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EFFECTS OF ADVERA® WARM MIX ADDITIVE ON THE RHEOLOGICAL PROPERTIES OF UNAGED AND SHORT TERM AGED ASPHALT BINDERS

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ABSTRACT

The performance of asphalt pavement is mainly governed by the properties of the binder. Many asphalt pavement distress are pronounced to be related to the rheological properties of asphalt binder. The oxidation changes the structure and composition of asphalt binder resulting stiffer and brittle of asphalt. This paper described Superpave™ binder that was used to characterize the rheological properties of PG64 asphalt binders blended with various Advera® contents subjected to unaged and short term aged. Rotational viscometer (RV) and Dynamic Shear Rheometer (DSR) were conducted to measure binder properties at higher and intermediate temperature respectively. The results indicated that, the addition of Advera® in the asphalt binder exhibited change in binder rheology which influenced rutting parametery

Keywords: Advera®; Aging; Viscosity; Rotational viscometer; Dynamic shear rheometer.

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1. INTRODUCTION

Asphalt binders are derived from the residual fractional distillation of crude oil. The performance of a binder is determined by its physical properties, which are determined by the chemical composition [1]. A broader range of chemical properties is demonstrated by asphalt binders depending on the source of crude oil and processes used to produce the asphalt binder [2]. Asphalt binder is a thermoplastic liquid which behaves as an elastic solid at low service temperatures and at high temperatures, it behaves as a viscous liquid [3]. According to Reference [4], the binder constitutes about 4 – 6% by weight of the mixture, while the aggregate makes up between 94 – 96% by weight of the asphalt concrete mix, bitumen used as the binder, has a viscoelastic characteristics and it is thermoplastic, it's soft when heated and harden on cooling.

The properties of asphalt binder play significant roles in asphalt pavement performance. Although the percentage of the binder is quite small, the binder influences pavement performances to a greater extent than the aggregate as environmental factors, such as high temperature due to solar radiation, and freeze at low temperature affects the binder to a greater extent than the aggregate [5]. When the binder in the pavement is exposed to the high temperature, the rutting will takes place while at low temperature exhibits brittleness and prone to crack [4].

Many asphalt pavement distresses are pronounced to be related to the rheological properties of asphalt binder [6-7]. Rheology is the study of deformation and flow of bitumen that describes the elastic and viscous behaviour of bitumen, when subjected to a stress [8]. These parameters are important in pavement performance. The high deformation and flow of pavements may contribute to rutting and bleeding, while stiffer pavements may be susceptible to fatigue cracking [9]. Asphalt binders are thermoplastic materials and their rheology is highly sensitive to temperature [9-10]. The bitumen becomes softer at high temperature, thus enable permanent deformation of the pavement whilst at low temperatures, the bitumen becomes stiff and inflexible and prone to crack due to strain and thermal contraction [11-12] Owing to its natural temperature susceptibility, the low temperature and high temperature, performance of asphalt binder need to be improved [13]. Due to the considerable increase in traffic level, axle loads, tyre pressure and heavier trucks, bitumen modification is a solution to overcome the distresses in flexible pavements [14-15]. Addition of modifiers into conventional bitumen results in the improvement of performance characteristics of bituminous mixes used in road construction.Warm mix asphalt (WMA) is technologies that allow production of the asphalt mixture at lower temperature than those of hot mix asphalt (HMA) without reducing their level of mechanical performance [16]. According to Reference [17], WMA additives and process can be differentiated into three distinct group such as organic additives, chemical additives and foaming process and additives.

