

# Reuse of Waste Plastic in the modification of Rheological Characteristics of Bitumen: Part II

**Mahmoud Abdel-Halim Abdel-Goad**

Chemical Engineering Dept., Faculty of Engineering, Minia University, Egypt  
E-mail:m.abdelhalim@mu.edu.eg

**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  $-10^{\circ}\text{C}$  to  $60^{\circ}\text{C}$  and frequencies from 100 to 0.1 radians per second. Improvement in rheological properties such as shear compliance, torque and complex viscosity were observed by the incorporation of the waste PVC into bitumen. The flow activation energy for neat bitumen and bitumen blends are calculated from the melt viscosity by using the rheometric software and it is found to be  $1.42 \times 10^5$ ,  $1.5 \times 10^5$ ,  $1.58 \times 10^5$  and  $1.7 \times 10^5$  J/mol.K for neat bitumen, bitumen-5%PVC, bitumen-7%PVC and bitumen-11%PVC, respectively.

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

## 1. INTRODUCTION

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

### *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.

### 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 dynamic shear compliances moduli for bitumen blends compared to pure bitumen are plotted in Figures 1-2. Figure 1 presents the master curves at 25°C of the storage ( $J'$ ) as a function of frequency and loss compliance ( $J''$ ) versus  $\omega$  are presented in Figure 2.  $J'(\omega)$  is a measure of the energy stored and recovered per deformation cycle, therefore is called the storage compliance. And  $J''(\omega)$  is a measure of the energy dissipated as heat per cycle of the sinusoidal deformation, for that is called the loss compliance. These Figures show clearly two regions reflect the behavior of the material under the measured temperatures as a function of frequency as explained earlier in the case of  $G^*(\omega)$  curves. As shown in Figures 1-2 the incorporation of the waste PVC into bitumen affects on the  $J'(\omega)$  and  $J''(\omega)$  moduli. Since the shear compliance moduli are enhanced for the bitumen blends. This is clear at  $\omega \sim 5.2 \times 10^3$  radians/s (Fig.6) where the values of  $J'$  changed from  $1.5 \times 10^{-7}$  for neat bitumen to  $1.0 \times 10^{-7}$  Pa<sup>-1</sup> in the case of bitumen-11wt% PVC. But at low frequencies the effect is more noticeable and the difference in  $J'$  and  $J''$  moduli among bitumen blends increases with PVC content. since at  $\omega \sim 5.9 \times 10^{-2}$  radians/s, the values of  $J'$  become  $4.0 \times 10^{-5}$ ,  $6.0 \times 10^{-6}$ ,  $2.3 \times 10^{-6}$  and  $1.3 \times 10^{-6}$  Pa<sup>-1</sup> for pure bitumen, bitumen-5wt%PVC bitumen-7wt% PVC and bitumen-11wt% PVC, respectively. The same effect is observed also for  $J''$  moduli in Figure 2. In this Figure at  $\omega \sim 91$  radians/s the values of  $J''$  are  $4.3 \times 10^{-7}$ ,  $1.1 \times 10^{-7}$ ,  $4.2 \times 10^{-8}$  and  $1.9 \times 10^{-8}$  Pa<sup>-1</sup> for neat bitumen, bitumen-5wt%PVC, bitumen-7wt% PVC and bitumen-11wt% PVC, respectively. This because of the interaction between the PVC chains and bitumen, results in PVC-bitumen network formation which leads to increase the strength and stiffness. This increase in the stiffness and strength by the introduction of the waste PVC to bitumen is confirmed also in the shear creep stress,  $J(t)$  in Figure 3. This Figure shows  $J(t)$  as a function of time for pure bitumen and

bitumen blends. As shown in Figure 3  $J(t)$  increases with time and the difference between the values of  $J(t)$  in the case of neat bitumen and bitumen blends is higher at long times than at short times and this difference increases with increasing the PVC content. Since at  $t \sim 200$  seconds, the values of  $J(t)$  are,  $1.1 \times 10^{-3}$ ,  $1.3 \times 10^{-4}$ ,  $4.1 \times 10^{-5}$  and  $1.4 \times 10^{-5}$  Pa<sup>-1</sup> for neat bitumen, bitumen-5wt%PVC, bitumen-7wt% PVC and bitumen-11wt% PVC, respectively. This indicates the improvement of the stability of the bitumen for a long time by the addition of the waste PVC due to network of bitumen-PVC.

