THE EFFECT OF DISSOLVED PLASTIC POLYMER MODIFICATION ON RUTTING AND FATIGUE RESISTANCE PROPERTIES OF WARM BITUMEN BLEND

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ABSTRACT

Recently, large amounts of waste polymers are being generated in Nigeria. One of the waste polymers is plastic bottles. Hot Mix Asphalt (HMA) are produced at high temperatures with high energy consumption and environmental hazard. The purpose of using Warm Mix Asphalt (WMA) is to reduce the production and laying temperature and emission of greenhouse gases. Therefore, this research investigated the effect of Dissolved Plastic Bottle (DPB) on the rheological, rutting and fatigue resistance properties of warm bitumen blend thereby reducing the environmental hazard associated with the Waste Plastic Bottles (WPB) disposal and consequently improving pavement service life. WPB was obtained from different waste generation points in Adeleke University, Ede, Nigeria. The obtained WPB was shredded and converted to dissolved form using pyrolysis machine @ 450^{0}C. 500g of 60/70 penetration grade bitumen was heated in an oven with 3% (15g) sasobit until it becomes fluidal. The bitumen was modified with 0 - 17% by weight of the bitumen at 2% interval. Mixing was continued for 1hour to produce homogenous bituminous mixtures. Rheological tests were then conducted on the prepared samples using the Brookfield programmable rheometer. The results indicated that addition of DPB improves the rheological properties of absolute viscosity, phase angle, complex shear modulus, rutting and fatigue resistance of modified binder at both 135°C and 165°C. Therefore, DPB can be used to improve bitumen rheological properties and subsequently resist rutting and fatigue on traffic roads. This can best be achieved upon 7% and 5% modification levels at 135°C and 165°C respectively.

Keywords: *Dissolved Plastic Bottles, Warm Mix Aspahalt, Waste Plastic Bottles, Rutting Resistance, Fatigue Resistance, Warm Bitumen, Brookfield Programmable Rheometer*

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Introduction

Waste plastic bottles is now a major problem in many societies as it can be found almost everywhere especially in landfills. Therefore, waste plastic bottles will cause environmental pollution if it is not properly managed. It can be managed by either reducing, reusing, or recycling. According to (Awaeed et el., 2015), recycled plastic bottles may be useful in bituminous pavements, resulting in reduced pavement deformation and increases the resistance of the material to temperature changes has been reported in the modified mixes as compared to the conventional mixes.

Hot Mix Asphalt (HMA) are produced at high temperatures with high energy consumption and environmental hazard. However, Warm Mix Asphalt (WMA) is now being used by the HMA industry to reduce the temperature for mixing, placing, and compaction of asphalt concrete. The purpose of using WMA is to reduce production temperature and emission of greenhouse gas. WMA also causes reduction in fumes and odours to the environment, reduction in the short-term aging of binders and ensure early opening of the road to traffic (Guo et al., 2014). WMA has reduced energy consumption, thus lowering energy costs and less wear on asphalt plant due to reduced temperature (D'Angelo, and John, 2008). However, WMA is susceptible to rutting due to its production at lower temperature and higher viscosity (D'Angelo, and John, 2008).

Asphalt is usually subjected to various detrimental types of distresses during its service life. Some of these serious distresses include rutting (permanent deformation), shoving, stripping, and fatigue cracking which finally may lead to complete failure of pavement at the same time. These distresses are caused by heavy traffic, poor binders' properties, weathering (temperature, humidity, rain etc.) and bad mix designs (Awaeed et el., 2015). Such distresses will reduce the performance of asphalt pavements and its service life. The most important property of the bitumen mixture in the wearing course design is its ability to resist fatigue and rutting under traffic load. According to Akinleye and Tijani (2017), assessment of the quality of asphalt concrete used in road construction in Nigeria suggested that the quality of asphalt need to be improved. Therefore, stability should be high enough to handle traffic adequately, but not higher than the traffic conditions required. The lack of stability in an asphalt mixture causes unraveling and flow of the road surface. Flow is the ability of an asphalt pavement to adjust to gradual settlements and movements in the subgrade without cracking (Awaeed et el., 2015).

