this study, was provided in loose form by packageing (Ecopak) Sdn. Bhd Malaysia. This cellulose fiber was grinded twice to be prepared for evaluating the physical properties and used in the mixture. The quantity of COPF required for this study was analysed as presented in Table 1.

Table 1
The amount of fiber used to blend with the 60-70 penetration grade asphalt binder

No.	Weight of asphalt [g]	COPF [%]	Weight of COPF for the penetration asphalt grade of 60-70 [g]
1	500	0.2	1.0
2	500	0.4	2.0
3	500	0.6	3.0
4	500	0.8	4.0
5	500	1.0	5.0
Total required quantity of COPF			15.0

Table 2
Physical properties of binder

Asphalt grade	Test	Temperature [˚C]	Average reading	Specification ASTM/AASHTO
	Penetration [deci-mm]	24	67.8	60-70
60-70	Softening point [˚C]	-	49.25	49-56
	Rotational Viscosity	135	500	-
	[cP]	165	242	-

Accordance with ASTM D2872 [14]

2.3.5 Long Term Ageing

The Pressure Ageing Vessel, PAV test was used to prepare sample for DSR test under long term ageing condition, which occurs in the service life of pavement. The test was conducted in accordance with ASTM D6521 – 13 [15].

2.3.6 Dynamic Shear Rheometer (DSR)

The Dynamic Shear Rheometer (DSR) is used to characterize the viscous and elastic behavior of asphalt binder at high and intermediate service temperatures. The DSR measures the complex shear modulus (G*) and phase angle (δ) of asphalt binder at the desired temperature and frequency of loading. In this study, DSR test was carried out on both modified and unmodified binder for the un-age, short and long term ageing conditions according to AASHTO T 315 [16].

2.3.7 Mesh screen analysis

Mesh screen analysis was carried out on the COPF to measure its particle size distribution. Figure 1 shows the sieve analysis of COPF and the particle size distribution of the used COPF.

3. Sample Preparation

Modification of asphalt binder by the COPF was investigated using 60-70 penetration grade asphalt. Six (6) samples were prepared by blending bitumen with different percentages of COPF.

The percentage of COPF was 0, 0.2, 0.4, 0.6, 0.8, and 1.0% by weight of asphalt binder, where 0% is the control specimen. Rutting and fatigue parameters were measured for each of the blended samples using the Direct Shear Rheometer (DSR) less than three (3) different conditions, un-aged, short and long term ageing samples.

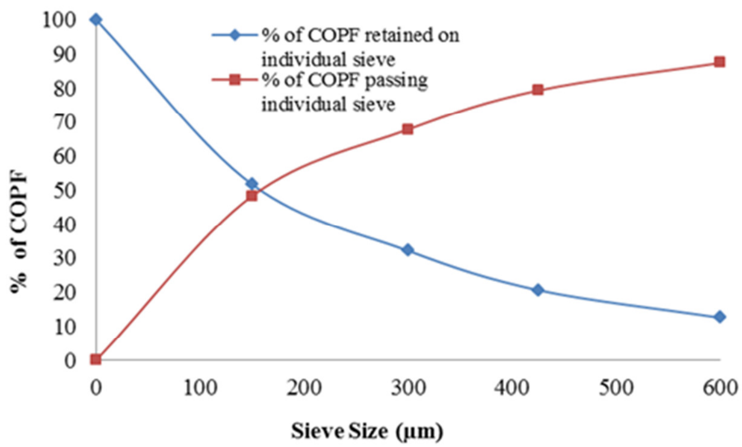

Fig. 1. Mess Screen analysis of COPF

4. Results and Discussion

Penetration, Viscosity and Softening point test were carried out on samples of binder blended with COPF to investigate the effect of COPF on 60-70 penetration grade binder. Table 3 presented the results of Penetration, Viscosity, and Softening point test on un-aged modified samples. The penetration value is decreasing with increase of COPF content. The viscosity values at 135ºC and 165ºC were increasing as the COPF content increases. The softening point of modified samples increases by increasing COPF content for 60-70 penetration grade binder.

4.1 Rheological Properties

Using the DSR equipment, the rheological properties of COPF modified 60-70 asphalt binder was evaluated by measuring the complex shear modulus, G* and phase angle, δ. The DSR test was carried out in three categories; un-aged, short term ageing (RTFO) and long term ageing (PAV) samples.

4.1.1 Rutting characteristics of un-aged binder

Figure 2 shows that the rutting resistance parameter (G*/sinδ) increases with decrease in temperature, meaning at high temperatures, chances of rutting is high for both modified and unmodified 60-70 binder. According to Strategic Highway Research Program (SHRP), for un-age binder, G*/sinδ must not be less than 1.0 kpa. Based on these results, at temperatures above 76ºC, 60-70 asphalt binder will not be able to resist rutting whether modified or not. However, the modified binders show better resistance to rutting at all test temperatures compared with the unmodified samples.

