International Journal of Engineering and Information Systems (IJEAIS)
ISSN: 2000-000X
Vol. 2 Issue 12, December – 2018, Pages: 31-35

Reuse of Waste Plastic in the Modification of Rheological Characteristics of Bitumen

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Abstract: *Waste polyvinylchloride (PVC) pipes were reused in the modification of commercially available bitumen. Waste PVC/ bitumen blends were prepared by melt-mixing method. Rheological characteristics of the neat bitumen and bitumen blends samples were investigated. The rheological properties were determined using an ARES- Rheometer (Rheometric Scientific, Co.) under nitrogen atmosphere in parallel plate geometry with diameter 25 mm. The measurements were performed over a wide range of temperatures ranged from -10°C to 60°C and frequencies from 100 to 0.1 radians per second. Improvement in rheological properties.*

Keywords: bitumen; rheology; polymer modification, waste polyvinylchloride pipes.

1. INTRODUCTION

Electricity the driving force of modern civilization, is indispensable in our day to day life. There are two basic types of electricity generation. One of which is through conventional energy resources which will get extinct in near future, hence demanding an alternative arrangement. Therefore, it is of great urgency to go for non-conventional energy resources. The non-conventional

Bitumen is the black adhesive that binds flexible pavements on roads and airfields together. Bitumen is also used in other areas of application, such as waterproofing, flooring and joint materials. Almost all Bitumen originates from crude oil and is the residue of a refining process. It is well-known that bitumen is a very complex and temperature dependent material consisting of hydrocarbon molecules. Naphtenic-base crude oils often give a large yield of bitumen that may be of good quality, while paraffinic crude oils may give bitumen of good quality or yield bitumen not suitable for road construction [1].

Nowadays a very large majority of the roads are constructed using a mixture of bitumen (5 wt %) and mineral aggregates. Notwithstanding this low bitumen content, the performance of the road pavement depends to a large extent on the properties of bitumen itself, since it constitutes the only deformable component. The correlation between the complex colloidal structure of bitumen and its viscoelastic response is therefore a subject of scientific and technical interest [2 -7].

The addition of synthetic polymers to enhance service properties over a wide range of temperatures in road paving applications was considered a long time ago and nowadays has become a real alternative. As has been pointed out in the literature about bitumen and polymer/ bitumen blends[8 -17]. Polymer additives are well-known to improve the rheological properties of bitumen The polymer addition allows an increase in the resistance of the binder to permanent deformation at high temperature.Besides, the fracture properties including critical stress intensity factor at low temperature of polymer modified bitumen were shown to be higher than those of the bitumen base.To determine the crack propagation mechanism controlling fracture properties, previous studies have focused on establishing the relationship between the fracture properties and the morphology of polymer modified bitumen. [18]

In recent years, the volume of municipal plastic waste has increased greatly, and this has resulted in a critical problem for modern society and future generations. Polyolefins, poly(ethylene terephthalate) (PET), Polyvinylchloride (PVC), polystyrene (PS), and high-impact polystyrene (HIPS) are among the most common components of plastic waste because they are among the most frequently used commercial plastics in our daily lives and in industry.Recycling mixed plastic residues in the form of blends is attractive from academic and industrial points of view because of the improvements in the impact strength , dimensional stability, stress cracking, and processability with respect to virgin blends[19].

In the present study, waste PVC pipes are used as a filler for making bituminous products for paving applications. The viscoelasticity of a bitumen modified with PVC wastes with level up to 11% is analysed and compared to neat bitumen.

2. EXPERIMENTS PART

2.1 Materials and preparation

Waste PVC pipes were collected from the garbage, sorted and shredded into coarse particles. The waste plastics and commercial bitumen were weighted and heated individually in an oven until melt. Molten waste plastic was poured into the molten bitumen and stirred vigorously to give a homogenous sample. The hot mixtures were then cast into a ring stamp with 25 mm diameter and 2 mm thickness for rheology testing .