Ajagbe et al. (2020), investigated the Effect of Waste Polymer Modified Bitumen with Milled Corn Cob as a Partial Replacement for Filler in Asphaltic Concrete. It was discovered that Penetration decreases as PET content increases, which indicates an improvement in shear resistance. Also, the softening point increases as

PET content increases which indicates an improvement in resistance to deformation of the resulting asphalt cement. The asphalt cement can be modified with DPB up to 10% weight of bitumen. This research will help in a great way by reducing non-biodegradable waste in the environment, extend pavement service life and equally reduce the cost of road construction.

Consequent upon the stated facts above, it is desirable to investigate the effect of DPB, a plastic polymer, on the rutting and fatigue resistance properties of warm bitumen blend for the production of WMA.

Rheology is the study of the flow of matter, primarily in a liquid state, but also as "soft solids" or solids under conditions in which they respond with plastic flow rather than deforming elastically in response to an applied force (Wikipedia, 2020). Rheology is also defined as, the study of deformation and flow of materials under the influence of external stresses (Akinleye et al., 2020a). The deformation and flow of bitumen depends upon the load applied, rate of loading and temperature. The rheological properties of bitumen presented in terms of complex shear modulus (stiffness) and phase angle, are usually determined using a rheometer. The rheology effect on bitumens are usually measured using rutting and fatigue resistance factors. According to Fazaeli et al. (2016), the higher the rutting resistance factor ($G^*/\text{Sin } \delta$) for the binder, the stiffer and more rutting resistant the asphalt concrete would be also reported that lowest Fatigue resistance ($G^*.\text{Sin } \delta$) value indicates the best fatigue resistance among all asphalt mixture (Fazaeli et al., 2016).

Materials and Method

Materials

60/70 penetration grade of bitumen was used for this study and it was obtained from Reynolds Construction Company Ltd, Ibadan, Nigeria. Table 1 shows the specification of the conventional bitumen before it was modified. The Waste Plastic Bottles (WPB) used was collected from different waste generation points within Adeleke University, Ede, Nigeria. The WPB were sun-dried and shredded to 2mm size manually with the use of scissors before being fed into the pyrolysis machine which turn it to liquid form.

Method

500g of bitumen was heated in an oven until it becomes fluid and pyrolysis method was used in melting the WPB that was shredded to 2mm size. 3% sasobit- 15g (by weight of bitumen), at constant rate was added to the sample to produce modified warm bitumen blend. It was stated on (www.sasobit.com) that a 3% addition of Sasobit yields the best results when aiming at a maximum temperature reduction of 30^{o}C for production of warm mix asphalt. The bitumen was modified by DPB of 0, 1, 3, 5, 7, 9, 11, 13, 15 and 17% by weight of the conventional bitumen. Then mixing was continued for 2hrs at 4000 rotation per minute (rpm) so as to achieve a homogeneous blend of warm bitumen blend. Rheological test was carried out on the prepared modified bitumen samples where dynamic viscosity, phase angle, peak shear stress and peak shear strain were measured using the Brookfield programmable rheometer model DV-III according to American Society for Testing and Materials Method.

Table 1 Waste Plastic Bottles and Bitumen Properties (Akinleye et al., 2020)

PROPERTY	DETAILS		
	PLASTIC BEFORE SHREDDING	PLASTIC AFTER SHREDDING	BITUMEN
Type	Pure water sachet	Pelletized pure water sachet	VG-30
Color	White	White	Black
Material	Low density Polyethylene (LDPE)	Low density Polyethylene (LDPE)	
Size (mm)		2.00	
Density (g/cm^3)	0.92	0.92	0.98
Melting point (°C)	105	105	-
Penetration	-	-	60-70dmm
Temperature	-	-	25°C

Fig. 1a Sasobit

Fig. 1b Brookfield Programmable rheometer

Results and Discussion

Table 2 shows the results of absolute viscosity(μ), phase angle(δ), complex shear modulus (G*), rutting resistance factor (G*/sin δ) and fatigue resistance factor (G*.Sin δ) of Warm Bitumen Blend Modified with dissolved Plastic Bottle.