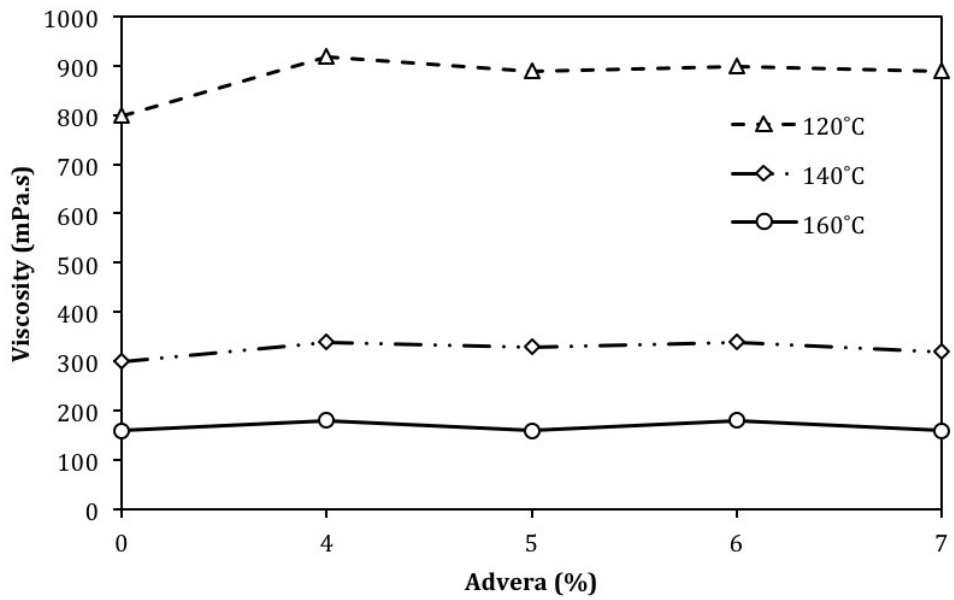
Modification of asphalt to improve the overall performance of pavements has been the focus of numerous researchers. Modification of bitumen with foamed asphalt additive namely Advera® has enable the reduction of the mixing and compaction temperature that translates to the reduction in emission of greenhouse gases and energy saving. Thus, this paper discover the potential of Advera® foamed asphalt additive in reducing the aging of the asphalt binder using SuperpaveT^{M} asphalt binder test under unaged and short term aged condition.

2. RESULTS AND DISCUSSION

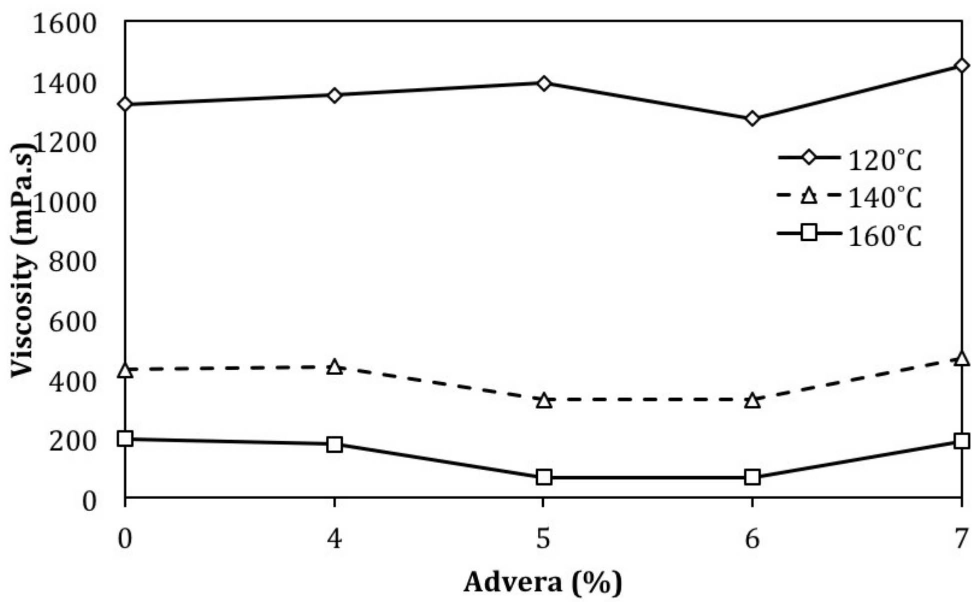
2.1 Effect of Advera® Content on Binder Viscosity

Figure 1 show the relationship between Advera® content and binder viscosity at different temperature. The result indicates a general trend that every content of Advera® results in a rise of the binder viscosity compared to the base binder whereas when the binder is aged the viscosity also increases except for binder modified by 5% and 6% of Advera® irrespective of the test temperature. . The viscosities of the binder were observed at peak when temperature equivalent to 120^{o}C for unaged and short term aged binder. At similar temperature, the asphalt binder modified by Advera® is higher for unaged and aged binder except aged binder containing 6% Advera® compared to the base binder.

