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"Research Note"

RUTTING AND FATIGUE BEHAVIOR OF NANOCLAY MODIFIED BITUMEN*

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Abstract– This research has accomplished a comparative rheological test on the unmodified and nanoclay modified bitumen. The results show that compared to unmodified bitumen, the nanoclay modification leads to changes in rheological parameter by increasing stiffness and decreasing the phase angle hence; it can also reduce aging effect on bitumen. Further, the comparison of the rutting parameter ($G^*/sin\delta$) shows that the nanoclay modification could increase the rutting resistance of bitumen where the improvement is dependent upon the type and amount of nanoclay. The fatigue resistance parameter ($G^*sin\delta$) at the low to medium temperature shows that the nanoclay modification reduces the fatigue life, however, it exhibits the same fatigue life as that of the unmodified bitumen after a particular ageing condition.

Keywords– Fatigue, rutting, Bitumen modifies, nanoclay, dynamic shear rheometer

1. INTRODUCTION

Temperature susceptibility characteristics and the physical properties of asphalt bitumen at high and low field-operating temperatures can affect the final performance of the mixture. To improve the performance of bitumen and asphalt concrete mixtures, the addition of modifiers such as polymers have become popular in recent years. As a matter of fact, polymeric nanocomposites are one of the most exciting of materials discovered recently and physical properties are successfully enhanced when a polymer is modified with small amount of nanoclay on the condition that the clay is dispersed at nanoscopic level [1]. Many studies have been conducted on nanoclay modified polymers, though relatively little published information is available about nanoclay modified bitumen. Material variables, which can be controlled and can have a profound influence on the nature and properties of the final nanocomposite include the type of clay, the choice of clay pre-treatment, the selection of polymer components and the way in which the polymer is incorporated into the nanocomposite [1]. The structure of bitumen and polymers are different, with bitumen being a very complex polymer and not stable. Bitumen is a highly heterogeneous mixture of hydrocarbons and is composed of polymers. Bitumen is a mixture of organic liquids that are highly viscous, black, sticky, entirely soluble in carbon disulfide, and composed primarily of highly condensed polycyclic aromatic hydrocarbons. It can be divided into the chemical families of saturates, aromatics, resins, and asphaltenes. The structure of asphaltenes on bitumen depends on the temperature and chemical composition of the bitumen. The asphaltenes are highly associated to each other in gel type, but they are not associated to each other in sol type, and as such have poor network and lower asphaltenes proportions and need different approaches of clay and bitumen interaction that probably limit the successes obtained in bitumen-nanoclay modifications.

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2. LITERATURE REVIEW

Bitumen is a complex mixture of about 300-2000 chemical components and can be separated into four functional groups [2]: asphaltenes, resinous components (polar aromatics), non-polar aromatics (naphtene aromatics) and saturates. Many researches have been conducted on nanoclay modified polymers, but little published information is available about nanoclay modified bitumen. Some researches were also performed on bitumen modification by polymer materials such as *SBS* (*Styrene Butadiene Styrene Block Copolymer*), *SBR* (*Styrene Butadiene Rubber Latex*) and *EVA* (*Ethyl Vinyl Acetate*). Studies on *SBS* show that *SBS* improves the rheological properties of asphalt bitumen due to the polymer network formation in the bitumen. This network forms in two stages: at low concentrations, the *SBS* acts as a dispersed polymer and does not significantly affect the properties; at higher concentrations, local *SBS* networks begin to form and are accompanied by a sharp increase in the complex modulus, softening point temperatures, and toughness [3, 4].

Permanent deformation of asphaltic materials has a major contribution to rutting. Under static loading, the steady-state deformation of asphaltic materials is the key component of the permanent deformation. The steady-state deformation behaviour of the DBM mixture is found to be more sensitive to the stress level. The temperature dependency of the steady-state deformation behaviour is found to be well captured by the Williams-Landel-Ferry (WLF) equation [5].

Recently, nanoscale inorganic fillers have attracted much the attention, as, theoretically, they significantly improve the properties of pristine polymers such as bitumen with relatively small percent of additive [6, 7]. Nanoclays are micro-scale fillers which may possibly make polymers efficient as filler reinforcements. Ghile performed mechanical tests on asphalt mixture modified by cloisite. The result showed that nanoclay modification improves the mechanical behavior properties of the mixture such as indirect tensile strength, creep and fatigue resistance [8]. Chow *et al* investigated surface modified montmorillonite nanoclay and compatibilizer, and came to the conclusion that the strength and stiffness of polyamide polypropylene nanocomposites improves due to the synergistic effects of surface modified montmorillonite nanoclay and compatibilizer [9]. Yasmin *et al* found that the addition of Nanomer I.28E and Nanoclay into some pure epoxy polymers produce materials with a higher elastic modulus than that of the pure epoxy [10].

