Waste Polyvinyl Chloride-Modified Bitumen

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ABSTRACT: Polyvinyl chloride (PVC) pipe wastes have been employed as a soft filler up to a level of 11 wt % in making bituminous products for paving applications. The PVC wastes were homogenously mixed with bitumen in the molten state. The viscoelastic properties of the bitumen blends such as storage modulus, loss modulus, and dynamic viscosity were studied and compared with those of neat bitumen. These properties were studied using an ARES-Rheometer (Rheometric Scientific, Co.) under nitrogen atmosphere. The results indicate that the incorporation of the waste PVC into bitumen enhances the dynamic mechanical moduli and viscosity of the bitumen. © 2006 Wiley Periodicals, Inc. J Appl Polym Sci 101: 1501–1505, 2006

Key words: bitumen; waste PVC pipes; bitumen blends; rheology

INTRODUCTION

Bitumen and bituminous binders have been used for over five thousand years as waterproofing and bonding agents. The earliest recorded use was by the Sumerians around 3800 B.C., and the Egyptians used it in their mummification processes.[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. However, the performance of these bituminous systems is questioned, given that they are brittle and hard in cold environments and soft in hot environments. These limitations of bitumen may be overcome and the properties significantly modified by blending a polymeric material with bitumen for improving viscoelastic behavior besides maintaining its own advantages. The correlation between the complex colloidal structure of bitumen and its viscoelastic response is therefore a subject of scientific and technical interest. The addition of synthetic polymers to enhance service properties of bitumen over a wide range of temperatures in road paving applications was considered a long time ago and nowadays has become a real alternative.[2–14] The modification provides increased viscosity at high pavement temperatures, resulting in a reduced tendency for permanent deformation (rutting). At the same time, polymers can provide increased ductility at low pavement temperatures and thus a reduced tendency for thermal cracking. Both of these effects produce extended pavement life.[15] However, the high cost of polymers has been an inhibitory factor for mass-scale adoption in place of conventional bitumen; even though, their use is profitable in terms of cost-benefit ratio. Other possibilities, such as the disposal of waste plastic in roads, as a modifiers for bitumen are reported in the literature.[16–17] The improved low-temperature ductility/resiliency and retention of molecular associations (more viscous) at high temperatures of bitumen can also be achieved by the addition of plastics waste in micronized form.[18]

With the increased usage of plastics in various sectors, the discharge of plastics wastes in huge quantities has serious implications on society from an environmental perspective. Therefore, adding suitably sized activated plastics waste to bitumen formulation opens new prospects in this field to be used as modifier/fine aggregate, thus disposing of the waste while making value-added products.

Polymer additives are well-known to improve the rheological properties of bitumen.[19–23]

The mechanical characterization of bitumens has historically been based on various empirical tests, which are difficult to interpret. Moreover, these tests are not able to give sufficient information about the structure of the tested material. A better understanding of the microstructure of bituminous materials can be obtained by the combination of classical chemical

characterization techniques (e.g., GPC) and the known rheological testing.[24–25]

In this study, we report the reuse of waste PVC in producing modified bitumen for paving application. The viscoelastic properties of the modified bitumen are investigated and compared to neat bitumen.

EXPERIMENTAL

Materials and preparation of samples

Waste PVC pipes materials were obtained and sorted from the garbage. An industrial grade bitumen was procured from an Egyptian supplier. The wastes were shredded (coarse, about 1–2 cm), heated until melt, and homogeneously mixed with molten bitumen. The molten mixtures were then cast into a ring stamp with 25 mm diameter and 2 mm thickness for rheology testing.

Methods

The viscoelastic response of the modified bituminous binders was evaluated using an ARES-rheometer (Rheometric Scientific, Co.) in the dynamic mode and 25-mm parallel-plate geometry with 2-mm gap. The measurements were performed at temperatures range from -10 to $+55°C$ and frequencies varying from 0.1 to 100 rad/s with 8 points per decade. The strain of 1% was selected to remain in the linear viscoelastic region over the entire temperature and frequency range.