For unaged binder tested at 120^{o}C, the binder containing 4% advera® increases 15% followed by 6% advera which shows 12.5% compared to the control binder while the binder containing 5% and 7% of Advera® depicts the same increase in viscosity which is 11.3% higher than the control binder. The same trend has been observed when tested at 140^{o}C and 160^{o}C which shows that the 4% and 6% of Advera® modified binder are higher than the control binder. After the binder were aged in RTFO for 163^{o}C, the viscosity shows an increment with every content of Advera® except 6% which is lower than the control binder when tested at temperature 120°C. It is noticed that when tested at temperature 140°C and 160°C, 5% and 6% of Advera® exhibit similar viscosity value of 330mPa.s and 70mPa.s respectively. When 7% of Advera® is added to the binder, the viscosity is slightly increase from 180mPa.s to 190mPa.s and the result also shows that, for short term aged binder the 7% of Advera® modified binder shows the highest viscosity for every tested temperature compared to the other binders.



(a)



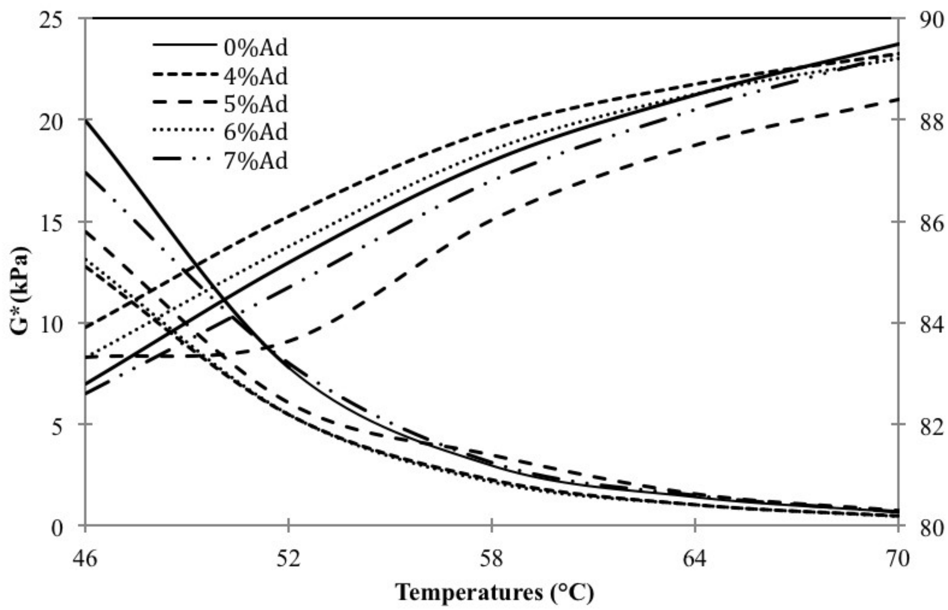
(b)

Fig.1. Relationship between Viscosity-Advera® for (a) unaged PG64 (b) short term aged PG64