Table 2 Rheological Properties Results of Warm Bitumen Blend Modified with DPB

DPB (%)	μ (P)		δ (°)		G* (kPa)		G*/sin δ (kPa)		G*.Sin δ	
	135°C	165°C	135°C	165°C	135°C	165°C	135°C	165°C	135°C	165°C
0	7.48	3.20	89.73	92.42	1.13	1.72	1.13	1.72	1.13	1.72
1	8.10	3.31	87.84	90.07	1.43	1.76	1.43	1.76	1.43	1.76
3	8.78	3.51	85.72	88.63	2.76	1.92	2.77	1.92	2.75	1.92
5	9.72	3.60	84.11	80.11	2.96	2.07	2.98	2.10	2.94	2.04
7	10.12	3.72	82.74	76.94	3.06	1.66	3.08	1.70	3.04	1.62
9	18.63	3.75	80.26	65.83	2.36	1.56	2.39	1.71	2.33	1.42
11	31.07	3.75	75.48	60.13	2.20	1.41	2.27	1.63	2.13	1.22
13	50.31	3.75	60.83	51.74	2.14	1.37	2.45	1.74	1.87	1.08
15	82.75	3.75	51.37	40.30	2.09	1.35	2.68	2.09	1.63	0.87
17	101.56	3.75	46.00	34.75	1.87	1.32	2.60	2.32	1.35	0.75

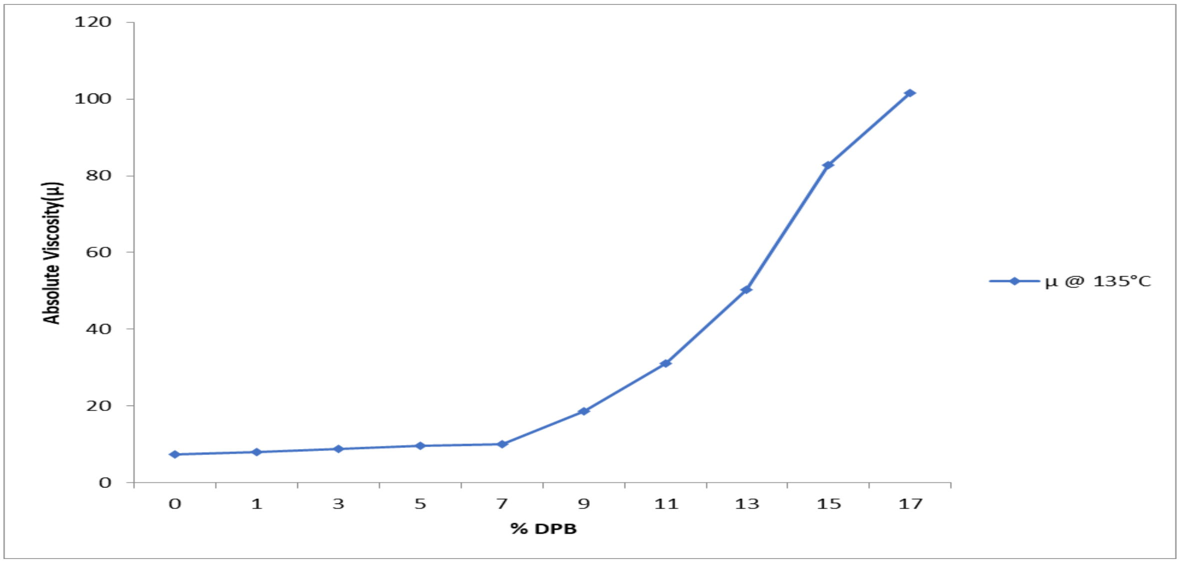

Fig. 2 Absolute viscosity of Warm Bitumen Blend Modified with DPB at 135°C

Dynamic or absolute viscosity (µ) is a measure of the resistance to flow of a liquid under an applied force. It is a property that characterizes the flow behaviour of certain bituminous material (Akinleye et al., 2020a). The unit of absolute viscosity is Poise. According to Aflaki and Tabatabaee (2008), modified asphalt binders are usually more viscous than unmodified ones. The values of the absolute viscosity were obtained using Brookfield programmable rheometer at temperatures 135ºC and 165ºC, spindle No. 27, and a rotating speed of about 200 rotation per minute (rpm).