Figure 4 presents log-log plot of the complex viscosity ( $\eta^*$ ) as a function of  $\omega$  for neat bitumen and bitumen blends at 25°C. In this Figure  $\eta^*$  increases rapidly with decreasing  $\omega$  up to  $\omega = 0.001$  radian/s after that it becomes independent on  $\omega$ . At this very low shear rates  $\eta^*$  is called the melt viscosity,  $\eta_0$  (zero-shear viscosity). As shown in this Figure the incorporation of the waste PVC into the bitumen increases the viscosity over all the frequencies range. This increase in the viscosity is found to be rises with the increasing in the PVC content and it is more noticeable at very low frequency (at  $\eta_0$ ). The flow activation energy for neat bitumen and bitumen blends are calculated from  $\eta_0$  by using the rheometric software and it is found to be  $1.42 \times 10^5$ ,  $1.5 \times 10^5$ ,  $1.58 \times 10^5$  and  $1.7 \times 10^5$  J/mol.K for neat bitumen, bitumen-5%PVC, bitumen-7%PVC and bitumen-11%PVC, respectively. Since the values of  $\eta_0$  increase from  $1.5 \times 10^5$  to  $8.9 \times 10^5$ ,  $2.9 \times 10^6$  and  $8.5 \times 10^6$  Pa.s by the addition of 5, 7 and 11% PVC, respectively. This because the viscosity of the PVC-bitumen network is higher than this of bitumen. Besides, bitumen softens rapidly at low deformation rates.

The torque in NM as a function of frequency for neat bitumen and bitumen blends are logarithmically plotted at 25°C in Figure 10. The torque decreases with decreasing the shear rates as shown in Figure 5. At very low frequencies ( $\omega \sim 0.0005$ ) torque rises in particular in the cases of neat bitumen and bitumen-11%PVC as shown in Figure due to the traces of cross-linked reasons as explained above. This Figure evidences also that the addition of waste PVC to bitumen enhances the torque. Since the torque increases at  $\omega = 0.07$  rad/s from  $2 \times 10^{-4}$  to  $1 \times 10^{-3}$ ,  $2.9 \times 10^{-3}$ , and  $4.7 \times 10^{-3}$  NM by the addition of 5, 7 and 11%PVC to bitumen, respectively. This because the formation of the bitumen-plastic matrix which leads to increase stiffness of the bitumen blends and the stiffness increases with increasing the waste PVC content.

### 4. CONCLUSION

Waste PVC pipes were used as a modifier in 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  $-10^{\circ}\text{C}$  to  $60^{\circ}\text{C}$  and frequencies from 100 to 0.1 radians per second

The flow activation energy for neat bitumen and bitumen blends are calculated from  $\eta_0$  by using the rheometric software and it is found to be  $1.42 \times 10^5$ ,  $1.5 \times 10^5$ ,  $1.58 \times 10^5$  and  $1.7 \times 10^5$  J/mol.K for neat bitumen, bitumen-5%PVC, bitumen-7%PVC and bitumen-11%PVC, respectively. 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

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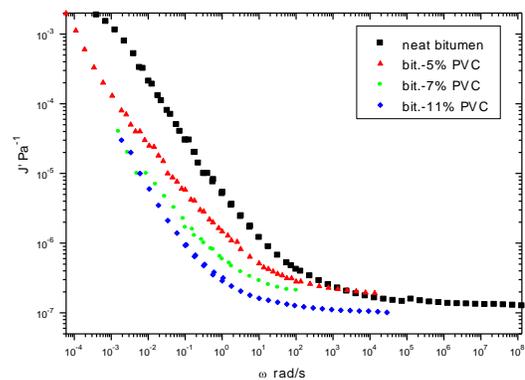


Figure 1: Master curves of  $J'$  for bitumen and bitumen blends as a function of  $\omega$  at  $T_0=25^{\circ}\text{C}$

