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EFFECT OF VISCOELASTIC BEHAVIOR OF CELLULOSE OIL PALM FIBER (COPF) MODIFIED 60-70 ASPHALT BINDER FOR DETERIORATION FOR ROADS AND HIGHWAYS

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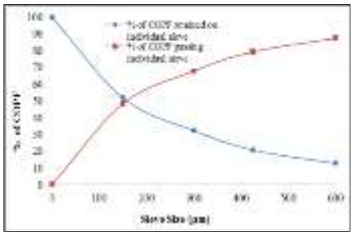
Graphical abstract



Abstract

This paper dealt with the viscoelastic behavior of Cellulose Oil Palm Fiber (COPF) modified 60-70 penetration grade asphalt binder for the deterioration of roads. The main objective of this study was to investigate the effect of various COPF contents on the physical and the rheological properties of penetration grade 60-70 asphalt binder. Laboratory tests performed comprised of viscosity, penetration, softening point, short & long term ageing, as well as 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 the increase of COPF content, whereas the penetration decreased as the COPF was increased for the binder. The complex shear modulus (G*), rutting factor (G*/sin δ), and fatigue factor (G*sin δ) showed significant improvement for the modified samples compared to the unmodified samples. The results indicated that the COPF modified asphalt binder had 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.

Abstrak

Kertas kerja ini mengkaji likatkenyal Fiber Selulosa Kelapa Sawit (COPF) dengan pengubahsuaian gred penembusan 60-70 pengikat asfalt untuk jalan raya. Objektif kajian adalah untuk mengkaji kesan COPF pada sifat fizikal dan reologi gred penembusan 60-70 pengikat asfalt. Ujian makmal dijalankan mengandungi kelikatan, penembusan, titik pelembutan, penuaan jangka pendek & panjang, dan modulus ricih kompleks (G *). COPF diadun dalam 0.2, 0.4, 0.6, 0.8, dan 1.0% mengikut berat pengikat asfalt, termasuk 0% sebagai kawalan. Pengikat asfalt COPF yang diubahsuai menunjukkan peningkatan kelikatan dan titik pelembutan dengan peningkatan kandungan COPF, manakala penembusan berkurangan apabila COPF ditambah sebagai pengikat. Modulus ricih kompleks (G*), aluran faktor (G*/sin δ), dan faktor keletihan (G*sin δ) menunjukkan peningkatan yang ketara bagi sampel yang diubahsuai berbanding dengan sampel tidak diubahsuai. Keputusan menunjukkan bahawa pengikat asfalt COPF yang diubahsuai mempunyai potensi yang tinggi untuk menahan (aluran) ubah bentuk kekal dan keletihan retak berbanding sampel yang tidak diubahsuai.

Kata kunci: Fiber selulosa kelapa sawit, sifat reologi , kemerosotan , likatkenyal , modulus ricih kompleks (G*) , penuaan jangka pendek dan panjang.

1.0 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 usually result in permanent deformation (rutting), fatigue, and low temperature cracking. Consequently, the service life of the road pavement is decreased. Fatigue cracking and rutting deformation are the most common distresses in road pavement that result in the shortening of pavement life and increasing in maintenance cost, as well as road user cost, vehicle operating cost, user delay cost, etc. So, it is vital to identify ways to reduce the asphalt pavement deterioration and increase its service life. In fact, many studies have been conducted to improve road pavement characteristics, which can provide a comfortable ride and to ensure greater durability, as well as 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 the 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 have been 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 tons of crude palm oil (CPO), making Malaysia to be one of the major producers 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, as well as 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, it has been 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.

2.0 MATERIALS

2.1 Bitumen (Asphalt) Binder 60-70 Penetration Grade

Asphalt binder is a low loss material as the loss tangent is tan δ (ε''/ε') <0.5, and its microwave permittivity (real part, dielectric constant) value ranges from 2 to 7, depending on the grade of bitumen and the asphaltenes content [9]. The dielectric constant can be described in terms of the polarity and the concentration of the various fractions of the bitumen [10]. Since the performance of the modifier had been the concern here, commonly used 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) via various methods of pulping. COPF are available in loose and pellet forms. The cellulose fiber, which was used in this study, was provided in loose form by packaging (Ecopak) Sdn. Bhd. Malaysia. This cellulose fiber was ground twice to be prepared for evaluating the physical properties and used in the mixture. The quantity of COPF required for this study was analyzed, 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
60-70	Penetration [deci-mm]	25	67.8	60-70
	Softening point [°C]	-	49.25	49-56
	Rotational Viscosity [cP]	135	500	-
		165	242	-

2.3 Preliminary Tests

Preliminary tests were carried out on 60-70 asphalt binder to ensure that it satisfied the requirement of this study. Viscosity, Penetration, and Softening Point tests were used in this study to characterize the asphalt binder. Besides, mesh screen analysis was conducted on the COPF. Table 2 presents the characteristics of the asphalt binder used.