Fig. 2 shows that the absolute viscosity of Warm Bitumen Blend Modified with Dissolved Plastic Bottles (DPB) at 135°C continuously increased with an increase in the percentage of DPB at 135°C which conform to findings from [(Fazaeli et al., 2016; Henok et al., 2018; Akinleye et al., 2020a). The increment in the values of absolute viscosity obtained was because the force needed by the bitumen to overcome its own internal molecular friction increased as the percentage of DPB added to the bitumen increased.

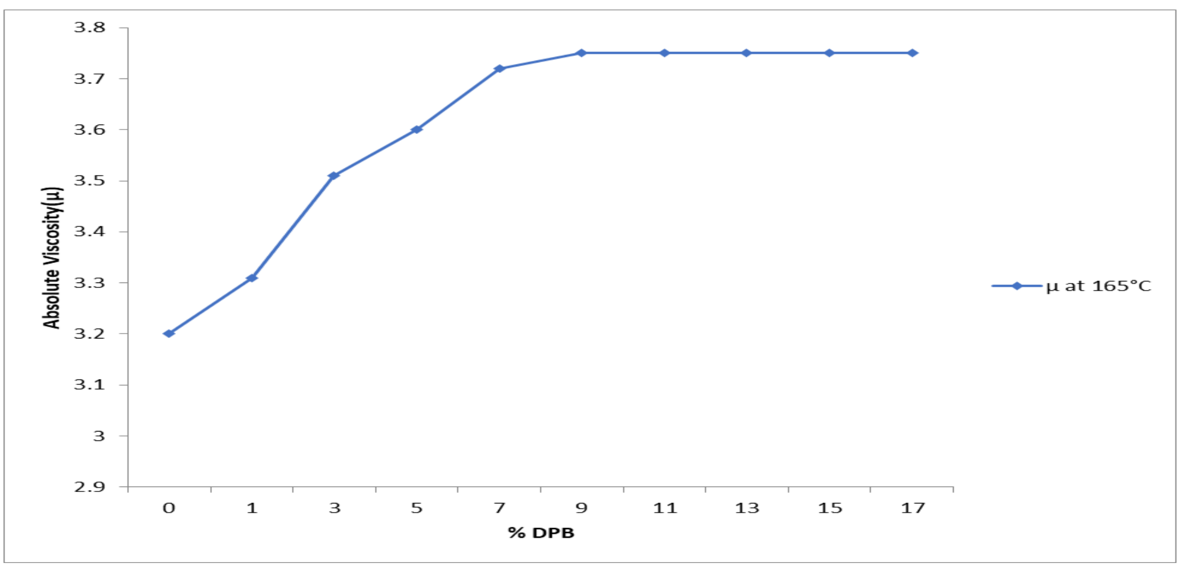

Fig. 3 Absolute viscosity of Warm Bitumen Blend Modified with DPB at 165°C

Similarly, Fig. 3 shows that the absolute viscosity (µ) of Warm Bitumen Blend at 165°C continuously increased with an increase in the percentage of DPB at 165°C which conform to findings from (Fazaeli et al., 2016; Henok et al., 2018 and Akinleye et al., 2020b). The increment in the values of absolute viscosity obtained was because the force needed by the bitumen to overcome its own internal molecular friction increased as the percentage of DPB added to the bitumen increased.

