Penerbit
Akademia Baru

Journal of Advanced Research in Applied Mechanics
ISSN (online): 2289-7895 | Vol. 7, No. 1. Pages 21-30, 2015

Rheological Properties of Cellulose Oil Palm Fiber (COPF) Modified 80-100 Asphalt Binder

A. A. Md. Maniruzzaman[*,a], *A. W. Hamad*[b], *A. M. Maleka*[c], *M. Elsergany*[d]

Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia.
[a,*]*mzaman@utm.my*, [b]*ir.eng_ahmed@yahoo.com* ,[c]*ammaleka@yahoo.com*, [d]*M.ElSergany@hbmsu.ac.ae*

Abstract – *This research paper dealt with Pavement Condition Index (PCI), deterioration of roads, effect of Cellulose Oil Palm Fiber (COPF) modified bitumen binder and complex shear modulus (G*). The PCI is an indicator of the condition of roads, and the value of PCI ranges from 0 to 100. Based on this value, road managers/authorities are able to decide one of the rehabilitation strategies for maintenance of the roads in managing pavements aiming with the lowest life cycle cost (LCC). Rutting deformation and fatigue cracking are the two most common distresses of roads and highways. Bitumen binder used in road construction due to its viscoelastic properties and this property of neat bitumen is inadequate to tackle the rutting deformation and fatigue cracking for the heavier axle loads. COPF is one of the bitumen modifiers used in highway industry to eradicate the deterioration of roads. The main objective of this study was to investigate the effect of various COPF content on the rheological properties of 80-100 penetration grade bitumen. The COPF was blended in ratio of 0.0, 0.2, 0.4, 0.6, 0.8, and 1.0% by weight of bitumen binder. The 0.4 to 0.6% COPF content showed better complex shear modulus (G*) values in all aging conditions and test temperatures considered. The maximum temperature, beyond which rutting deformation will occur, is 640C for modified 80-100 un-aged and short term aging binder. This study concludes to modify bitumen binder with COPF up-to the required viscoelastic values to arrest the deterioration of roads.* ***Copyright © 2015 Penerbit Akademia Baru - All rights reserved.***

Keywords: Cellulose oil palm fiber, complex shear modulus (G*), pavement condition index (PCI), life cycle cost (LCC)

1.0 INTRODUCTION

The pavement condition index (PCI) value decreases with the rate of deterioration of roads and leads to rehabilitation strategies and road managers/authorities are able to take decision for maintenance with lowest life cycle cost (LCC). Heavier axle loads together with drainage issues are the main factors for deterioration of roads. The challenges of early pavement failures are being reported on asphalt pavements by road agencies all over the world [1]. Many efforts are being put into developing better quality asphaltic concrete mixtures through research and innovation, but the problems still persist. In Malaysia, flexible pavements are designed for a period of ten to fifteen years [2], however, some of these roads have not being able to withstand the service loads especially in industrial areas. A study was cconducted based on the relationship of performances of pavement and chemical properties of asphalt binder. The authors reported that each particular failure mechanism is a function of asphalt's basic intermolecular chemistry [3]. Asphalt (bitumen) binder is a rheological, viscoelastic, thermoplastic and Newtonian fluid at elevated temperature. It deformation characteristics vary with variation of temperature, load together with the rate of load application; it is semi-solid in room temperatures and becomes liquid when heated [4]. Rutting deformation, fatigue and thermal cracking are some of the more common pavement defects associated with temperature variation sensitivity of asphalt binder [5]. Various modifiers have been used to improve the rheological properties of asphalt binder among which are polymer, fiber etc. Fiber generally improves the service properties of bituminous mixes by forming micromesh netting in the asphalt mix to prevent drain down of asphalt and at the same time improve the stability and durability of the pavement mix [6]. In this work, COPF was employed to modify 80-100 penetration grade bitumen.