Figure 3 shows how COPF content affect rutting resistance at different temperatures for 60-70 un-aged binder. From the plot, it can be observed that 0.4% to 0.6% COPF content give better rutting resistance compared to the control sample (refer Figure 3). The highest rutting resistance (G*/sinδ) value was found at a temperature of 46ºC, which reduces as the temperature increase. At

76ºC, the rutting resistance factor (G*/sinδ) value reduces to less than 1.0 kpa, which failed to meet the SHRP specification for rutting resistance of an un-age asphalt binder.

Figure 4 shows an un-age binder, with the increase of temperature, the phase angle δ become high and the lower value of δ for the each temperature is for the 0.4% in COPF blended. The result shows the relationship between (G*/sinδ) and δ is opposite, meaning that with the increase in phase angle δ, the corresponding value of (G*/sinδ) is decreasing. But also 0.4% in COPF blended is the ultimate result for the δ compare with other percentages (%) of COPF blended.

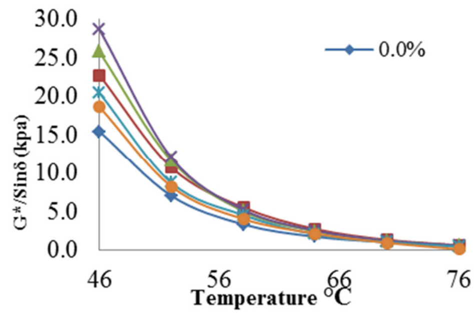

Fig. 2. Variation of G*/sinδ with temperature of COPF modified un-aged binder

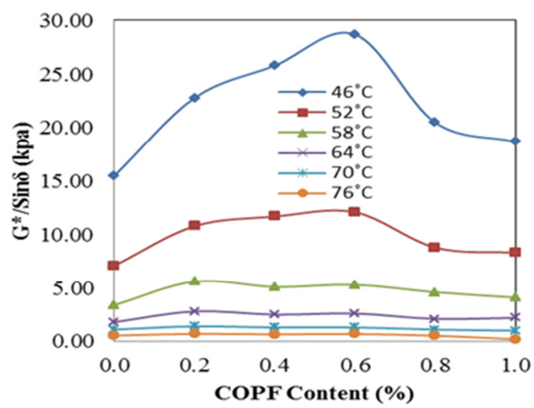

Fig. 3. Variation of G*/sinδ with COPF content at various temperatures for un-aged binder

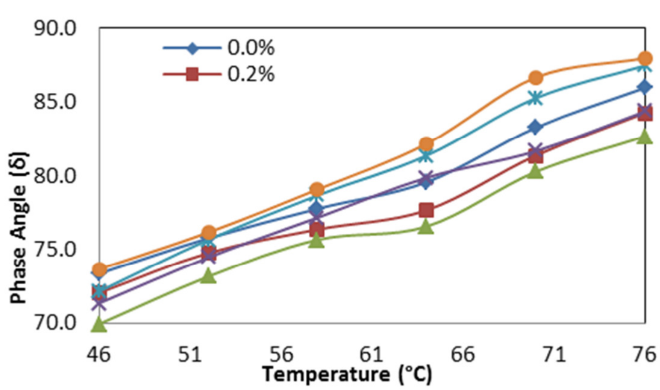

Fig. 4. Variation of phase angle δ with temperature of modified un-aged binder

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4.1.2 Rutting characteristics of short term aged binder

Figure 5 shows that the rutting resistance parameter (G*/sin δ) increases with decrease in temperature, implies that at high temperatures, chances of rutting is high for both modified and unmodified 60-70 short term aged binder. According to SHRP, for short term-age binder, G*/sinδ must not be less than 2.2 kpa. Based on these results, at temperatures above 70ºC, short term aged 60-70 asphalt binder will not be able to resist rutting whether modified or not. However, the modified binders show better resistance to rutting at all test temperatures compared with the unmodified samples.

Figure 6 (left) shows how COPF content affect rutting resistance at different temperatures for 60-70 short term-ageing binder. From the plot, it can be observed that 0.4% to 0.6% COPF content give better rutting resistance compared to the control sample.

Figure 6 (right) shows, from an un-age binder, by increasing the temperature δ become high and the lower value of δ for the each temperature is for the 0.4 and 0.6% in COPF blended respectively. The result shows the relationship between (G*/sinδ) and δ is opposite, meaning that with the increase in phase angle δ, the corresponding value of (G*/sinδ) is decreasing. But at 0.4 and 0.6% of COPF blended binder is the ultimate result for the δ compare with other percentages (%) of COPF blended.