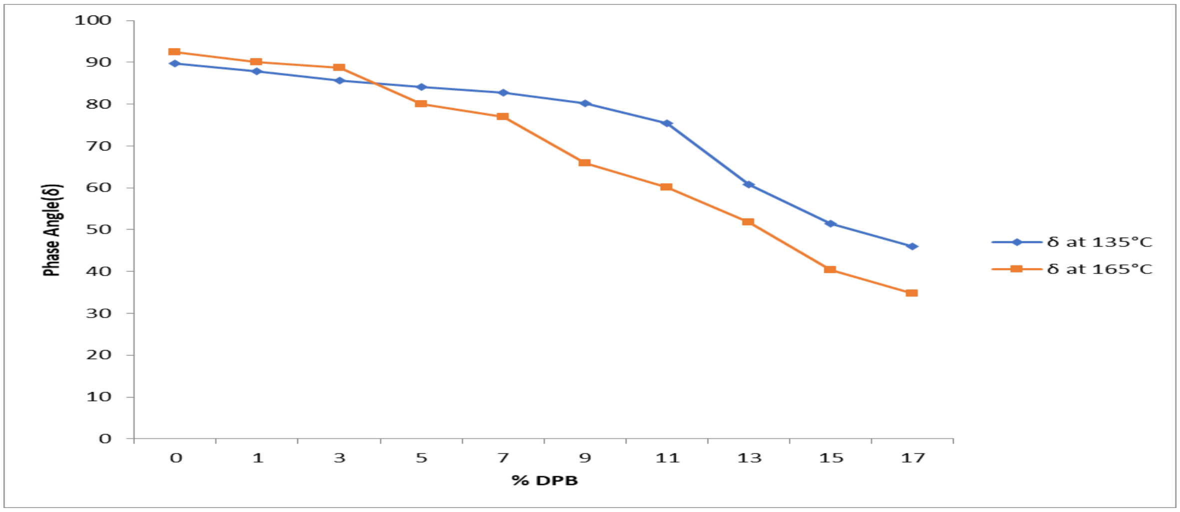

Fig. 4 Phase angle of Warm Bitumen Blend Modified with DPB at 135°C and 165°C

Phase angle of bitumen (δ) is a lag between the applied shear stress and the resulting shear strain. It provides a relative indication of the viscous and elastic behaviour of the asphalt binder. According to Akinleye et al. (2020b), the larger the phase angle, the more viscous the material. Moreover, (Yusoff et al., 2011 and Fazaeli et al., 2016) reported that Phase angle of bitumen having values above 90° is purely viscous. Therefore, from the results obtained, 0% and 1% DPB at 165°C were 92.42° and 90.07° respectively implies that the asphalt binder is purely viscous (Fazaeli et al., 2016).

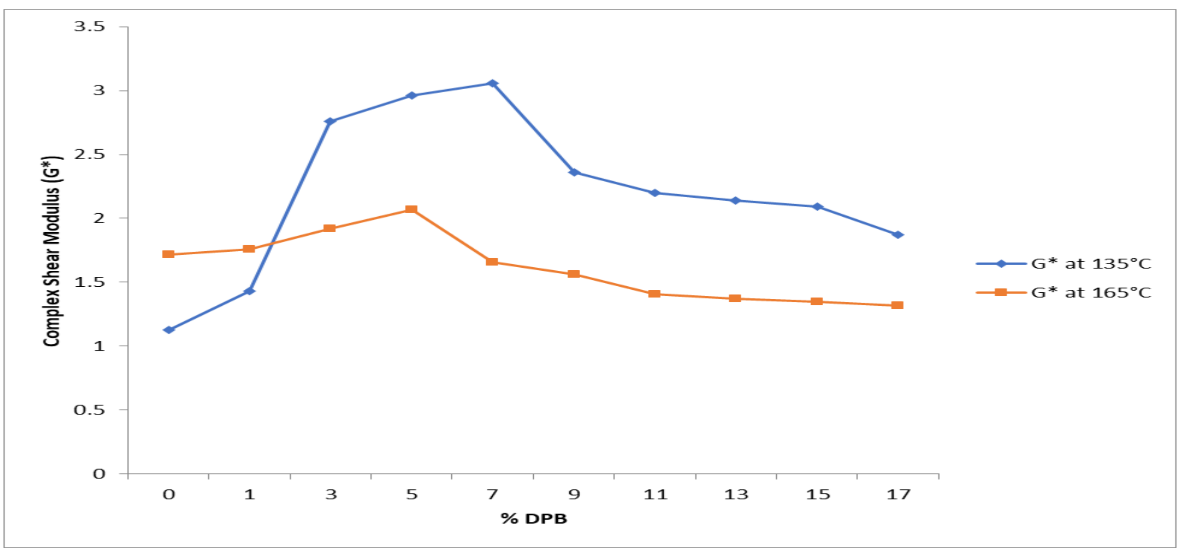

Fig. 5 Complex shear modulus of Warm Bitumen Blend Modified with DPB at 135 & 165°C