2.2 Measurements

Solid-state dynamic viscoelastic measurements of all the pure bitumen and bitumen blends samples were accomplished in a Solid state institute, Research center Juelich, Germany. In this study we used an ARES- rheometer (Advanced Rheology Expanded System, Rheometric Scientific Co.,) in the dynamic mode, under nitrogen atmosphere, plate-plate geometry with 25 mm in diameter to determine the rheological characteristics of the neat bitumen and bitumen blends. The measurements were performed over a wide range of temperatures ranged from 25°C to 160°C and frequencies from 100 to 0.1 radians per second. A sample to be tested was placed in the lower plate then the upper parallel plate was lowered for a tight contact with the sample. All the samples were held at a constant temperature of 50°C for 10 min, cooled to 25°C and measured at temperatures in the range from –10 to 60°C. The applied strain was in the linear viscoelastic regime (2%).

3. RESULTS AND DISCUSSIONS

In this section the results are presented in a master curves. The master curve is a single curve at which the experiments data which measured over a wide range of the temperature, T are shifted into this curve at a reference temperature T_0 . By using of the time-temperature superposition principle which described by Williams-Landel-Ferry [20] as, $\log a_T = -C_1 (T-T_0) /(C_2+(T-T_0))$.Where a_T is the horizontal shift factor and constants C_1 and C_2 are material specific. T_0 is chosen in this study to be 25°C. a_T is plotted as a function of temperatures in Figure 1. This Figure a_T decreases with increasing the temperature by a slop about –0.18 up to about 25°C then decreases slowly until nearly becomes independent on the temperature. a_T shifts the data obtained at different temperatures along the log frequency, ω axis as shown in Figure 2. Since a_T shifts the high temperatures data toward the left ω-wing at low ω and the low temperatures data toward the right ω-wing at high ω. In vertical direction the experiments data are shifted by b_T ($b_T = \rho T / \rho_0 T_0$ [21]). Where ρ is the material density. b_T shifts the data up-and-down by a factor related to the temperature as seen in Figure 2. Where high temperatures data are multiplied by a factor and low temperatures data divided by a factor. Because the modulus decreases with increasing the temperatures as shown in Figure 3, b_T decreases with increasing the temperature.

The master curve enable us to enlarge the range of the frequencies which it looks like data measured at a single temperature as a function of an extremely wide range of frequencies. As an example ω can be enlarged from 10^2 –10^{-1} radians/s to 10^8 –10^{-4} radians/s and this range is difficult to measure by a machine until now.

The master curves of the shear complex modulus, G* for bitumen and bitumen blends at 25°C are logarithmically plotted in Figure 4 against the angular frequency. This quantity of G* is a combination of the storage modulus (G') and loss modulus (G'') as, $G^* = G' + i G''$ [22] .Where, G' is the ability of the material to store energy in the cycle of the deformation and G'' is the energy dissipated as heat in this cycle. Master curves of G* display two regions of behavior. These region are : the melt and rubber-like zones from the left side to the right side. The third regime of the dynamic glass transition is observed at very high frequency ($\omega \sim 1\times10^9$) in the case of pure bitumen as shown in Figure 4 because it could measured at low temperature (-10°C). At the flow regime, G* decreases further as shown in Figure 4. At very low frequencies ($\omega \sim 0.0005$) G* rises and that is more observable in the cases of neat bitumen and bitumen-11%PVC as shown in Figure 4. May be because of the traces of cross-linked reasons at the testing temperatures for a long time (very low frequencies). As the deformation shear rate increases, G* increases until the intermediate regime of a rubber-like plateau is observed. This rubber-like region is somewhat flat and it is nearly independent on the frequency as shown in Figure 4. Because this rubber like behavior reflects the elasticity at which the loss energy is minimum. But in the melt regime G* falls by many order of magnitude because of the high loss energy per the cycle of deformation due to the effect of the viscosity in this regime. The beginning of the melt regime is shifted toward low frequencies by the addition of waste PVC to bitumen as shown in Figure 4. Since the melt regime begins at $\omega \sim 2.4\times10^4$, 400, 100 and 30 radian/s in the cases of neat bitumen, bitumen-5%PVC, bitumen-7%PVC and bitumen-11%PVC, respectively. This because of the high elasticity due to the bitumen-PVC network formation. The adding of waste plastics to bitumen showed a high effect as seen in Figure 4 the values of G* mouli for bitumen blends are higher than those of neat bitumen and G* is found to rise with increasing the waste PVC content as shown in Figure 5. The increase of G* at low frequency is higher than at high frequency . At ω =100 radian/s (Fig.5a) $G^* \sim (PVC)^{0.08}$ but at ω =0.001 radian/s (Fig.5b) $G^* \sim (PVC)^{0.15}$ as shown in Figure 5 . This increase in G* moduli by the addition of waste plastics reflects the interaction between polymer and bitumen which increases the stiffness. that leads to high stability for a long time of deformation (low frequencies) than neat bitumen. This interaction is mostly happened between polymer with saturate resins, owing to their closer solubility. Besides, Some authors have attributed this improvement to the existence of a third mixed phase modifying the asphaltene network. [23]. Since bitumen consists of matlenes and asphaltenes and 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 [24].