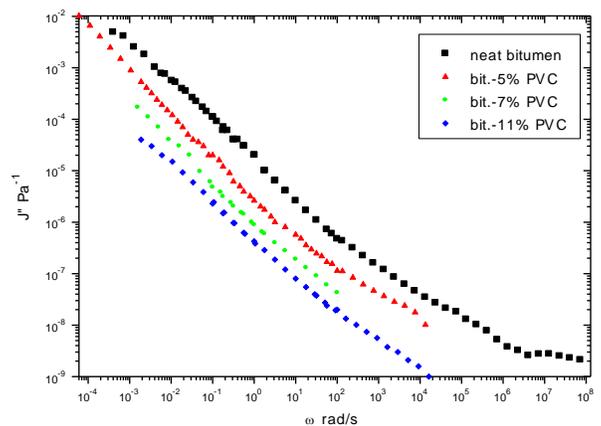


Figure 2: Master curves of  $J'$  for bitumen and bitumen blends as a function of  $\omega$  at  $T_0=25^{\circ}$

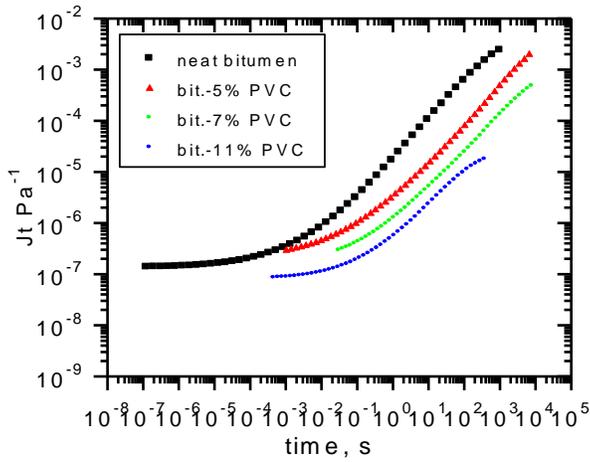


Figure 3:  $Jt$  for bitumen and bitumen blends versus time at  $T_0=25^\circ\text{C}$

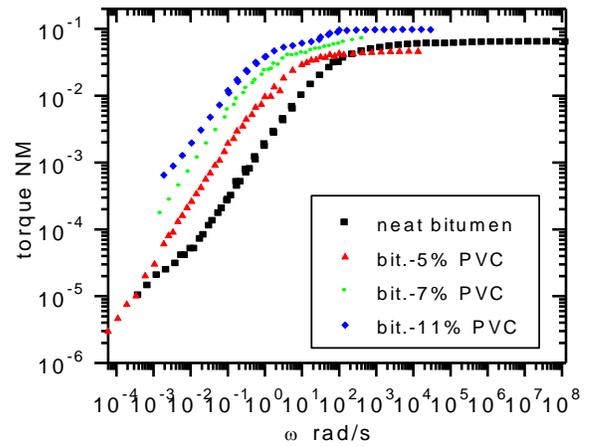


Figure 5: Master curves of torque for bitumen and bitumen blends as a function of  $\omega$  at  $T_0=25^\circ\text{C}$

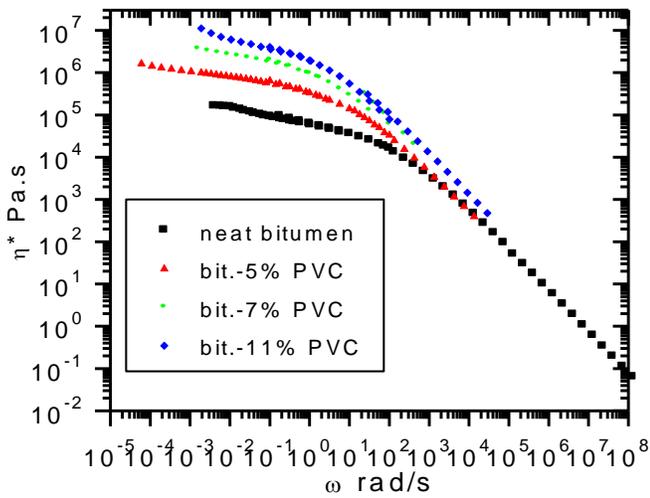


Figure 4: Master curves of  $\eta^*$  for bitumen and bitumen blends as a function of  $\omega$  at  $T_0=25^\circ\text{C}$