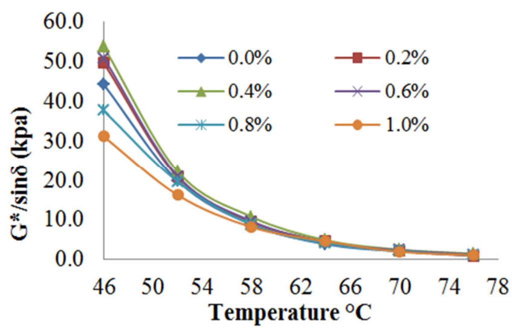

Fig. 5. Variation of G*/sin δ with temperature for short term aged COPF modified binder

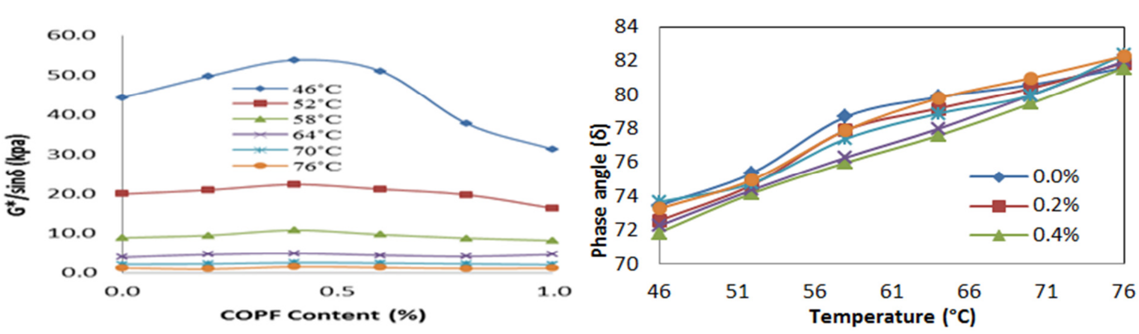

Fig. 6. (left) Variation of G*/sinδ with COPF content at various temperatures (right) Variation of phase angle δ with temperature of 60-70-COPF modified asphalt binder for Short term-aged binder

4.1.3 Fatigue Characteristics of Long Term Aged Binder

The fatigue characteristic of the binder was calculated from the DSR's complex shear modulus (G*). The higher the product of G* and sinδ, the higher the fatigue resistance.

Figure 7 (left) shows that the fatigue resistance parameter (G*sinδ) increases with decrease in temperature, meaning at high temperatures, chances of fatigue cracking is low for both modified and unmodified 60-70 long term aged binder. According to SHRP, for a long term-aged binder, G*sinδ must not be greater than 5000 kpa. Based on these results, at temperatures above 310C, unmodified 60-70 binder will be able to resist fatigue cracking, but modified 60-70 asphalt binder can resist fatigue cracking for as low as 31˚C. Thus, the modified binders show better resistance to fatigue cracking at all test temperatures compared with the unmodified samples. Figure 7 (right) shows how COPF content affect fatigue resistance at different temperatures for 60-70 long term-ageing binder. From the plot, it can be observed that 0.4% to 0.6% COPF content gives a better fatigue resistance compared to the control sample.

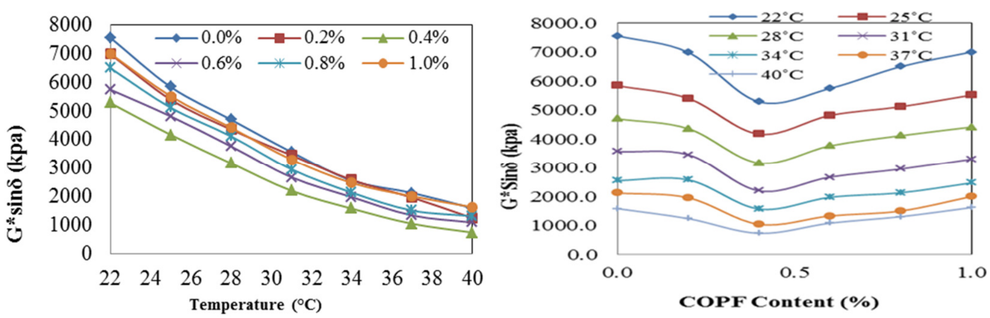

Fig. 7. (left) Variation of G*sinδ with temperature for COPF modified (right) Variation of G*sinδ with COPF content at various temperatures for long term ageing binder

5. Conclusion

The following conclusions can be drawn from the study:

The complex shear modulus, G* shows significant improvement for the modified samples compared to unmodified samples. The COPF modified 60-70 binder shows better rheological properties compared to the unmodified samples. The modified binder gave the best fatigue resistance at 0.4% COPF content. Similarly, rutting resistance factor of the modified binder is best at 0.4% COPF content. The modification of 60-70 binder with 0.4% COPF gives the optimum improvement of rheological properties of asphalt binder.

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