Oil palm industries generate at least 30 million tonnes of lignocellulosic biomass annually in the form of oil palm trunks (OPT), empty fruit bunches (EFB), oil palm fronds (OPF) and palm pressed fibres (PPF). At present, the biomass is either left to rot in the plantations to provide organic nutrients to the oil palm trees (mulching) or used as solid fuel in the boilers to generate steam and electricity at the mills which is contribute to environmental protection issues [7]. The cellulose oil palm fibers (COPF) were made from empty fruit bunch (EFB) various methods of pulping, of which the Chemical-R type was found to produce the best results [8]. The use COPF was found to improve the fatigue performance of SMA. A study showed that the fatigue life increased to a maximum at fiber content of about 0.6%. Likewise, the tensile stress and stiffness also showed a similar trend in performance. The initial strains of the SMA mix were at lowest at fiber content of 0.6%. A similar trend was also observed for the initial stiffness of the SMA mix. Maximum stiffness values were observed at about 0.4% - 0.6% fiber content [9].

2.0 MATERIALS

2.1 Bitumen (asphalt) binder 80-100 penetration grade

Asphalt binder is a lowloss material as loss tangent, tan δ (ε''/ε') <0.5 and its microwave permittivity (dielectric constant) value ranges from 2 to 7 depending on grade of bitumen and asphaltenes content [4]. Since the performance of the modifier is of concerned here, commonly use bitumen binder was selected.

2.2 Cellulose oil palm fiber (COPF)

The cellulose fiber, which was used in this study, was provided in loose form by packaging (Ecopak) Sdn. Bhd. Malaysia. This cellulose fiber was grinded twice in preparation for evaluating its physical properties and used in the mixture.

2.3 Motor oil grade 15W40

The oil retaining ability of the cellulose oil palm fiber was determined using Dr. Scallenburg's motor oil test [9]. Appropriate amount of motor oil grade was heated in a beaker up to 160°C and was poured onto the cellulose oil palm fiber specimens in a specified mesh. The oil drain down was recorded against time.

3.0 METHODOLOGY

3.1 Sample Preparation

Six (6) blending samples were prepared at different percentage of COPF. The percentages of COPF used were 0.0, 0.2, 0.4, 0.6, 0.8, and 1.0% by weight of asphalt binder, where 0% is the control specimen. Rutting (G*/Sin δ) and fatigue (G*Sin δ) parameters were measured for each of the blended samples using Dynamic Shear Rheometer (DSR) in three (3) different conditions: i. Un-aged ii. Short term aging, and iii. Long term aging, where G* is complex shear modulus and δ is phase angle. The blending procedure was carried out as follows: A container of approximately 800ml was filled with 500g of asphalt binder. The asphalt binder samples were heated up in the oven to the required mixing temperature. The fibers were added gradually (1±0.001 gram every 5 minutes) while keeping the temperature within the range. During the fiber addition and the subsequent 30 minutes of blending, the stirrer (blender or mixer) was set to 700 rpm for the first two proportions of fiber added (first two grams), after 10 minutes of blending, the stirrer was set to 900 rpm while adding the third and the fourth proportion of fiber. After adding the fifth proportion of fiber (fifth gram), the speed of stirring was set to 1500 rpm. When the fiber addition was completed, the sample was stirred for thirty minutes at a speed of 2000 rpm [1].

3.2 Preliminary Tests

Preliminary tests were carried out on the supplied 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. Table 1 presents the characteristics of neat (unaged) asphalt binder used.

Table 1: Physical properties of neat (unaged) asphalt binder

Bitumen grade	**Type of test**	**Temperature [ºC]**	**Average reading**	**Specification** ASTM / AASHTO
80-100	Penetration [deci-mm]	25	86.2	80-100
	Softening point [ºC]	-	47.5	45-52
	Rotational Viscosity [cP centipoises]	135	400	-
		165	160	-