2.3.1 Viscosity Test

Viscosity tests were carried out at 135°C and 165°C because those temperatures were approximate to the paving in the field and quarry mixing plant respectively. Brookfield rotational viscometer was used in this study based on ASTM D4402 / D4402M – 13 [11] to determine the viscosity of the asphalt binder at different temperatures.

2.3.2 Penetration Test

The standard penetration test procedure used standard needle under 100g loads for 5 seconds at the temperature of 25° C. The test was conducted in accordance with ASTM D5 / D5M – 13 [12].

2.3.3 Softening Point Test

In this study, Softening point test was carried out in accordance with ASTM D36 / D36M – 12 [13].

2.3.4 Short Term Ageing

Short Term Ageing test was carried out by Rolling Thin Film Oven Test (RTFOT), to simulate short term ageing that occurred in asphalt plants during the manufacture of hot mix asphaltic concrete. The RTFOT test was used to prepare the sample for DSR test under short term ageing condition. The test was conducted in 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 occurred in the service life of the pavement. The test was conducted in accordance with ASTM D6521 – 13 [15].

2.3.6 Dynamic Shear Rheometer (DSR)

The Dynamic Shear Rheometer (DSR) was used to characterize the viscous and the 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, as well as frequency of loading. In this study, DSR test was carried out on both modified and unmodified binder for the un-age, as well as 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.

3.0 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 percentages of COPF were 0, 0.2, 0.4, 0.6, 0.8, and 1.0% by weight of asphalt binder, where 0% was 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, as well as short, and long term ageing samples.

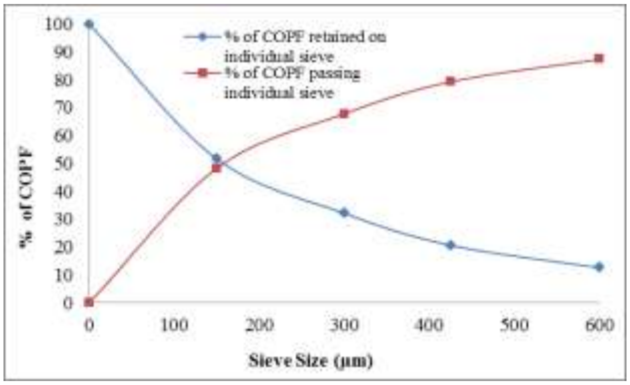


Figure 1 Mess Screen analysis of COPF

4.0 RESULTS AND DISCUSSION

Penetration, Viscosity, and Softening point tests were carried out on samples of binder blended with COPF to investigate the effect of COPF on 60-70 penetration grade binder. Table 3 presents the results of Penetration, Viscosity, and Softening point tests on un-aged modified samples. The penetration value decreased with the increase of COPF content. Besides, the viscosity values at 135°C and 165°C increased as the COPF content was increased. The softening point of modified samples increased as well by increasing the 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) increased with the decrease in temperature, meaning at high temperatures, chances of rutting was high for both modified and unmodified 60-70 binder. According to the Strategic Highway Research Program (SHRP), for un-age binder, the G*/sinδ must not be less than 1.0 kpa. Based on these results, at temperatures above 76°C, 60-70 asphalt binder failed to resist rutting whether modified or not. However, the modified binders showed better resistance to rutting at all test temperatures compared to the unmodified samples.

In addition, Figure 3 shows how COPF content affected 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 gave better rutting resistance compared to the control sample (refer to Figure 3). The highest rutting resistance (G*/sinδ) value was found at a temperature of 46°C, which reduced as the temperature increased. At 76°C, the rutting resistance factor (G*/sinδ) value reduced 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, whereby with the increase of temperature, the phase angle δ became high and the lower value of δ for each temperature was for the 0.4% in COPF blended. The results showed that the relationship between (G*/sinδ) and δ was opposite, meaning that with the increase in phase angle δ, the corresponding value of (G*/sinδ) decreased. But also, 0.4% in COPF blended was the ultimate result for the δ compared to other percentages (%) of COPF blended.