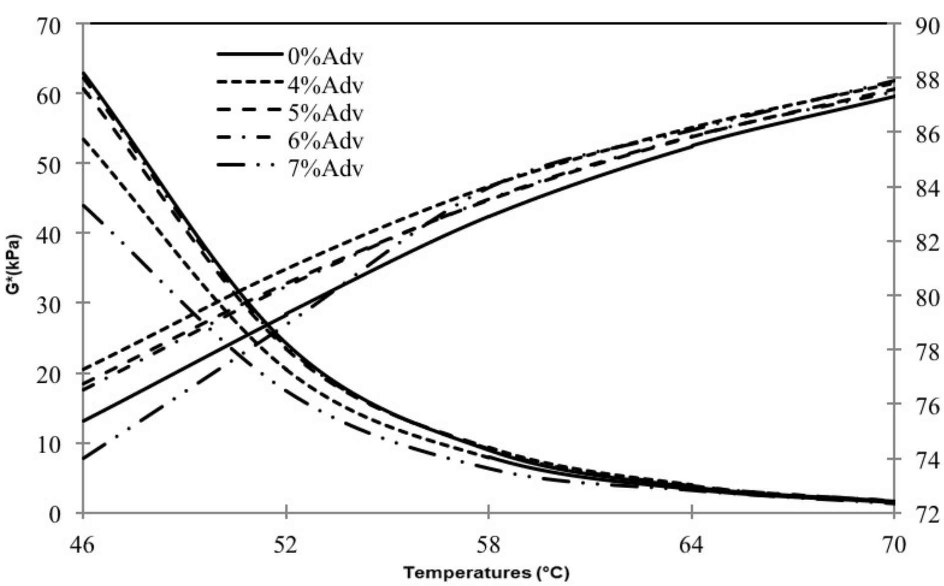
The increase in viscosity with Advera® is thought to be caused by the addition of fine powder to the binder which acts as a filler [20-21; 22-2]. Reference [24] stated that, the increase in viscosities of the binder after RTFO aging may not entirely due to increased aging of asphalt binder in the presence of Advera® but due to subsidence of the foaming effect of Advera® during the aging process. After initial foaming, the Advera® particle remain undissolved in the binder thereby increasing the viscosities of the binder. However, some previous finding shows that the addition of Advera® into the binder results in increase the viscosity of asphalt binder and some shows the opposite statement. This is mainly due to chemical structure and source of particular synthetic zeolite [20]. However, based on viscosity data, all modified asphalt binders are lower than 3Pa.s when tested at 135°C hence meet the standard specification of Superpave™.

2.2 Effect of Advera® Content on G* and sin δ of Asphalt Binder

Complex modulus, G* and phase angle, δ were measured at low shear strain to get the linear viscoelastic properties of the asphalt binders. From the parallel plate tests, the average complex shear modulus, G* and phase angle, δ can be determined.



(a)



(b)

Fig.2. Effect of Advera on G* and δ for (a) unaged PG64 (b) short term aged PG64

Figure 2(a) illustrate the graphical plot for G* and δ versus temperature for the unaged specimen. Overall trend shows that, at higher temperatures, decreases the stiffness, G* and increases the phase angle, δ for unaged. Airey and Rahimzadeh (2004) found that, elasticity of the asphalt binder to resist deformation increased by the increasing of the temperature; as a result, the δ increases, which urged to improve the linear strain limit of binders. The control asphalt binder has higher complex modulus than that of Advera® modified asphalt binder. With the addition of Advera® into the control asphalt, the complex shear modulus decreases by an average of 30%.

After adding 5% of Advera® additive, the asphalt binder experienced higher complex modulus, G* and lower phase angle, δ to 1600 Pa and 87.5^{o} respectively compared to the control binder 1380 Pa and 88.5^{o}C. In comparison to the dosages of Advera® content, the 5% of Advera® modified asphalt binder demonstrates better rutting resistance compared to control. Overall, the addition of Advera® slightly affected the rutting resistance in both type of binder. Lower complex modulus, G* will makes the binder becomes less stiff and able to deform without building up large stress while lower phase angle, δ will make the asphalt binder more elastic. The percentage increases of G* and decreases of δ are 15.9% and 1.2% respectively.