4. CONCLUSION

Waste PVC pipes were used as a modifier in making improved bitumen for paving application. Various bitumen blends were prepared in the molten state by adding waste PVC up to 11%. The blends were subjected to evaluate their response against temperature and frequency sweeps. By using an ARES- Rheometer (Rheometric Scientific, Co.) under nitrogen atmosphere in parallel plate geometry with diameter 25 mm. The measurements were performed over a wide range of temperatures ranged from -10°C to 60°C and frequencies from 100 to 0.1 radians per second

It was observed that improvement of rheological behavior of conventional bitumen compositions with the addition of PVC wastes. The PVC addition allows an increase in the resistance of the binder to permanent deformation.

5. ACKNOWLEDGMENTS

The financial support by the International Bureau in Germany, helpful discussions of Dr. W.Pyckhout and Dr.S. Khale at FZJ, Germany are greatly acknowledged.

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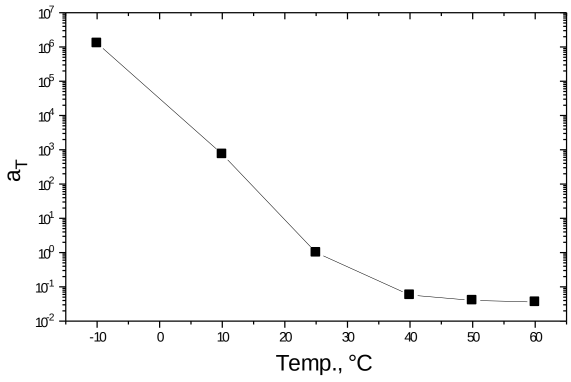

Figure 1: a_T of neat bitumen as a function of temperature

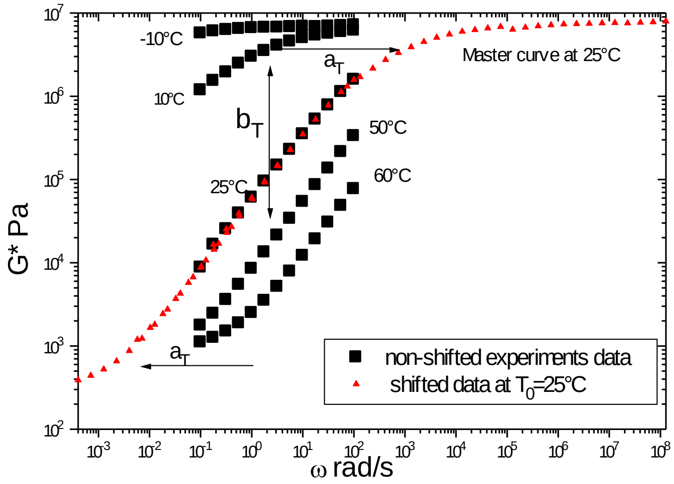

Figure 2: shifting the experiments data of G* for neat bitumen at different temperatures to the reference temperature by using a_T and b_T .

