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Study on the Application of Lime to Improve the Rheological Properties of Polymer Modified Bitumen

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***Abstract*—**Bitumen is one of the most applicable materials in pavement engineering. It is a binding material with unique viscoelastic properties, especially when it mixes with polymer. In this study, to figure out the viscoelastic behaviour of the polymer modified with bitumen (PMB), a series of dynamic shearing rheological (DSR) tests were conducted. Four percentages of lime (i.e. 1%, 2%, 4% and 5%) were mixed with PMB and tested under four different temperatures including 64ºC, 70ºC, 76ºC and 82ºC. The results indicated that complex shearing modulus (G*) increased by increasing the frequency due to raised resistance against deformation. The phase angle (δ) showed a decreasing trend by incrementing the frequency. The addition of lime percentages increased the complex modulus value and declined phase angle parameter. Increasing the temperature decreased the complex modulus and increased the phase angle until 70ºC. The decreasing trend of rutting factor with increasing temperature revealed that rutting factor improved by the addition of the lime to the PMB.

***Keywords*—**Rheological properties, DSR test, polymer mixed with bitumen, complex modulus, lime.

I. Introduction

IN recent years, modified bitumen has been an interest of many research projects. Improving the viscoelastic characteristics of the bitumen has been the interest area of many studies [1]-[4]. Bulatović et al. [5] performed a series of rheological tests on natural bitumen (BIT) and PMB and indicated that PMB has a higher resistance against permanent deformation. In another study by Wu et al. [6] using DSR device, a series of laboratory aging tests and natural exposure aging tests were performed on BIT samples and different ranges of G* and phase angle values were obtained. Eberhardsteiner et al. [7] also performed studies on ageing behaviour of the bitumen.

Hintz and Bahia [8] performed a study to figure out the fatigue behaviour of the binders of asphalt using DSR device. Moreno-Navarro et al. [9] also performed a study to assess the fatigue behaviour of the rubber in bitumen. Shen and Amirkhanian [10] investigated the effect of crumb rubber on the rheological properties of the binders. Radziszewski et al. [11] indicated that bituminous binders with the same level of hardness show variable low and high temperature properties. Veytskin et al. [12] also performed a study on mastic viscoelasticity. Toraldo et al. [13] investigated the effect of fibres on bituminous mixtures. This study aims to figure out effect of the lime on the rheological behaviour of the PMB by performing a series of DSR tests. This study is part of an ongoing investigation at Curtin University [14].

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II. Materials Used

A. Bitumen

A PMB class A15E was used to conduct the tests. Table I shows the physical properties of the used bitumen.

TABLE I
PHYSICAL PROPERTIES OF THE PMB

Characteristics	Description
Form/colour/odour	Black – solid at ambient temperature
Solubility	Insoluble in water
Specific gravity at (25%)	1.02
Vapour pressure (25 °C)	<1 mmHg at 180 °C
Flash point (°C)	>260 °C
Boiling Point/Range (°C)	> 400 °C

B. Lime

The characteristic of the lime used in this study showed in Table II.

TABLE II
THE PROPERTIES OF THE LIME APPLIED IN THIS STUDY

Composition	Formula	Percentage
Calcium Hydroxide	$Ca(OH)_2$	80 – 95%
Magnesium Hydroxide	$Mg(OH)_2$	0 – 6%
Crystalline Silica (respirable <7μm)	SiO_2	<1%
Silicon Dioxide, Quartz	SiO_2	0 – 8%

III. Methodology

To conduct the experimental section, PMB class A15E was heated at the temperature of 150±5 °C, then lime was added and mixed manually based on determined percentages. Table III reveals the mix designs for the materials applied in this study and the temperatures that tests were ran. The DSR device was adopted to perform the tests. The selected frequency was in a range of 0.1 rad/s to 10 rad/s under 64 °C, 70 °C, 76 °C and 82 °C. A plate with 8 mm diameter used for frequency sweep test and 2 mm gap was applied between the plates. The test procedures were in accordance with AASHTO T315-10 [15] standard.