Complex shear modulus (G*) is the ratio of the peak shear stress to the resulting peak shear strain. It can be considered as the sample's total resistance to deformation when repeatedly sheared. Values of the complex shear modulus were obtained using the Brookfield programmable rheometer.

In Fig. 5, it was observed that the complex shear modulus, at 135°C increases as % DPB increases and up to 7% DPB and before the values started declining from 9% DPB modification and this is in line with Akinleye et al. (2020b) thereby making 7% DPB to be the optimum percentage modification at 135°C. Furthermore, it was observed that the results obtained between 0% - 5% DPB increases as DPB at 165°C increases thereby making 5% DPB to be the optimum percentage modification using at 165°C. According to Fazaeli et al. (2016), the viscous behaviour of modified binders is lower than the base bitumen. Therefore, the viscous behaviour of the Complex shear modulus (G*) values obtained for 9% - 17% at 135°C and 7% -17% at 165°C has a lower viscous behaviour compare to the values obtained for 0% - 7% at 135°C and 0% - 5% at 165°C.

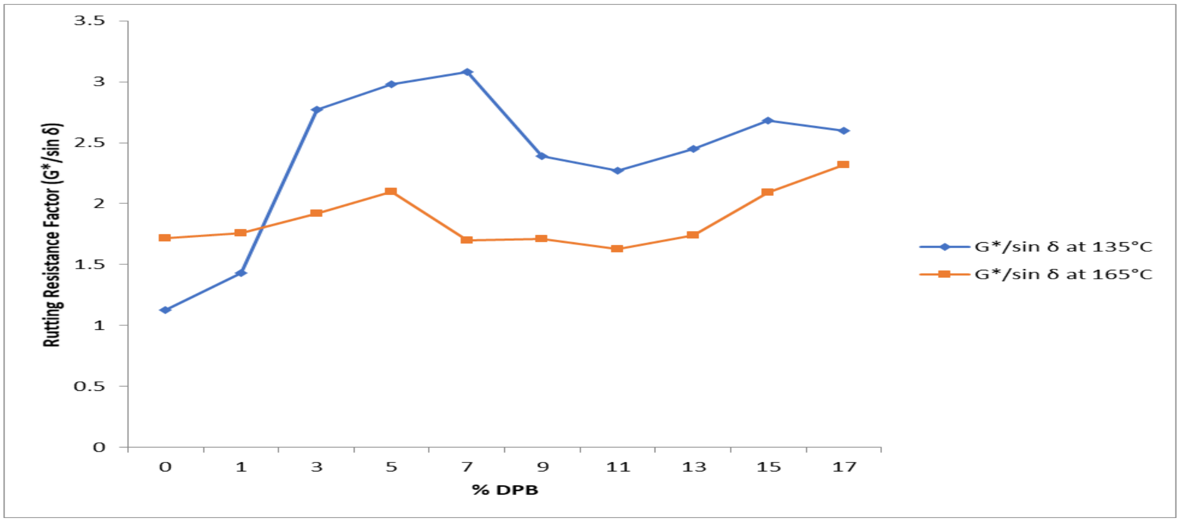

Fig. 6 Rutting resistance factor of Warm Bitumen Blend Modified with DPB at 135 & 165°C

Rutting, in asphalt, is measured using rutting resistance factor which is merely dependent on the rheological properties of asphalt binder. It is the ratio of complex shear modulus to the sine of phase angle of the binder. Fig. 6 showed that, at 135°C, the values of rutting resistance factor increases until it reaches the maximum at 7% DPB modification. It however declined upon further modification. this is in line with Akinleye et al. (2020b) thereby making 7% DPB the optimum percentage modification at 135°C. Furthermore, it was observed that the results obtained increases from 0% - 5% DPB and continue to decline afterwards before reaching the peak at 17% modification. However, it is safer to use the first peak value at 5% when working at 165°C, as optimum modification because of the declined in the values between 5% and 17% DPB modification. According to Fazaeli et al. (2016), the higher the rutting resistance factor for the binder, the stiffer and more rutting resistant the asphalt concrete would be.

