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Effect of Bio based rejuvenator on Permanent Deformation of Aged Bitumen

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Abstract: Rutting has been and continues to be a problem in performance of asphalt mixes. The purpose of this paper is to provide a summary of studies on effect of bio-based rejuvenator on rutting performance of aged asphalt. Aged asphalt binder incorporating different percentage of bio-based rejuvenator extracted from jatropha curcas (JCO) was evaluated to investigate the effect of the rejuvenator content on rutting deformation of rejuvenated aged asphalt binders. The findings showed that, the addition of bio-based rejuvenator affects the rutting performance under ageing condition. The results of rutting evaluation from rheological analyses of aged and blended binders indicate that the characteristics of blended binders are dependent on bio-based rejuvenator (JCO). The results show that the complex modulus decreases with the increase in temperature which corresponds to a decrease in loading frequencies.

Keywords: Bio – based rejuvenator, Jatropha curcas (JCO), Asphalt binders, RAP, Rutting, Deformation.

1. Introduction

Rutting is defined as the accumulation of small amount of unrecoverable of strain resulting from applied loads to the pavement. The deformation is caused by consolidation, a lateral movement of HMA under traffic load or both shear failure (lateral movement) of the HMA courses generally occurs in the top 100mm of the pavement surface. Rutting not only decreases the useful service life of the pavement, but also creates a safety hazard for the traveling public. In recent years the potential for rutting on the nation's highways has increased due to higher traffic volumes (equivalent single axle loads ESALs) and the increased use of radial tires, which typically exhibit higher inflation pressures[1].

Furthermore, analysis of January 2011 global industries market report, 118.4 million metric tons of asphalt is to reach global asphalt market by 2015. The asphalt paving industry accounts for the largest end-use market segment of asphalt. Asphalt binder supplies are shrinking, while the demand for it is increasing rapidly and petroleum oil reserves becoming depleted; this in turn has led to an increase in the price of asphalt. This is because of technological advances in the refining process, which are now able remove more of the high value resins and oils for other more profitable markets such as synthetic rubbers, plastics, fuels, perfumes, and cosmetics[2-6].

For this reason, as well as increased environmental concerns and awareness of depleting natural resources, the use of recycled asphalt materials has received increased recognition in the asphalt industry, because if the supply of crude oil is cut, the asphalt industry is in risk of falling into the severe situation[7][8][9][10]. From the previous study, bio based rejuvenator from jatropha curcas oil (JCO) that are able to be used as rejuvenator. However, the unknown history of the bio based rejuvenator and its ability to achieve the desired criteria have become the main concern among practitioners and justification is needed. At high temperature, rutting is the predominant damage on the pavement surface. Hence, this paper focuses on the rutting evaluation of partial aged binder incorporated with bio based rejuvenator.

2. Methodology

2.1 Binder: Two types of binder were used in this study: control binder (80/100 PEN) and artificial aged binder. The artificial aged binder was obtained by subjecting the original binder of 80/100 PEN to long-term aging by means of a pressure aging vessel (PAV) to simulate standard method and hasten the aging process of the

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binder in the laboratory. After aging, the binder was tested for Performance Grade (PG).

2.2 Bio-based rejuvenating agent: A non-edible oil from jatropha curcas seed that cannot be used for nutritional purpose was used as bio-based rejuvenator. The blend was performed by mixing the aged binder with the bio-based rejuvenator. The dosage of the bio-based rejuvenator varies from 1 % up to 5 % based on the weight of the aged binder. Before adding bio-based rejuvenator into the aged binder, the physical properties were investigated as shown in Table 1:

Property	Value
pH	5.2
Free fatty acids	0.0718 mg KOH g–1 oil
Specific gravity	0.8945
Flash point	245°C
Peroxide value	7.20 meq g–1 oil
Iodine value	51.27 g 100 g–1 oil
Density at 27°C	0.725 g cm–1
Viscosity	8.2 cst

After blending with three doses of rejuvenator the dynamic shear rheometer evaluates the specimen's response to the sinusoidal stresses and calculates the specimen complex modulus (G*) and phase angle (δ) with computer software equipped with rheometer. This testing is best described by ASTM D 7175. The rheological properties assessed by this test are based on the ranges of in service temperature of the geographical location in which the binder will be used, or 6^{o}C higher to accommodate slow moving vehicle.

3. Results and Discussion

3.1 Effect on Isochronal Curve

The rheology or Visco-elastic properties of asphalt binders are best defined by two parameters; complex modulus 'G*'and phase angle 'δ' (Brown et al., 2009). The G* gives an idea of the binder stiffness at different temperature and loading rate, while δ is the phase angle between stress and strain, it's values range from 0^{o} to 90^{o} , from a perfectly elastic materials to a perfectly viscous materials respectively, this means the smaller the value of δ, the higher elastic the binder is [11-13].