TABLE III
MIX DESIGN AND LIME PERCENTAGES USED IN THIS STUDY

NO	ID	Lime (%)	Temperatures (°C)
1	PMB	-	64, 70, 76 & 82
2	PMB-1L	1	64, 70, 76 & 82
3	PMB-2L	2	64, 70, 76 & 82
4	PMB-4F	4	64, 70, 76 & 82
5	PMB-5F	5	64, 70, 76 & 82

IV. Results and Discussion

A. Relationship between Frequency and Complex Modulus (G)*

The relationship between complex modulus (G*) of the PMB mixed with lime with loading frequency under 64 °C, 70 °C, 76 °C and 82 °C was shown in Figs. 1-4 respectively. An increasing inclination could be seen in all figures under the mentioned temperatures. In all graphs, the PMB has a lower value of complex modulus in comparison with the lime modified specimens. Increasing inclination of G* parameter could be explained that at the higher frequency levels, there is a lesser time for the stresses to apply their loads to the tested specimen. Therefore, sample's ultimate shearing resistance to deformation incremented and as a result the G* graphs raised up and vice versa.

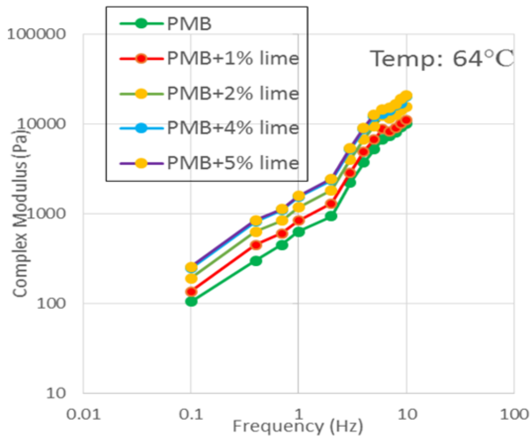

Fig. 1 Effect of lime on complex modulus at 64 °C

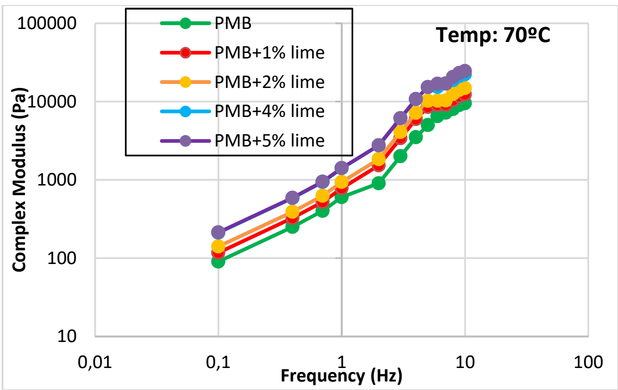

Fig. 2 Effect of lime on complex modulus at 70 °C

B. Relationship between Frequency and Phase Angle (δ)

The relationship between phase angle of the PMB mixed with lime with loading frequency under 64°C, 70°C, 76°C and 82°C was revealed in Figs. 5-8, respectively. The results at temperatures of 64°C and 70°C showed a declining inclination by increasing the loading frequency rates. This trend causes an increasing elastic deformation of the tested specimens. The trend was contrary at 76°C and 82°C. Meaning that the graph increased by increasing the frequency values. The phase angle is a parameter that illustrates the lag between applied shearing stress and resulted strain. The higher rates of the phase angle are a sign of the greater viscosity properties of the specimens. Therefore, at higher temperatures, the specimens react more similar to viscose materials and lesser like to elastic products that results in the increase in the phase angle.