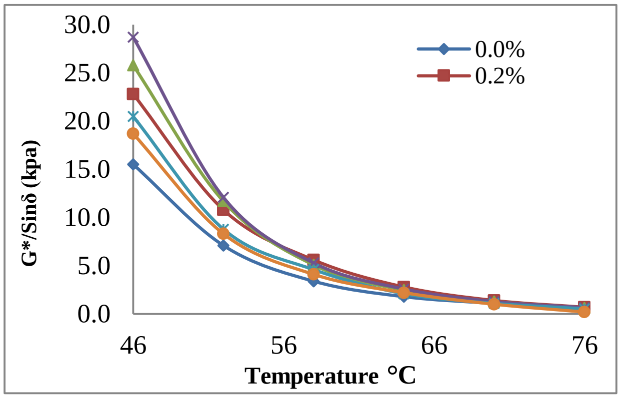


Figure 2 Variation of G*/sinδ with temperature of COPF modified un-aged binder

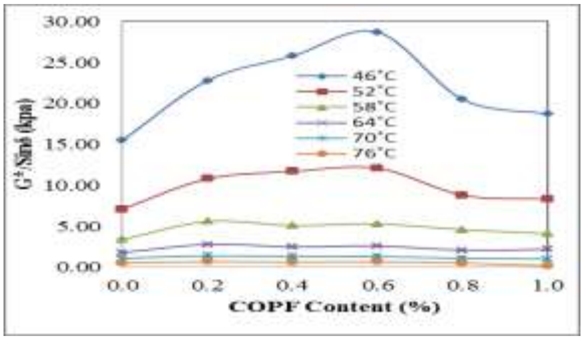


Figure 3 Variation of G*/sinδ with COPF content at various temperatures for un-aged binde

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Table 3 Characteristics of the 60-70 asphalt

Asphalt grade	Type of test		Percentage of COPF blended					
			0%	0.2%	0.4%	0.6%	0.8%	1.0%
60-70	Penetration[deci-mm]		67.8	65.1	62.5	61.7	60.7	59.3
	Softening point [°C]		49.3	49.6	50.8	51.3	51.5	52.0
	Viscosity [cP]	135 °C	500	533	633	667	633	733
		165 °C	242	334	450	467	533	667

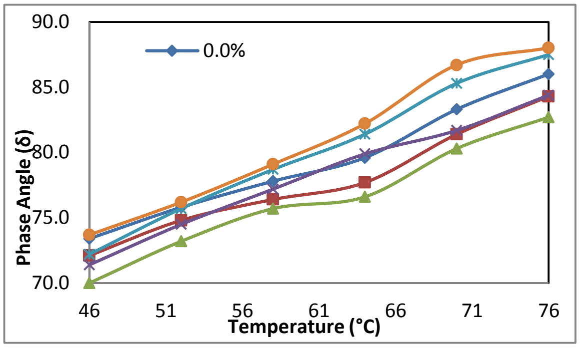

Figure 4 Variation of phase angle δ with temperature of modified un-aged binder

4.1.2 Rutting Characteristics of Short Term Aged Binder

Figure 5 shows that the rutting resistance parameter (G*/sin δ) increased with the decrease in temperature, implying that at high temperatures, chances of rutting had been 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 70°C, short term aged 60-70 asphalt binder failed to resist rutting whether modified or not. However, the modified binders showed better resistance to rutting at all test temperatures compared to the unmodified samples.

Figure 6 shows how COPF content affected 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 gave better rutting resistance compared to the control sample.

In addition, Figure 7 shows, from an un-age binder, by increasing the temperature, δ became high and the lower value of δ for each temperature was for 0.4% and 0.6% in COPF blended respectively. The results showed that the relationship between (G*/sinδ) and δ was opposite, meaning that with the increase in phase angle δ, the corresponding value of (G*/sinδ) decreased. However, 0.4% and 0.6% of COPF blended binder were the ultimate results for the δ compared to other percentages (%) of COPF blended.

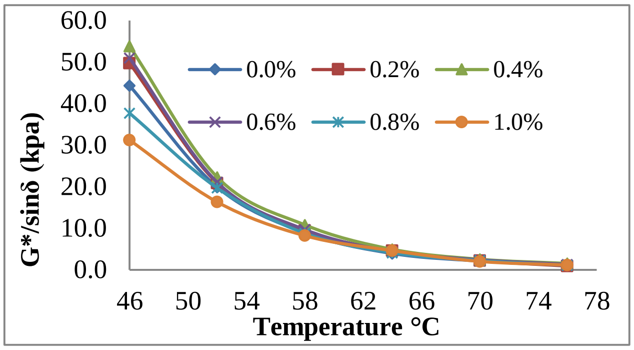

Figure 5 Variation of G*/sin δ with temperature for short term aged COPF modified binder