3.3 Mesh screen analysis

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

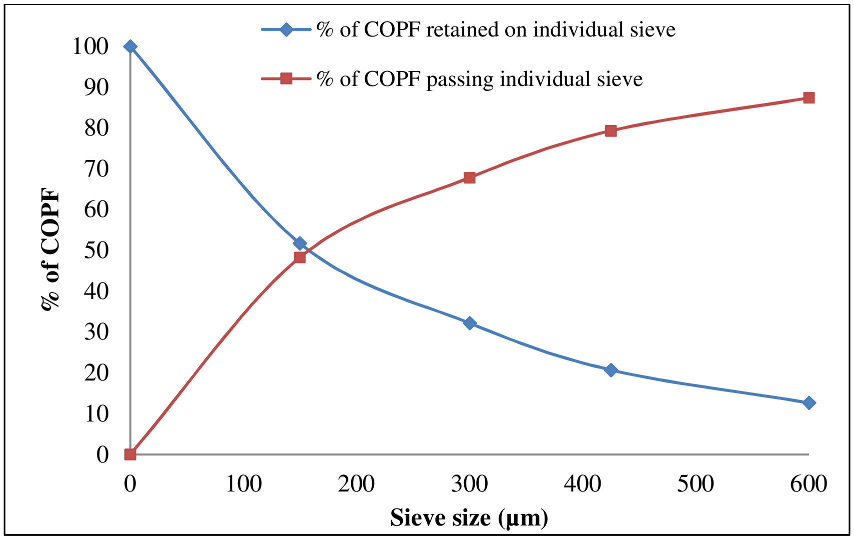

Figure 1: Mess Screen analysis of COPF

3.4 Oil-Fiber Drain down test

Oil-fiber draindown test was performed to simulate cellulose mesh netting effect in the mixture. Synthetic motor oil grade 15W40 was used to replace asphalt in the test. Oil-Fiber draindown test tested the stability of the fiber to hold the motor oil from draindown throw sieve. The test was carried out by weighting 300g motor oil 15W40 with an electronic balance machine in a 500ml beaker. Then, it was placed on an electronic hot plate and heated up to 160ºC. When the temperature reached 160 ºC, the glass beaker was placed on a stirrer. Then 25g of fiber was added and stirred for exactly 2 minutes at a speed of 1000rpm. Next, the content of the glass beaker was put in the middle of the 600µm-sieve above the sieving pan. After 5 minutes, the mass of the oil running through the sieve was measured. The maximum allowable draindown is 180g or 60% of the oil weight [8].

3.5 Short Term Aging (Rolling Thin Film Oven Test, RTFOT)

The rolling thin film oven test (RTFO) was developed to simulate short term aging that occurs in asphalt plants during the manufacture of Hot Mix Asphalt (HMA). The RTFO test residue was used to prepare sample for DSR test under short term aging condition. The test was conducted in accordance with ASTM D2872 [10].

3.6 Long Term Aging (Pressure Aging Vessel, PAV)

The PAV test was used to prepare sample for DSR test under long term aging condition. The test was conducted in accordance with ASTM D6521 [11].

3.7 Dynamic Shear Rheometer (DSR)

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 term and long term aging conditions according to AASHTO T 315 [12].

4.0 RESULTS AND DISCUSSION

Penetration, Viscosity and Softening point tests were carried out on samples of bitumen binder blended with COPF to investigate the effect of COPF on the penetration of 80-100 binder. The penetration test results reveal that the penetration of needle decreases with the increase of COPF content. Therefore, COPF content has a strong effect on reducing the penetration value by increasing the stiffness of COPF modified bitumen. Thus, it would make the binder less temperature susceptible and lead to high resistance to permanent deformation.

The temperature of softening point increases with the increase of COPF content. The increase in softening point indicates that the resistance of the binder to the effect of heat is increased and it will reduce its tendency to soften in hot weather. Thus, with the addition of COPF, the modified binder will be less susceptible to temperature changes. The value of viscosity increases with the increase of COPF content and also the viscosity of binder decrease with the increase of temperature. Table 2 presents the results of Penetration, Viscosity and Softening point tests on un-aged samples.

Table 2: Characteristics of COPF modified 80-100 binder

Bitumen grade	Type of test	Temperature [°C]	Percentage of COPF blended 0.0%	0.2%	0.4%	0.6%	0.8%	1.0%
80-100	Penetration [deci-mm]	25	86.2	75.0	72.0	73.5	71.4	64.1
	Softening point [ºC]	-	47.5	47.8	48.5	48.6	48. 7	49.4
	Rotational Viscosity [cP]	135	400	467	567	633	600	700
		165	160	280	400	433	467	633

4.1 Rutting Characteristics of Un-aged Binder

Figure 2 shows that the rutting resistance parameter (G*/sin δ) increases with decrease in temperature, meaning at high temperatures, chances of rutting are high for both modified and unmodified binder. According to SHRP, for the un-age binder, G*/sin δ should not be less than 1.0kpa. Based on these results, at temperatures above 64˚C, unmodified 80-100 binder will not be able to resist rutting but modified 80-100 binder can resist rutting until 69˚C. Thus, the modified binders show better resistance to rutting at all test temperatures compared with the unmodified samples.