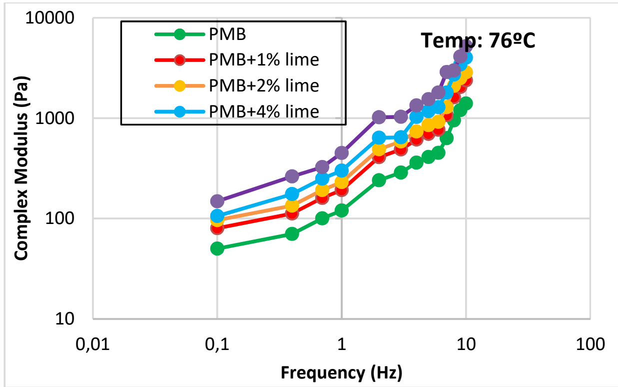

Fig. 3 Effect of lime on complex modulus at 76 °C

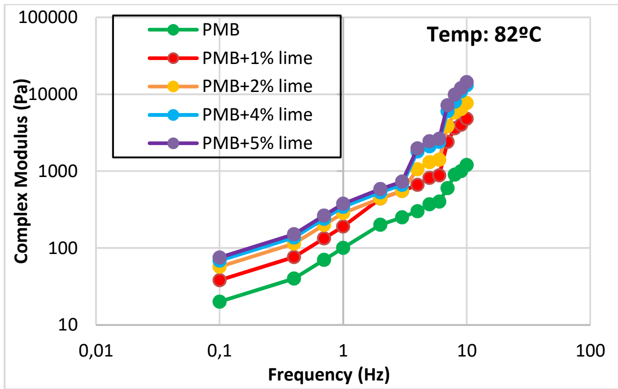

Fig. 4 Effect of lime on complex modulus at 82 °C

V. Conclusion

In this study, viscoelastic characteristics of the PMB mixed with lime in different percentages by conducting a series of experimental tests was figured out. The lime in four percentages of 1%, 2%, 4% and 5% was mixed with the PMB and tested under temperatures of 64 °C, 70 °C, 76 °C and 82 °C. The complex modulus (G*), phase angle (δ) and rutting resistance of the specimens were measured using a DSR device. The results showed that by increasing the loading frequency values, the complex modulus values were incremented, while the phase angles declined, which was due to the decreasing contact time of the plate when the stresses were applied to the samples. In addition, it was revealed that by increasing the temperature values, the complex modulus declined and the phase angles were increased until 70°C. This could be due to the changes in elastic properties of the specimens at lower temperatures to the viscosity properties at higher temperatures. The results of this study showed that 5% of lime when mixed with PMB enhances the rutting resistance of the PMB more than other percentages of lime applied in this study.

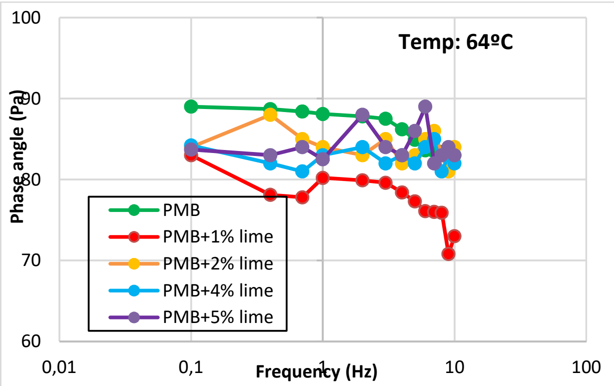

Fig. 5 Effect of lime on phase angle at 64 °C

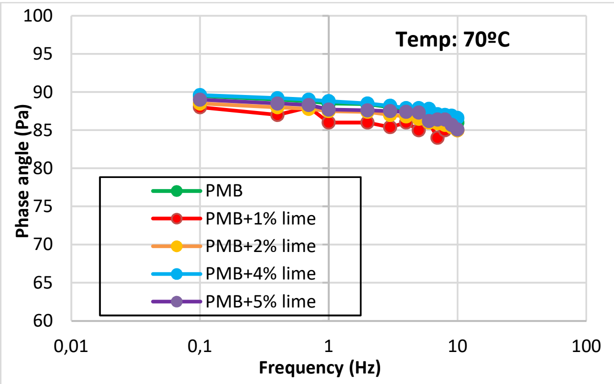

Fig. 6 Effect of phase angle and loading frequency at 70 °C

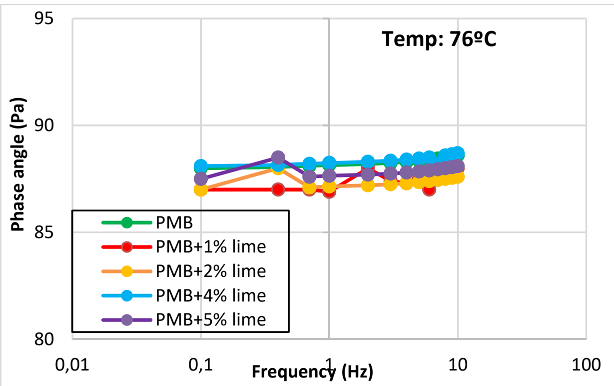

Fig. 7 Effect of phase angle and loading frequency at 76°C temperature

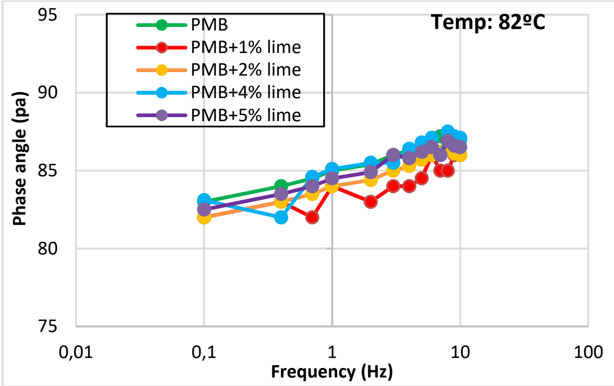

Fig. 8 Effect of phase angle and loading frequency at 82°C temperature

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