3. MATERIAL AND METHODS

This study used 60/70 penetration grade bitumen and two types of common nanoclays; *Cloisite-15A* and *Nanofill-15*. The modification of bitumen with nanoclay was performed at nanoscale level with thermodynamic driving force. In the proposed research, the Dynamic Shear Rheometer (*DSR)* tests were performed on the available samples in three given conditions: virgin (un-aged), short-term and long-term ageing. Furthermore, three types of modified bitumen with 4% cloisite, 7% cloisite and 7% nanofill were used during the experiments.

In the viscoelastic region, the complex shear modulus (G^*) and phase angle (δ) are indicators of the bitumen resistance to shear deformation that can predict the potential of rutting and fatigue resistance of hot asphalt mixture. At high temperatures, the complex shear modulus and phase angle are proven indicators of the rutting susceptibility of the pavement ($G^*/\sin\delta$), similarly at medium temperatures they may be used to predict fatigue cracking ($G^*\sin\delta$).

To relate G^* and δ with the actual traffic loading condition, a loading time of *0.1* sec. that is related to the passing of a truck tire at a speed of 80 km/h, was selected as a loading frequency. With sinusoidal loading, 0.1 second corresponds to 10 rad/s (1.6 Hz). To find the effects of high temperature on rutting performance, the *DSR* test was carried out at high temperature ranges (40, 50, 60, 70 and 80°C), however, for fatigue resistance comparison, the same test was carried out at low to medium temperature ranges (0, 5, 10 and 20°C).

4. ANALYSES OF *DSR* RESULTS ON MODIFIED UNMODIFIED BITUMEN

a) Permanent deformation resistance (G/Sinδ)*

The analysis on un-aged bitumen in Fig. 1 shows that the rutting parameter (*G*/Sinδ*) increases twice or thrice as compared to unmodified bitumen, with the addition of 7% cloisite. These results, therefore, prove that the cloisite modified bitumen performs much better than the unmodified bitumen in rutting performances.

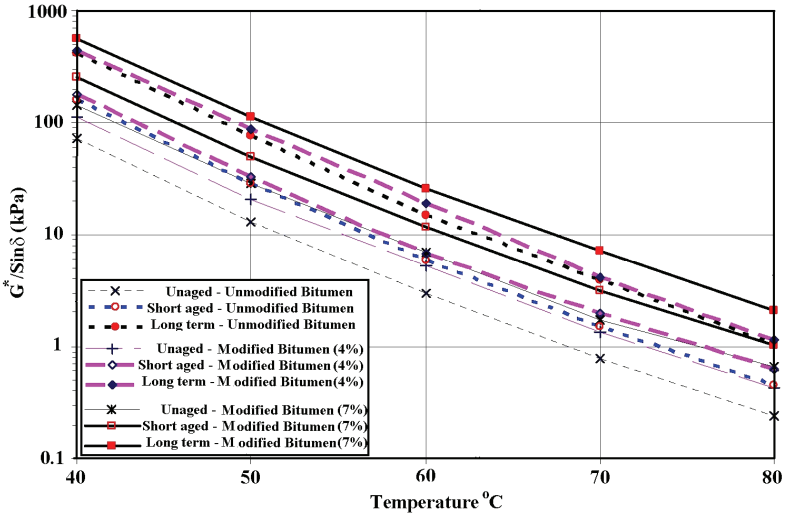

Fig. 1. Comparison of *G*/Sinδ* of unmodified and cloisite modified Bitumen

Results on nanofill modification in Fig. 2 show that the rutting parameter increases about 1.6 times by adding 7% nanofill as compared to unmodified bitumen in temperature ranges of 40 to 50°C. However, this change was not found at a temperature more than 60°C. This parameter is less for the nanofill modified bitumen in short and long-term conditions compared to the unmodified bitumen (85% in *RCAT* short-term and long-term ageing).

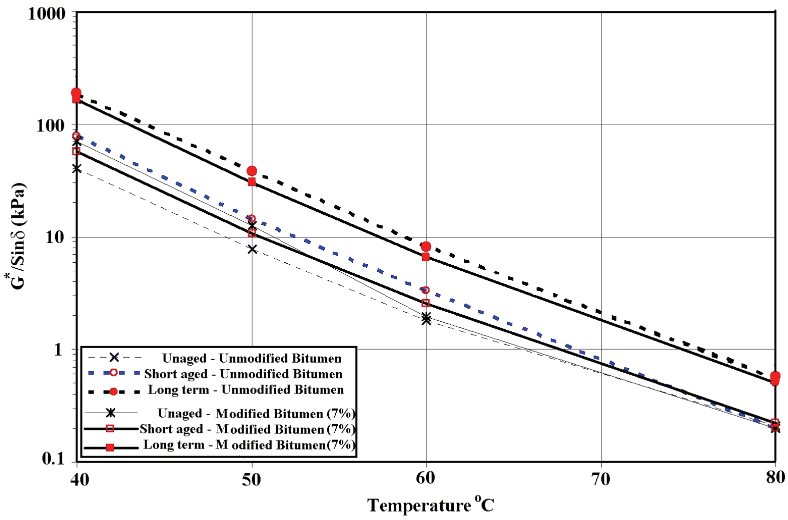

Fig. 2. Comparison of *G*/Sinδ* of unmodified and nanofill modified bitumen

b) Fatigue resistance parameter (G*Sinδ)