Fig. 1 below is a plot of complex modulus 'G*parameters against phase angle obtained from the DSR test results. These results are for the 40/50 binder that was then blended with 1%, 3% and 5% and JCO for subsequent testing (M. E. Abdullah et al., 2016). The binder blend with 3% JCO, shown in light blue, fails specification at 70ºC, which is expected for a PG 64 or 80/100 binder. 40/50 have an upward shift for all data points, and had an overall of PG 76, indicating the binder stiffness. As the temperatures are increased from 46°C to 76°C, the complex shear modulus decreases steadily [14-16].

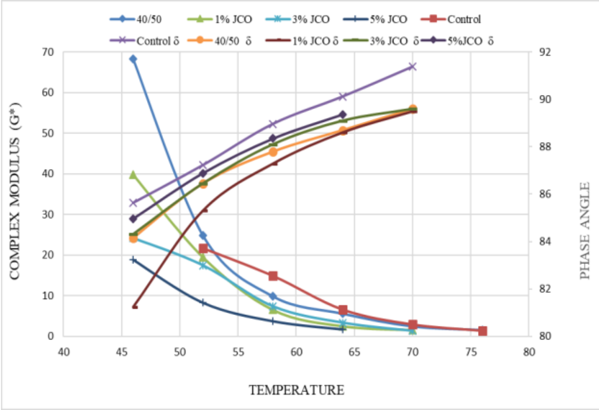

Fig.1: plot of 40/50 complex modulus 'G*parameters against phase angle

3.2 Rutting Resistance

For rutting resistance, a high complex modulus 'G*' value and low Phase angle 'δ', are required which equates to higher rutting parameter 'G*/Sin δ'. Typical asphalt binder are more prone to rutting at a high temperature under heavy traffic load when it has a lower viscosity and are more likely to creep. According to superpave specifications, 'G*/Sin δ' is used to define permanent deformation of an asphalt binder at high-performance temperature. Fig. 2 on the other hand shows a plot of G*/sinδ against temperature. The binder blend with 3% JCO in the case of (40/50) aged bitumen performed almost identically to the original binder by reducing the PG to 64 40/50 aged bitumen have G*/Sin(δ) values higher than 1.0 kPa (unaged condition) at 64ºC testing condition. The addition of JCO oil into the aged binder led to a drop in high temperature of the binder, which means the rutting resistance is moving toward the rejuvenated binders[17, 18].

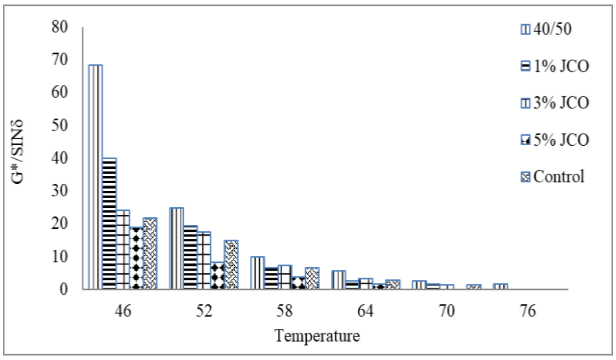

Fig. 2: G*/sin δ of 40/50 unaged asphalt binders blended with different percent of JCO at 64˚C

3.3 Ageing Index Rutting Factor

The ageing index rutting factor is an alternative option to clearly express the effects of ageing of binder. Ageing index rutting factor can be defined as the ratio of rutting factor of aged binder to the original binder as illustrated in the Equation below. Generally, higher value of AIRF describes the binder is more susceptible to ageing. The aged binders rejuvenated with JCO exhibits lower resistance to oxidation compared to binder with the lowest AIRF denotes by 40/50 aged binder which indicates that aged binder is less susceptible to temperature after ageing due to increased complex shear modulus (Fig. 3). This finding is due to high increased for $G^*/\sin\delta$ as induced by ageing [19, 20].

$$AIRF = (G^*/\sin(\delta)\ aged) / (G^*/\sin(\delta)\ unaged)$$

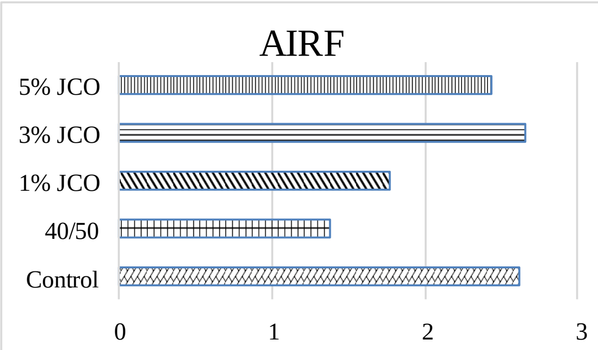

Fig. 3: Ageing index rutting factor of 40/50 aged binder blended with different percent of JCO at 64°C

3.4 Failure Temperature

The failure temperature of asphalt cement is defined as the temperature at which the ratio $G^*/\sin\delta$ is less than 1.0 KPa and a minimum $G^*/\sin\delta$ value of 2.2KPa for RTFO aged binders, according to the Superpave binder-grade specifications. The higher the failure temperatures from the DSR test implies that the binder are less susceptible to permanent deformation at high pavement temperature. Moreover, the failure temperature is frequently used to identify the performance grade of asphalt cement. The failure temperature of binders was calculated based on the DSR data obtained, it is determined through interpolation as the temperature
at which $G^*/\sin\delta$ value is less than the required value at testing temperature.