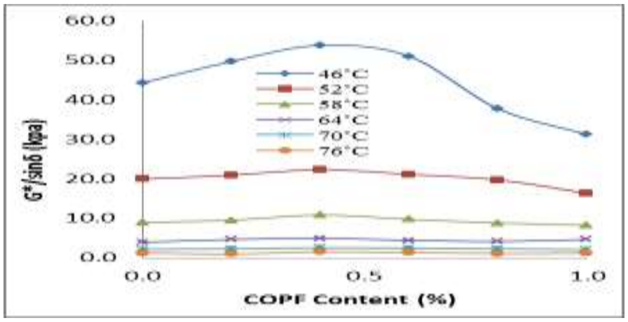

Figure 6 Variation of G*/sinδ with COPF content at various temperatures for Short term-aged binder

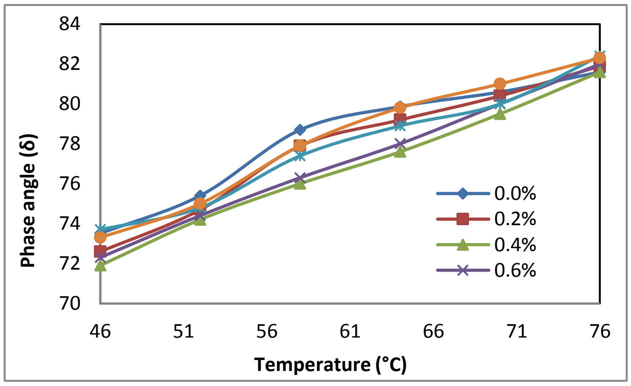

Figure 7 Variation of phase angle δ with temperature of 60-70-COPF modified asphalt binder for short term ageing

4.1.3 Fatigue Characteristic 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 sin δ, the higher is the fatigue resistance.

Figure 8 shows that the fatigue resistance parameter (G*sinδ) increased with the decrease in temperature, meaning at high temperatures, the chances of fatigue cracking was 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 310˚C, unmodified 60-70 binder would be able to resist fatigue cracking, but modified 60-70 asphalt binder could resist fatigue cracking for as low as 31˚C. Thus, the modified binders showed better resistance to fatigue cracking at all test temperatures compared to the unmodified samples. Figure 9 shows how the COPF content affected 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% of COPF content gave better fatigue resistance compared to the control sample.

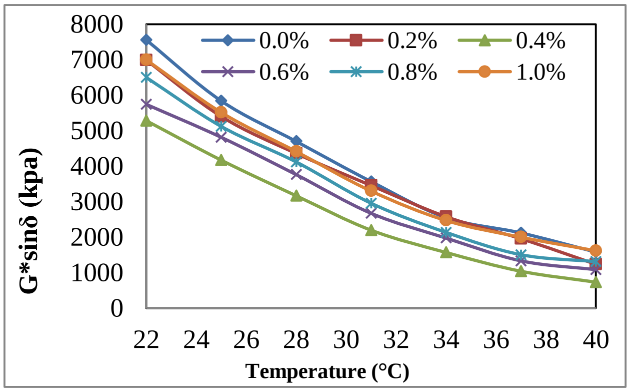

Figure 8 Variation of G*sinδ with temperature for COPF modified long term ageing binder

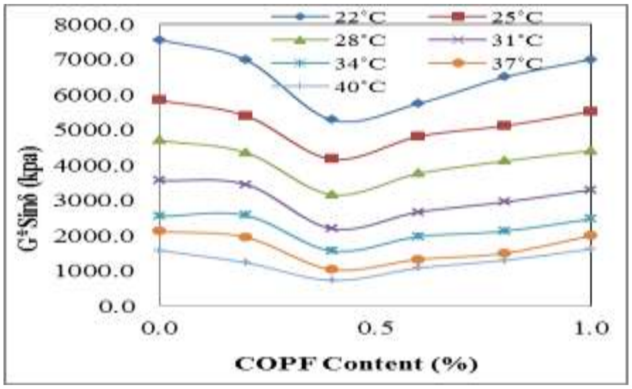

Figure 9 Variation of G*sinδ with COPF content at various temperatures for long term-aged binder

5.0 CONCLUSION

The following conclusions were drawn from the study: The complex shear modulus, G*, showed significant improvement for the modified samples compared to unmodified samples. The COPF modified 60-70 binder showed better rheological properties compared to the unmodified samples. Besides, the modified binder gave the best fatigue resistance at 0.4% of COPF content. Similarly, rutting resistance factor of the modified binder was best at 0.4% of COPF content. The modification of 60-70 binder with 0.4% of COPF gave the optimum improvement of rheological properties of asphalt binder.

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