Rheological Characteristics of Waste Polyvinyl Chloride-Bitumen Composites: Part II

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Abstract— Waste Polyvinyl chloride-bitumen composites were prepared in the molten state by addition waste PVC pipes to commercial bitumen in different concentrations. The original material of the pure bitumen and bitumen composites are rheologically characterized. The viscoelastic properties such as shear compliance, torque and viscosity were measured and compared. These properties were studied using an ARES- Rheometer (Rheometric Scientific, Co.) equipment. The measurements were performed in the dynamic mode, plate-plate geometry of 25 mm diameter over the temperature range from –10 to 60°C and angular frequency, ω varied from 102 to10-1 radian/s. The results are compared at reference temperatures10 and 60°C over a wide range of ω. The results evidence that the incorporation of the waste PVC into bitumen enhances the dynamic mechanical moduli and the viscosity. The moduli were found to rise with increasing the waste PVC content. The stability of the bitumen blends is more noticeable at 60°C as confirmed by the results.

Keywords: Waste Polyvinyl chloride-bitumen composites, dynamic sheer compliances, dynamic viscosity.

1. INTRODUCTION

The chemical composition of bitumen is very complex. Bitumen is a complex mixture of organic and inorganic compounds. Such compounds may be separated into asphaltenes and maltenes [1-9].The asphaltenes are the most polar fraction and have the highest molecular weight, giving its dark color to the bitumen. The maltene fraction consists of polar aromatics, naphthene aromatics, and saturates. The ratio of the asphaltenes to the maltenes has a significant effect on the viscoelastic properties of bitumen and, consequently, on its performance as road paving binders.Thus, road pavements may show different distresses depending on temperature-for example, rutting (or permanent deformation at high temperatures) related to the viscosity of the bitumen matrix, and low-temperature cracking, as a result of brittle fracture of the glassy bitumen matrix [10].

The concept of using mineral fillers in the modification of bitumen has been recognized for a long time because of their cost and stiffness advantages. However, concerns have been raised that mineral fillers may cause mastics to exhibit excessively brittle behavior and result in cracking at low temperatures.Recently, considerable attempts have been made on the modification of bitumen by soft fillers, such as polymers for road, roofing, and waterproofing applications[11-18]. The performance of these blends can be further achieved by controlling their rheology at a critical level with polymer addition. For this reason the study of the rheology for bitumen blends has considerable efforts from many researchers [19-24].

Nowadays, an increasing number of people are coming to the realization that plastic wastes are a potential worldwide source of raw materials. As we know, plastic wastes are usually commingled thermoplastics, that is, a mixture of polyethylene (PE), polyvinyl chloride (PVC), poly(ethylene terephthalate) (PET), polypropylene (PP), polystyrene (PS), and other common plastics. To recycle the commingled plastic waste in the form of blends is very attractive because it avoids the difficult task of separation [25].

The aim of this work is to recycle the waste PVC by using it as a modifier for the bitumen and study the rheological properties of the modified bitumen compared to the original material of the neat bitumen.

2. EXPERIMENTS PART

Materials and preparation
Bitumen blends were prepared from commercial bitumen and waste PVC pipes. Waste PVC were obtained from the garbage, sorted and shredded into coarse particles. The bitumen was melted in an oven followed by melting waste plastics and mixed homogeneously. The hot mixtures were then cast into a ring stamp with 25 mm diameter and 2 mm thickness for rheology testing .

Method
The rheological behavior was studied for pure bitumen and bitumen blends by using dynamic an ARES-Rheometer (Rheometric scientific) equipment. The measurements were performed in the dynamic mode, plate-plate geometry of 25 mm diameter over the temperature range from –10 to 60°C and angular frequency, ω varied from 102 to10-1 radian/s. With gap setting 2 mm and the actual gap size is read electronically and allows absolute moduli to be determined. The strain amplitude was1% to ensure the linear viscoelastic regime. 6 points per decade in frequency were obtained.

3. RESULTS AND DISCUSSIONS

Figures 1-2 present the master curves of the dynamic shear compliances moduli (J' and J") at 10°C,and 60°C as a function of frequency for bitumen blends compared to neat bitumen. J'(ω) is the storage compliance and it is a measure of the energy stored and recovered per deformation cycle, therefore is called the storage compliance. And J"(ω) is a measure of the energy dissipated as heat per cycle of the sinusoidal deformation, for that it is called the loss compliance. Figures 5 and 6 show also two zones of behaviour as melt and rubbery zones from the left to right side of ω as explained above in G' and G" curves. Since J' and J" represent the image of a mirror reflects in the ω-axis for G' and G". The enhancement of the dynamic shear compliances moduli by the introduction of the waste PVC is clear in Figures 1-2. As shown in Figure 1 at 10°C and 0.01 rad/s (at the end of the flow zone) the values of J' are 101 , 101 , 102 , 103 and 105 Pa for pure bitumen, bitumen-5%PVC, bitumen-7%PVC and bitumen-11%PVC, respectively. In Figure 2 J" modulus of bitumen-11%PVC at 0.01 rad/s and 10°C is higher than neat bitumen by a factor about 5 and this factor rises to around 9 at 0.0001rad/s.