Figure 3 shows the effect of COPF content on rutting resistance at different temperatures for un-aged binder. From the plot, it can be observed that 0.4% to 0.6% of COPF content provide better rutting resistance compared to the control sample.

Figure 4 shows that the phase angle, δ increases with increase in temperature, meaning the relationship between phase angle, δ and rutting factor, G*/ sin δ are inversely proportional.

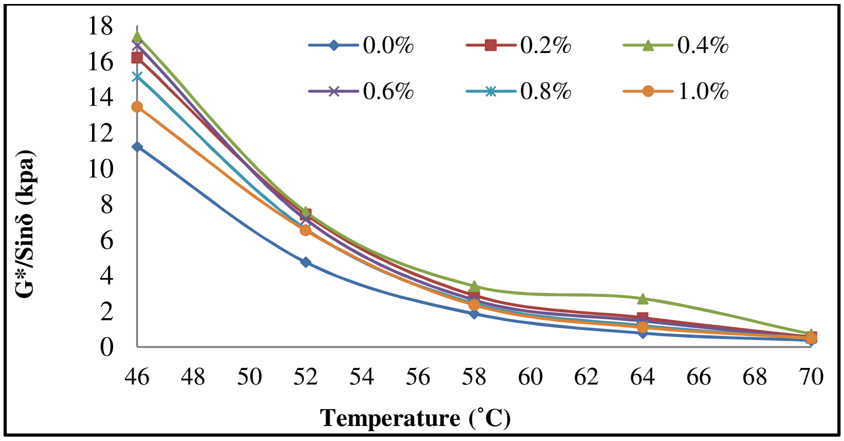

Figure 2: Variation of G*/sinδ with temperature of 80-100-COPF modified un-aged binder

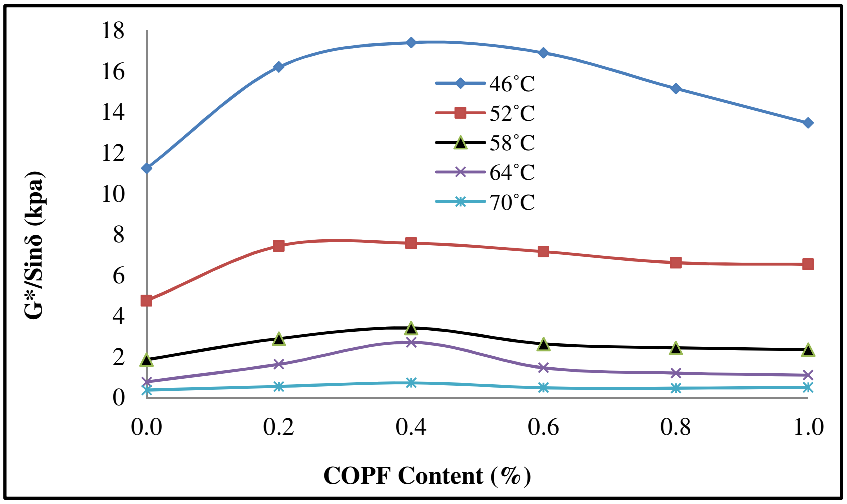

Figure 3: Variation of G*/sinδ with % of COPF content for 80-100-COPF un-aged binder

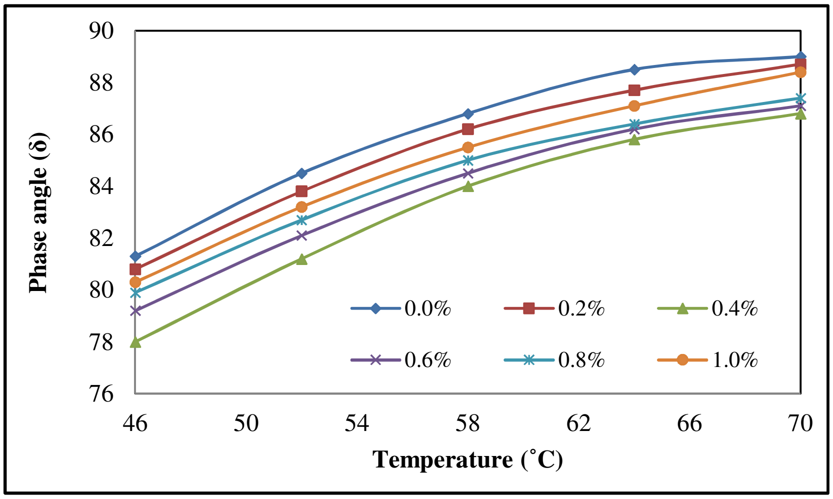

Figure 4: Variation of phase angle δ with temperature of un-aged 80-100-COPF modified binder