Analysis in Fig. 3 shows that, the fatigue resistance parameter ($G^*Sin\delta$) improves 1.2 to 1.4 times in un-aged condition by adding 7% cloisite compared to unmodified bitumen. It is 1.1 to 1.5 times higher after short-term ageing and 1.4 to 1.5 times higher after long-term ageing. These differences decree in 4% cloisite modification in all conditions. Thus, the analysis shows that the cloisite modification reduces the fatigue life of bitumen at the low to medium temperature ranges, although the reduction in fatigue is bigger when the amount of cloisite increases in the bitumen.

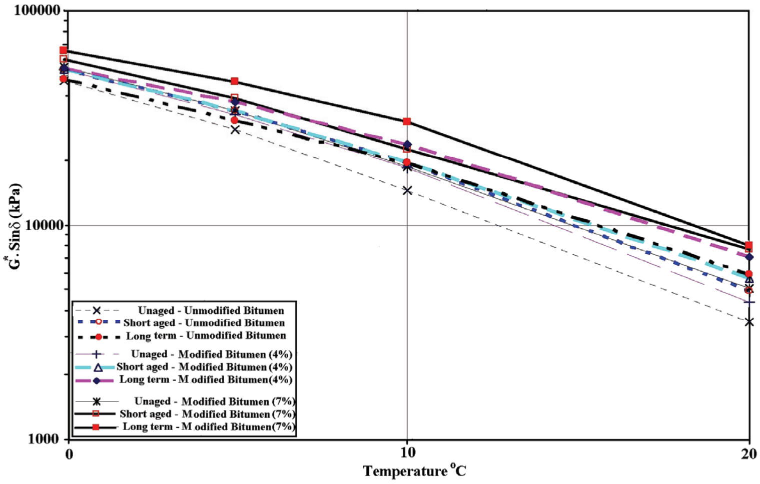

Fig. 3. Comparison of $G^*.Sin\delta$ of unmodified and cloisite modified bitumen

The above analysis on nanofill modification in Fig. 4 also shows that the energy dissipation factor ($G^*Sin\delta$) in unaged condition is 1.2 to 1.3 times higher than the unmodified bitumen. However, such dissipation factor is more or less the same in aged conditions.

According to the same analysis, though the nanofill modification reduces the fatigue life at low to medium temperature ranges, the nanofill modified bitumen shows the same fatigue life as that of the unmodified bitumen, after aged condition.

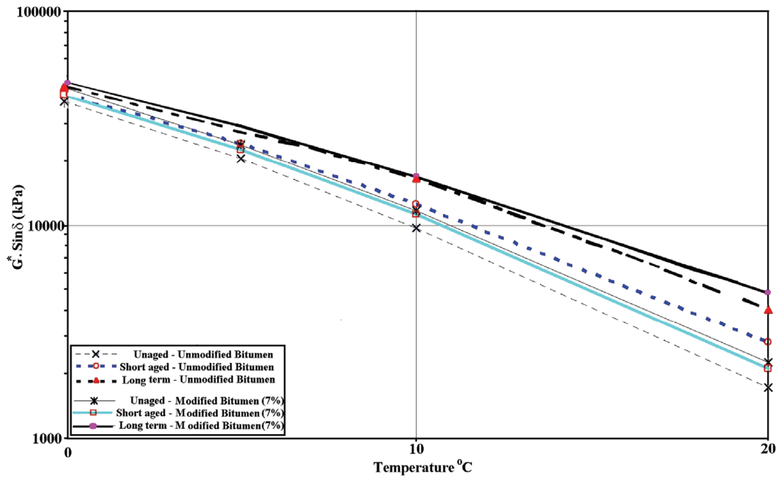

Fig. 4. Comparison of $G^*.Sin\delta$ of unmodified and nanofill modified bitumen

5. DISCUSSION AND CONCLUSION

Tests performed on bitumen samples proved that the nanoclay modifications help increase the stiffness and aging resistances. Comparison of the rutting parameter ($G^*/Sin\delta$) shows that nanoclay modification can improve the rutting resistances of bitumen, depending upon the type and amount of nanoclay. So as far as the analysis of fatigue resistance parameter ($G^*Sin\delta$) is concerned, it was shown that the nanoclay modification reduces the fatigue life at the low to medium temperature ranges. However, the nanoclay modification shows the same fatigue life as that of the unmodified bitumen after aged condition.

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