For unaged binder, the addition of Advera® result in an increase in failure temperature for binder incorporating 5% and 7% of advera®. It is observed that the temperature failure for 0%, 4%, 5%, 6% and 7% Advera® are 67.5°C, 65.3°C, 68.8°C, 64.8°C and 67.9°C respectively. Adding 5% Advera® into the binder shows the highest failure temperature compared to the other percentage of Advera® followed by 7%, 4% and 6%.

Figure 2(b) demonstrates that the control asphalt binder has higher complex shear modulus than that of Advera® modified asphalt binder. With the addition of Advera® into the control asphalt, the complex shear modulus decreases by an average of 30%. Short term aged also found that by incorporating 5% Advera® depicts the highest G* compared to control binder which shows 6.7% increases from 3.71kPa to 3.96kPa compared to control binder but the δ increases 0.4% from 85.49^{o} to 85.80^{o}. The short term aged binder shows that the highest failure temperature is 5% which is fail at 68.88°C followed by 6%, 4%, 0% and 7% Advera® which are fail at 68.8°C, 67.9°C, 68.5°C and 64.4°C respectively.

Table 1. One way ANOVA on the the increase of G* and reduction δ for the unaged binder

Dependence Variable	Source	DF	SS	MS	F	p-value
	Temp.	1	101.89	101.889	14.78	0.031
Increasing of G*	Error	3	20.68	6.895		
	Total	4	122.57			
	Temp.	1	38.025	38.0250	61.23	0.004
Decreasing of δ	Error	3	1.863	0.6210		
	Total	4	39.888			

A one way ANOVA was used to analyze the effect of temperatures on G* and reduction of δ. Table 5 shows the result which increasing the test temperature has statistically significant effect on both dependent variables at 95% level of confidence. It prove that the addition of Advera® into asphalt binder increased the G* and decreased the δ value.

Table 2. One-way ANOVA on the increase of G* and reduction of δ for STA binder

Dependence Variable	Source	DF	SS	MS	F	p-value
	Temp.	1	989.4	989.4	11.67	0.042
Increasing of G*	Error	3	254.3	254.3		
	Total	4	1243.7			
	Temp.	1	122.290	122.290	56.61	0.005
Decreasing of δ	Error	3	6.481	2.160		
	Total	4	128.771			

A one way ANOVA was performed to analyze the effect of temperatures on G* and reduction of δ. Table 6 shows the result of the statistical analysis for STA binder which increasing the test temperature has significant effect on both dependent variables with the *p*-value of less than 0.05. Clearly, the addition of Advera® into asphalt binder increased the G* and decreased the δ value

2.3 Effect of Advera® Content Rutting Resistance of Asphalt Binder

The G*/sin δ is proposed as an indicator of pavement rutting resistance, where the higher value of this parameter indicates higher resistance to rutting. A higher value of complex modulus is favorable as it represents a higher total resistance to deformation. The rutting parameter is related to the total dissipated energy during a loading cycle [25]. Meanwhile, fatigue parameter is known as G*sin δ and used as an indicator of fatigue resistance base on the concept that part of the dissipated energy is spent in generating microscopic damage (cracks) that eventually leads to fatigue. The results of SHRP parameters, rutting and fatigue are shown and discussed as the following.

The SHRP rutting parameter suggested at the maximum pavement design temperature, the G*/sin δ must be greater than 1.0 kpa and 2.2 kpa for unaged and RTFOT aged asphalt binder, respectively. It was observed that decreased G*/sin δ increased test temperature for unaged binder containing Advera® All superpave™ dynamic shear binder test were performed at frequency 0f 1.59 Hz.The effect of temperature on the rutting parameter (G*/sin δ) of unaged asphalt binder at different test temperature is shown in Table 3.