4.2 Rutting Characteristics of Short Term Aged Binder

Figure 5 shows that at high temperatures, chances of rutting are high for both modified and unmodified short term-aged binder. According to SHRP, for short term-aging binder, G*/sin δ must not be less than 2.2kpa. Based on these results, at temperatures above 64°C, short term aged 80-100 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 to the unmodified samples. A percentage of 0.4 COPF shows best result compared to other percentages.

Figure 6 shows how COPF content affect rutting resistance at different temperatures for 80-100 short term-age binder. From the plot, it can be observed that 0.4% COPF content give better rutting resistance compared to the control sample.

Figure 7 shows that the phase angle, δ increases with increase in temperature, meaning the relationship between phase angle, δ and rutting factor, G*/sin δ is opposite.

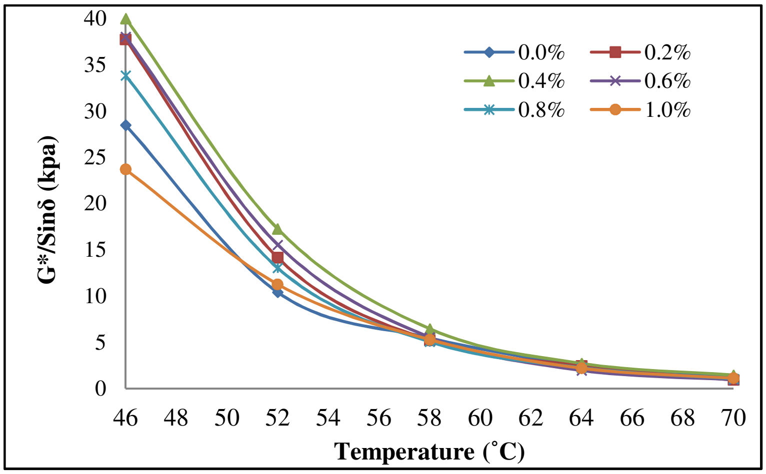

Figure 5: Variation of G*/sinδ with temperature of 80-100-COPF short term aging modified asphalt binder

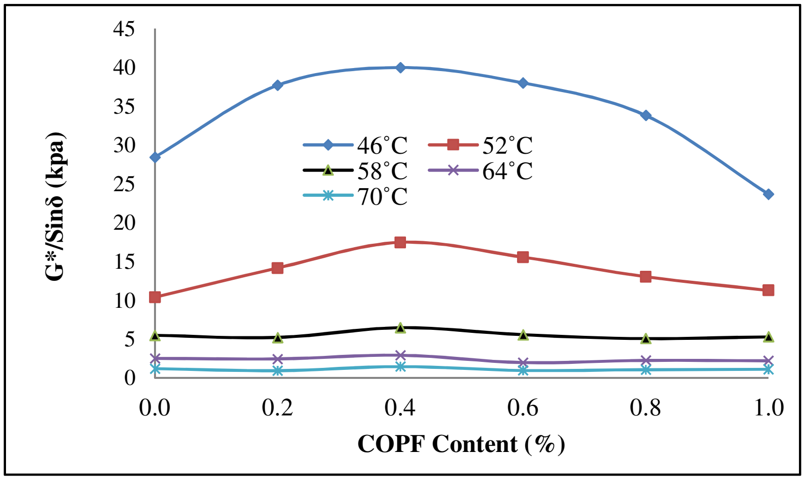

Figure 6: Variation of G*/sinδ values versus % of COPF of 80-100- COPF modified short term aging binder at various temperature