Based on this, the failure temperatures of the aged bitumen binders and rejuvenated asphalt binders were obtained based on the DSR test results, as shown in Fig. 4 and Fig. 5. It is found that with the increase of the JCO content, the failure temperature also decreased which means the rutting resistance is moving toward the rejuvenated binders. The critical temperature of 1%, 3% and 5% JCO rejuvenated asphalt binders were 69, 67, and 61°C lower than that of the Aged bitumen asphalt binder (75˚C).

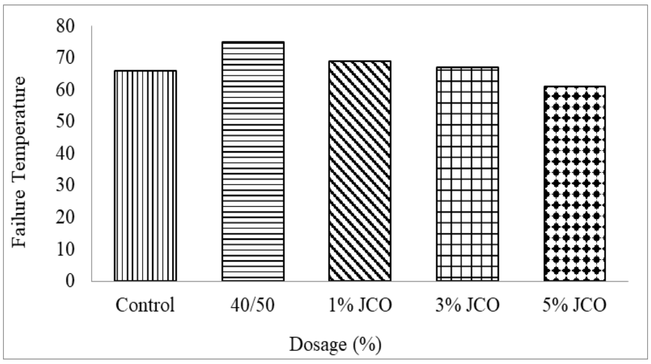

Fig. 4: Failure Temperature of binders

3.5 Temperature susceptibility

Temperature susceptibility is defined as the change in the consistency parameter as a function of temperature. The temperature susceptibility of the modified asphalt binder samples was calculated in terms of penetration index (PI), using the results obtained from penetration and softening point tests according to proposed equation of shell binder handbook.

$$PI = \frac{1952 - 500\log(pen\ at\ 25^{\circ}c) - 20(sp)}{50\log(pen\ at\ 25^{\circ}c) - sp - 120}$$

As illustrated the value of PI increased with the addition of jatropha curcas oil content into the aged binder especially for binder with 3% of JCO in the case of (40/50) aged binder but it does not resemble the original binder value. Higher PI value indicates less temperature susceptibility and more rubbery elastic behaviour. However, it is noted that although JCO could modify the temperature susceptibility of aged binder it does not resemble the original binder value. Hence, PI value of aged binder increases with the addition of jatropha curcas oil (JCO). The higher the percentage added, the higher the PI value increases which indicate lower thermal susceptibility. Asphalt mixtures containing asphalt binder with higher PI are more resistant to low temperature cracking as well as permanent deformation (rutting)[17, 21-23].

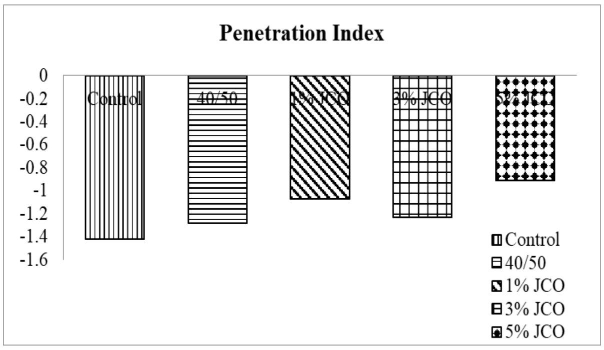

Fig. 5: temperature susceptibility results of 40/50 binder blended with JCO

4. Conclusion

From the study, the findings can be concluded into the following points:

1. 4% of JCO has the ability to counteract the stiffening effect of the 40/50 aged binder and restore the aged binder to resemble the original 80/100 PEN binder. This implies that lower dosage of bio based rejuvenator is require compared to petroleum and engineered rejuvenators to provide similar softening effect on aged bitumen.

2. The addition of Bio based rejuvenator (JCO) in the partial aged binder reduced the stiffness of the binder (complex modulus) and its resistance to rutting and fatigue cracking but increased the resistance to thermal cracking. Moreover, from the AIRF value, the binders containing high amount of bio based rejuvenator are susceptible to ageing.

3. PI value increases which indicate lower thermal susceptibility. Asphalt mixtures containing asphalt binder with higher PI are more resistant to low temperature cracking as well as permanent deformation (rutting).

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