Table 3 G*/Sin δ of unaged and short term at different temperatures

G*/Sin δ (kPa)						
Aging Condition	**T (°C)**	**Advera® (%)**				
		0	**4**	**5**	**6**	**7**
Unaged	46	20.08	12.86	14.85	13.09	17.52
	52	7.806	5.51	6.108	5.489	8.016
	58	2.934	2.291	3.514	2.148	3.095
	64	1.375	1.069	1.596	1.026	1.476
	70	0.6367	0.5172	0.7788	0.4592	0.666
Short Term	46	65.01	54.79	45.70	64.03	62.34
	52	24.66	20.77	17.75	24.19	23.85
	58	9.026	7.904	6.357	9.241	9.382
	64	3.715	3.407	3.209	3.926	3.968
	70	1.651	1.493	1.315	1.755	1.733

It is clear from this Table 3 that the binder with 6% of Advera® has less capability to resist the rutting at higher temperature among all others binders. It seems the addition of Advera® to the control binder by 6% (by weight) lowers the resistance to rutting of control binder. However, the addition of Advera® to the control binder stiffen the binder consequently increasing the rutting resistivity.

The DSR test conducted to measures rheological properties of asphalt binder rather than empirical properties such as penetration values or softening point. According to Superpave™ specifications, the testing temperature for PG64 is 64°C for virgin and RTFO aged binders. The specification defines and places requirements on a rutting parameter, G*/sin δ which represents the high temperature viscous component of overall binder stiffness. G*/sin δ must be at least 2.20kPa after aging in the RTFO test. The results of SHRP parameters, rutting and fatigue of RTFO aged binder are shown and discussed as the following.

Generally, increases test temperature decreases the G*/Sin δ for short-term aged binders containing Advera®. In table 5.6, all G*/Sin δ value for RTFO aging are higher than 2.2kPa respectively at 64°C. The unaged binder containing 5% of Advera® exhibit higher rutting resistance compared to control binder and binder containing 4%, 6% and 7% of Advera®. It can be seen that the G*/Sin δ of the unaged with 5% of Advera® tested at 64°C increases 16% from 1.38kPa to 1.60kPa compared to control binder. However The short term aged depicts that by adding 7% Advera® increases 6.8% of the G*/Sin δ from 3.72kPa to 3.97kPa while the lowest G*/Sin δ is 5% which decrease 0.51kPa from 3.72kPa to 3.21kPa compared to control binder.

The short term aged binder shows that the highest failure temperature is 5% which is fail at 68.88°C followed by 6%, 4%, 0% and 7% Advera® which are fail at 68.8°C, 67.9°C, 68.5°C and 64.4°C respectively.

3. MATERIALS AND METHOD

Asphalt binder is characterized by their consistency or ability to flow at different temperature. Conventional asphalt binder grade PG64 was used in this study and its rheological properties are shown in Table 4.

Table 4. Rheological properties of binder used

Test Properties	Base Binder (PG64)	4% Advera®	5% Advera®	6% Advera®	7% Advera®
Unaged Binder					
Viscosity at 135°C (mPa.s)	300	340	330	340	320
G*/Sinδ at 64°C (kpa)	1.375	1.069	1.596	1.026	1.476
Failure Temp. (°C)	67.5	65.3	68.8	64.8	67.9
Short-Term Aged Binder					
Viscosity at 135°C (mPa.s)	430	440	330	330	470
G*/Sinδ at 64°C (kpa)	3.175	3.407	3.209	3.926	3.968
Failure Temp. (°C)	68.5	67.9	68.8	68.9	64.4

3.1. Advera® WMA Additive

Advera® WMA (Figure 3) is a synthetic mineral in powder form containing 18-20% moisture which is chemically and structurally bound. Advera® also free flowing white to grey powder (100% passing the 0.075mm) produced by PQ Chemicals (Thailand) Ltd. Table 5 and Table 6 show the properties and chemical composition of Advera® that consists of Sodium Oxide, Aluminum Oxide and Silicon Oxide respectively.