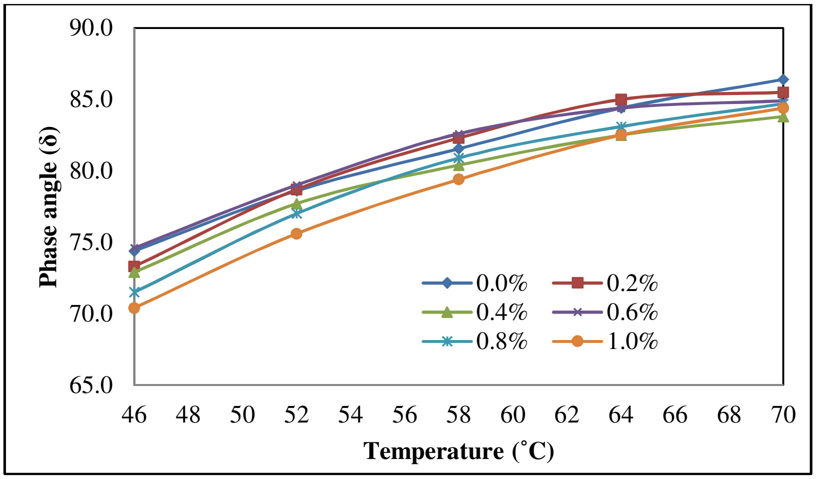

Figure 7: Variation of phase angle, δ with temperature of 80-100-COPF modified short term aged binder

4.3 Fatigue Characteristics of Long Term Aged Binder

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

The fatigue resistance parameter (G*sinδ) increases with decrease in temperature, thus, at high temperatures, chances of fatigue cracking is low for both modified and unmodified 80-100 long term aged binder. According to SHRP, for a long term-age binder, G*sinδ must not be greater than 5000kpa. Based on these results, long term aging 80-100 binder will be able to resist rutting whether modified or not under all test temperature. However, the modified binders show better resistance to rutting at all test temperatures compared with the unmodified samples.

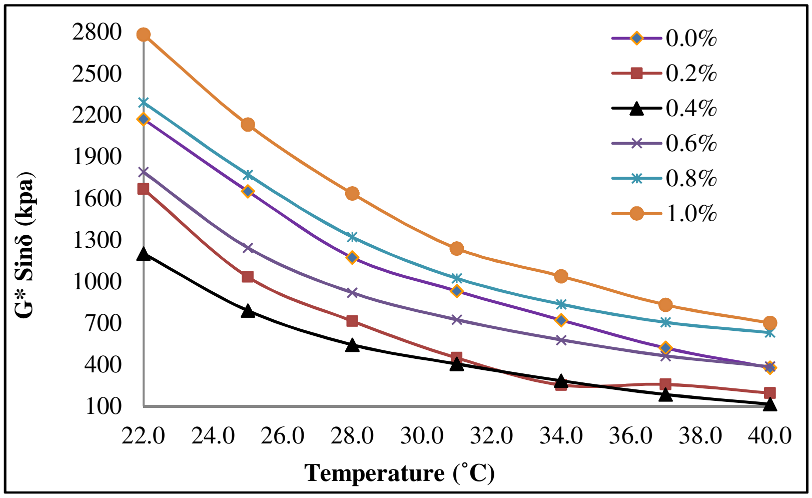

Figure 8: Variation of G*sinδ with temperature of 80-100-COPF long term aging modified asphalt

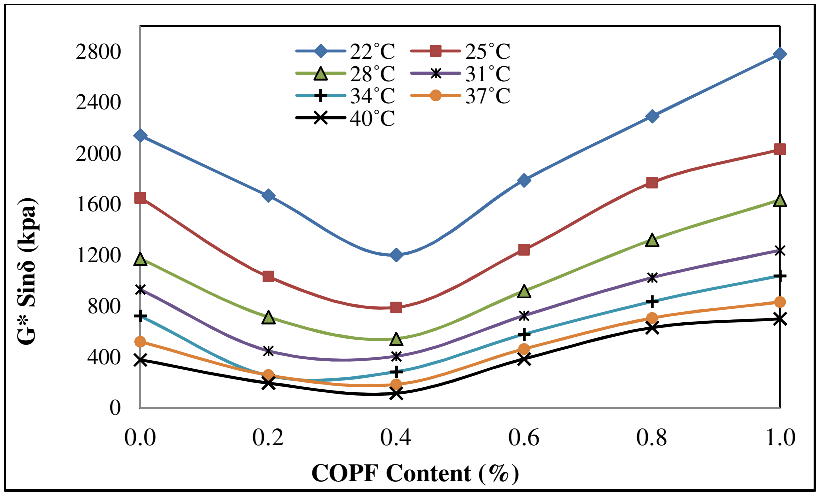

Figure 9: Variation of G*sinδ values versus % of COPF of 80-100-COPF modified long term aging binder at various temperature