The enhancement in the J' and J" moduli by the addition of PVC to bitumen because the interaction between PVC chains and bitumen compounds results in bitumen-PVC network formation and the cross-linked increases with the polymer content, as a result the stiffness increases. The difference between the dynamic moduli of bitumen blends and neat bitumen is higher at 60°C than at 10°C as shown in Figures 1-2.

.Figure 3 shows the comparison between the dynamic viscosity ή of neat bitumen and those of bitumen blends as a function of frequency at low and high temperature (at T0 10 and 60°C). ή increases with decreasing frequency and decreases with the temperature as shown in Figure 9. In this Figure ή reaches the Newtonian zone at low deformation rate of each T0 at which it becomes independent on ω. In this zone ή is called melt viscosity η_0 (zero-shear viscosity) As shown in this Figure ή increases by the addition of waste PVC and it is observed to rise with increasing the waste PVC contents particularly in the Newtonian zone.

4. CONCLUSION

Bitumen blends are prepared by the introduction of waste PVC up to a level of 11wt% in the molten state. The viscoelastic properties such as shear compliance,, and viscosity of bitumen blends and neat bitumen are determined. These properties were studied using an ARES- Rheometer (Rheometric Scientific, Co.) equipment. The measurements were performed in the dynamic mode, plate-plate geometry of 25 mm diameter over the temperature range from –10 to 60°C and angular frequency, ω varied from 102 to10-1 radian/s. The experiments data which measured at different temperatures as a function of ω are shifted into a master curve at low temperature (10°C) and high temperature 60°C. The results are compared at T0 10 and 60°C over a wide range of ω . The results evidence that the incorporation of the waste PVC into bitumen enhances the dynamic mechanical moduli and the viscosity. The moduli were found to rise with increasing the waste PVC content. The stability of the bitumen blends is more noticeable at 60°C as confirmed by the results.

5. ACKNOWLEDGMENTS

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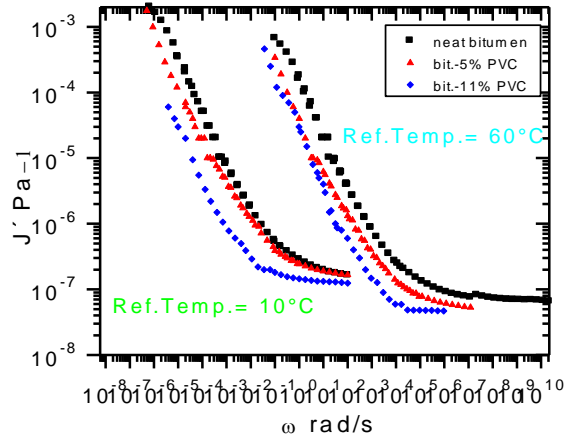
Figure 1: Master curves of J' for bitumen and bitumen blends as a function of ω at $T_0=10$ and $60°C$
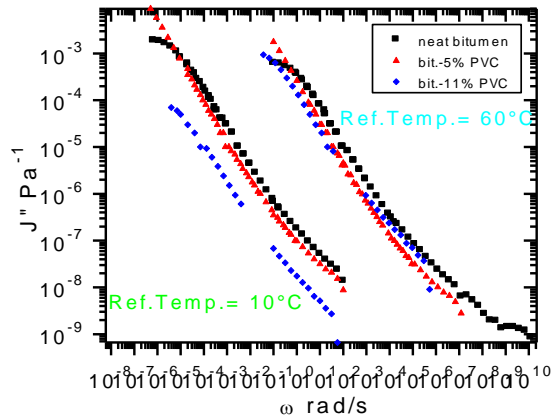

Figure 2: Master curves of J'' for bitumen and bitumen blends as a function of ω at $T_0=10$ and $60°C$
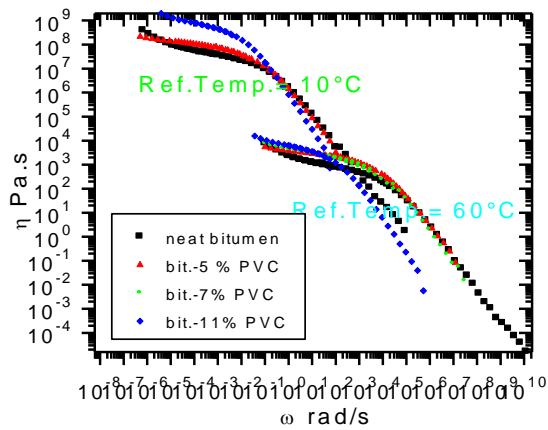

Figure 3: Comparison between ή for bitumen and bitumen composites at different temperatures