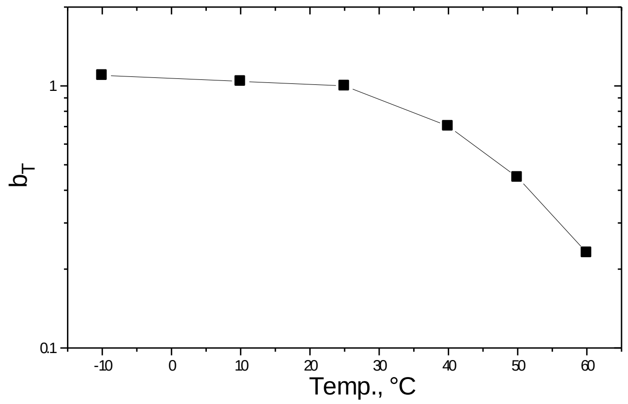

Figure 3: b_T of neat bitumen as a function of temperature

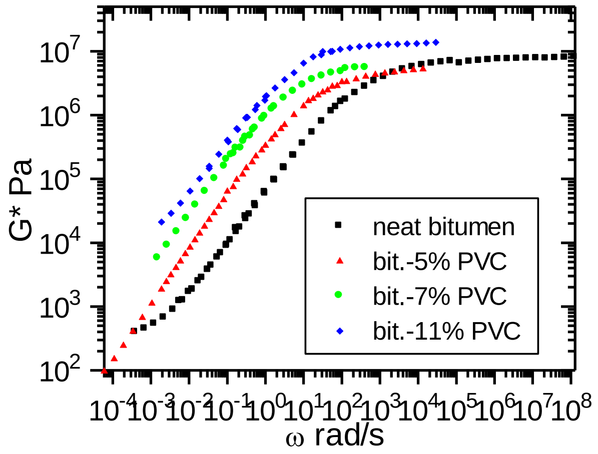

Figure 4: Master curves of G for bitumen and bitumen blends as a function of ω at T_0=25°C*

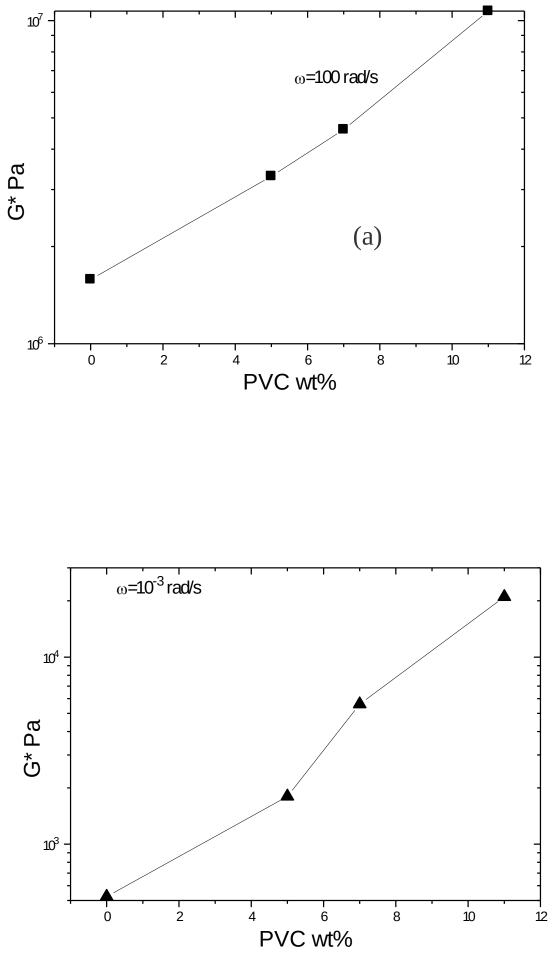

Figure 5: The effect of the PVC content on G* of bitumen blends at a) ω = 100 rad/s and b) ω=10^{-3} rad/s