Figure 8 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 80-100 long term aged binder. According to SHRP, for a long term-age binder, G*sinδ must not be greater than 5000kpa. Based on these results, long term aging 80-100 binder will be able to resist rutting whether modified or not under all test temperature. However, the modified binders show better resistance to rutting at all test temperatures compared with the unmodified samples.

Figure 9 shows how COPF content affect fatigue resistance at different temperatures for 80-100 long term-age binder. From the plot, it can be observed that 0.4% to 0.6% COPF content give better fatigue resistance compared to the control sample.

5. CONCLUSSIONS

The following conclusions are derived from the study.

- COPF content has a strong effect on COPF modified bitumen by increasing the stiffness, thus, making the binder less temperature susceptible and lead to high resistance to permanent deformation.
- The complex shear modulus G* shows significant improvement for the modified samples compared to 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 80-100 binder with 0.4% COPF give the optimum improvement of rheological properties.

ACKNOWLEDGEMENTS

The support provided by Malaysian Ministry of Higher Education (MOHE), Universiti Teknologi Malaysia (UTM) in the form of a research grant (Vote No. 09H33) for this study is very much appreciated. Authors also appreciate Shell Singapore for sullying bitumen for this research.

REFERENCES

[1] R. Muniandy, B. B. Huat, Laboratory diameteral fatigue performance of stone matrix asphalt with cellulose oil palm fiber, American Journal of Applied Sciences 3 (2006) 2005-2010.
[2] N. E. Kordi, I. R. Endut, B. Baharom, Types of Damages on Flexible Pavement for Malaysian Federal Road, Proceeding of Malaysian Universities Transportation Research Forum and Conferences (2010) Malaysia.
[3] R. E. Robertson, Chemical properties of asphalts and their relationship to pavement performance, Strategic Highway Research Program: Laramie, WY, (1991).
[4] M. B. Maniruzzaman, R. Muniandy, K. Abdullah, A. R. Mahmud, K. Khalid, A. Ismail, Preliminary determination of asphalt properties using microwave techniques, ARPN Journal of Engineering and Applied Sciences 5 (2010) 70-81.
[5] A. Kebritchi, A. Jalali-Arani, A. A. Roghanizad, Rheological behavior and properties of bitumen modified with polymeric coated precipitated calcium carbonate, Construction and Building Materials 25 (2011) 2875-2882
[6] M. S. Abtahi, S. Esfandiarpour, M. Kunt, M. S. Hejazi, G. M. Ebrahimi, Hybrid Reinforcement of Asphalt-Concrete Mixtures Using Glass and Polypropylene Fibers, Journal of Engineered Fibers and Fabrics, 8 (2013) 25-35.
[7] H. Hassan, R. Soom, Road-Making Using Oil Palm Fibre (BIT5) Malaysian Palm Oil Board (MPOB) Information Series, Ministry of Primary Industries, Malaysia MPOB TT No. 171 (2002).
[8] R. H. Muniandy, R. Jafariahangari, R. Yunus, S. Hassim, Determination of Rheological Properties of Bio Mastic Asphalt, American Journal of Engineering and Applied Sciences 1 (2008) 204-209.
[9] R. Muniandy, B. B. Huat, Laboratory diameteral fatigue performance of stone matrix asphalt with cellulose oil palm fiber, American Journal of Applied Sciences 3 (2006) 2005-2010.
[10] American Society for Testing and Material, ASTM D2872 - 12e1 (2012). Standard Test Method for Effect of Heat and Air on a Moving Film of Asphalt (Rolling Thin-Film Oven Test). Philadelphia, USA,
[11] American Society for Testing and Material, ASTM D6521 – 13 (2013). Test Method of Standard Practice for Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV). Philadelphia, USA,
[12] American Association of State Highway and Transportation Officials, AASHTO T315-09. Standard method of test for determining the rheological properties of asphalt binder using a Dynamic Shear Rheometer (DSR); 2009.