Fig.3. Advera®

Table 5. Table Properties of Advera®

Test Item	Unit	Value Range
Form	-	Free Flowing Powder
Whiteness (Hunter L Scale)	-	>90
Apparent Bulk Density (Untamped)	g/l	300 – 480
Moisture Loss at 800°C	% by weight	22 max

Table 6. Average Chemical Compositions

Chemical	Composition
Na_2O	17-19%
Al_2O_3	28-35%
SiO_2	31-34%

3.2 Advera® Modified Binder Preparation

The blending of Advera® and asphalt was carried out using the high shear mixer. Table 7 summaries the mixing parameters used in the blending procedure. Viscosity for the binder, differing in terms of compaction and mixing time were tested. This process was setup to obtain a dispersive mixing of asphalt and Advera® by applying a constant high shear (3000 rpm) for 20 minutes at 120°C

Table 7. Blending binders' protocol

Asphalt Weight (g)	Percent of Asphalt (%)	Advera® weight (g)	Total weight (g)	Mixing time (min)	Mixing speed (rpm)	Mixing temp. (°C)
600	0	0	600	-	-	-
600	4	24	624	20	3000±10	120
600	5	30	630	20	3000±10	120
600	6	36	636	20	3000±10	120
600	7	42	642	20	3000±10	120

3.3 Asphalt binder Aging Condition

Unaged and aging condition of the binder was carried out accordance to ASTM procedure. The procedures were ASTM D2872 Standard Test Method for Effect of Heat and Air on a moving Film of Asphalt (Rolling Thin Film Oven Test) for short term aged.

3.4 Brookfield Rotational Viscometer

The effect of Advera® content on the viscosity of unaged and aged asphalt binder samples at elevated temperatures (120°C, 140°C and 160°C) were evaluated using a Brookfield Rotational viscometer (RV) accordance to AASHTO TP 48-2000

3.5 Dynamic Shear Rheometer

Despite improving the workability of the asphalt mixtures, the changes in the warm mix asphalt binder rheological properties influenced the asphalt mixtures performance [18]. These properties were analysed using a Dynamic Shear Rheometer. Complex modulus (G*) and the phase angle (δ) are two important parameters obtained from the dynamic shear rheometer test and these parameters can be used to characterize both viscous and elastic behaviour of the material [19]. The SHRP rutting parameter suggested at the maximum pavement design temperature, the G*/sin δ must be greater than 1.0 kpa and 2.2 kpa for unaged and RTFOT aged asphalt binder, respectively. Temperature sweeps were applied from 46°C to 82 °C at

60^{o}c increments for unaged and short term aged samples. All superpaveTM dynamic shear binder test were performed at frequency 0f 1.59 Hz. The effect of temperature on the rutting parameter (G*/sin δ) of unaged asphalt binder at different test temperature is shown in Table 3

4. CONCLUSION

The addition of Advera® into the asphalt binder increases the viscosity of the binder at high and intermediate temperature regardless of the aging state. In addition, aged binder exhibits increased viscosity due to binder hardening that increased the binder stiffness. According to rotational viscosity results, the addition of Advera® increased the viscosity, therefore raising the mixing and compaction temperatures. The previous study claimed that, the increase in viscosity is mainly due to the Advera® that acts as a filler which remain undissolved in the asphalt binder. Thus, Advera® failed to exhibit a reduction temperature of the asphalt binder which is the main purpose of warm mix asphalt additive. However, the aging index which is the ratio between aged over unaged viscosity depicts that, adding Advera® into the asphalt binder could reduce the resistance to aging compared to control binder irrespective to the test temperature.

The addition of Advera® had a very little effect on the complex modulus (G*) and phase angle (δ) of the binder. This, in turn, had very little effect on the high temperature grade. The dynamic shear rheometer shows the G* for modified asphalt binder reduces at lower temperature but increases at high temperature for unaged and aged binder whereas the phase angle, δ reduces for every test temperature which enhanced the elasticity of the binders containing Advera®. Further analysis is need to be conducted to construct the master curve diagram, and the results prove that the Advera® modified binder experienced higher complex modulus compared to control binder, however the stiffness reduces after the binder being aged in the RTFO oven for 163^{o}C but the stiffness for binders with and without Advera® for short term aged are almost similar. Thus, it can be concluded that Advera® make the binder stiffer and beneficial to improve the rutting resistance of asphalt binder.

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