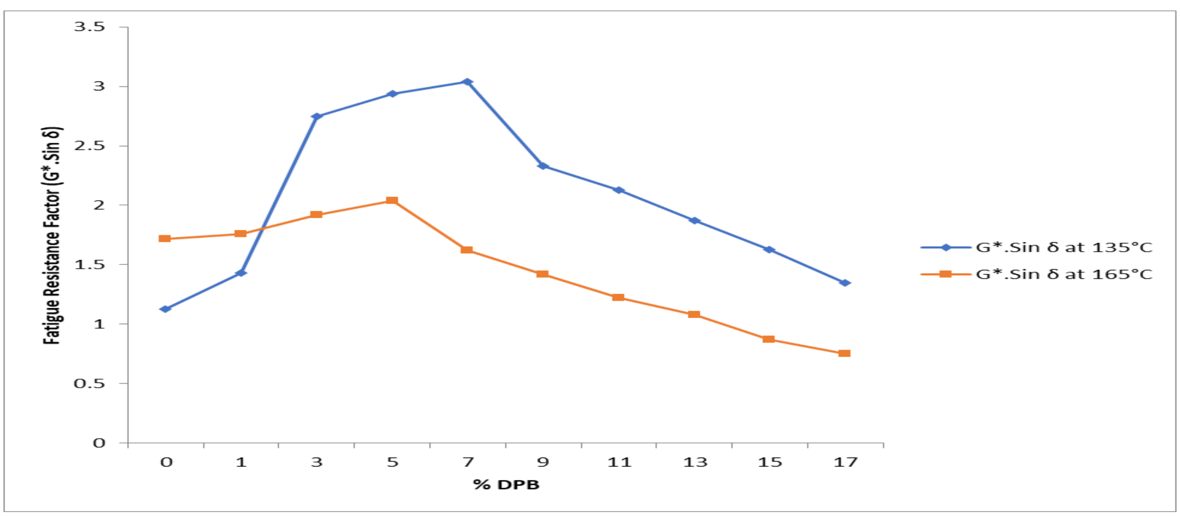

Fig. 7 Fatigue Resistance Factor of Warm Bitumen Blend Modified with DPB at 135&165°C

Fatigue is the interconnected cracks that appears in flexible pavement when it is subjected to repeated traffic loading. It is measured using fatigue resistance factor, which is the product of complex shear modulus and sine of phase angle of the binder. According to Fazaeli et al. (2016), lowest Fatigue resistance (G*.Sin δ) value indicates the best fatigue resistance among all asphalt mixture. The effect of DPB modification at

135°C and 165°C showed similar trend by first increasing to 7% and 5% respectively before decreasing upon further modification. Therefore, the best fatigue resistance was obtained at 17% DPB modification at both 135°C and 165°C.

Conclusion

Rheological properties of modified and unmodified warm bitumen blends with increasing level of modifications with DPB were evaluated, to find alternative way of waste plastic bottle disposal, reduce asphalt concrete production cost and extend pavement service life. The results indicated that addition of DPB improves viscosity, phase angle, complex shear modulus, rutting and fatigue resistance factors of the modified binder at both 135 and 165°C. The rutting resistance factor was maximum at 7% and 5% modification level for 135 and 165°C respectively while similar trend was observed in fatigue resistance factor though with a little difference at 17% DPB modification. It is therefore recommended that dissolved Plastic Bottle be used to improve bitumen rheological properties and subsequently resist rutting and fatigue on traffic roads.

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