RESULTS AND DISCUSSIONS

The experiments data measured at different temperatures as a function of frequencies are shifted and reduced to a reference temperature T_0. By means of the
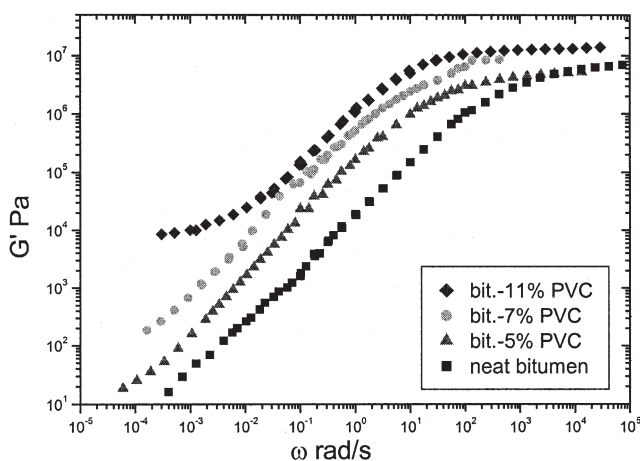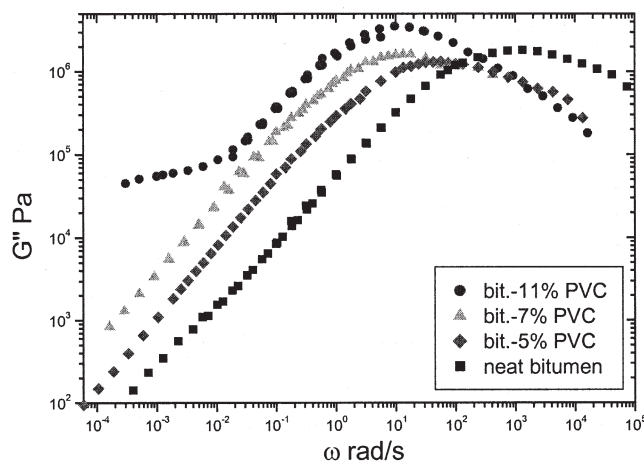

Figure 2 Master curves of G'' for bitumen and bitumen blends as a function of ω at $T_0 = 25°C$.

time–temperature superposition principle as proposed by Williams, Landel, and Ferry (WLF)[26] by introducing a shift factor a_T that permits data, obtained at some temperature T, to be shifted and reduced to a reference temperature T_0 as, $\log a_T = -C_1 (T-T_0)/(C_2+(T-T_0))$. T_0 is taken in this study to be 25°C. In vertical direction, the shift factor is given by the ratio of $\rho T/\rho_0 T_0$.[27]

The master curves of the storage modulus G' and loss modulus G'' for modified and neat bitumen at the reference temperature (25°C) are logarithmically plotted against the frequency in Figures 1 and 2. G' is defined as 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. The dynamic spectrum of shear storage modulus G' (Fig. 1) and shear loss modulus G'' (Fig. 2) with respect to frequency contains information regarding the manner in which a sample responds to small magnitude deformation applied over varying temperatures and time scale.

Figures 1 and 2 indicate that the addition of PVC to bitumen increases the storage and loss moduli particularly is noticeable at low frequencies and rises with PVC content. In Figure 2, G'' of bitumen blends are lower than neat bitumen at high frequency ($\omega \geq 100$ rad/s). This is related to the high elasticity of bitumen blends, which leads to low energy dissipated. In the cases of bitumen-11% PVC, at very low frequencies ($\omega \sim 10^{-3}$ rad/s), the G' and G'' moduli become nearly independent on ω as shown in Figures 1 and 2. This may be due to the network-like structure formation.

The increase in the G' values for bitumen by the incorporation of PVC wastes at different frequencies is clearly presented in Figure 3. As an example, the value of G' increases by a factor about four by the addition of 7 wt % PVC to bitumen at $\omega = 5 \times 10^2$ rad/s. This
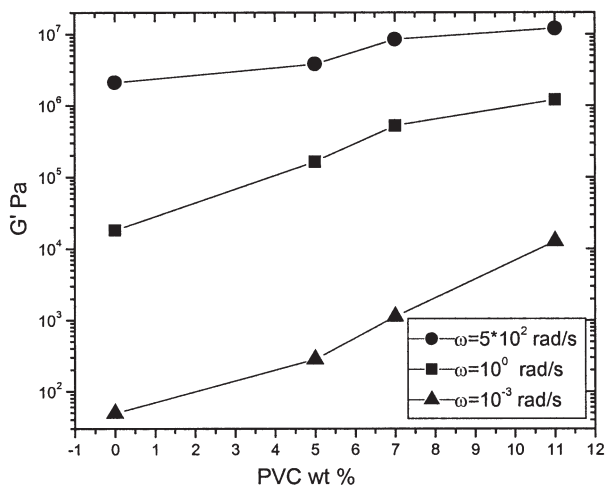

Figure 1 Master curves of G' for bitumen and bitumen blends as a function of ω at $T_0 = 25°C$.

Figure 3 G'' versus PVC wt % for bitumen and bitumen blends at different ω.

Figure 5 G'' for bitumen and bitumen blends as a function of temperature at $\omega = 0.1$ rad/s.

factor rises to about 23 at $\omega = 10^0$ rad/s and 28 at $\omega = 10^{-3}$ rad/s, as shown in Figure 3.

G'' and G'' are plotted also as a function of temperature at $\omega = 0.1$ rad/s in Figures 4 and 5, respectively. These Figures show a decrease of G'' and G'' moduli with increasing the temperatures. G'' and G'' moduli of bitumen blends are higher than those of neat bitumen over the entire temperatures range, as shown in Figures 4 and 5. The difference in the values of the G'' and G'' moduli for bitumen blends and neat bitumen is higher at high temperatures and more noticeable than at low temperatures. This is because the bitumen properties change considerably with temperature and softens rapidly unlike the bitumen blends.[1]

The increase in G'' moduli reflects the increase in the stiffness of the bitumen blends, compared with that of pure bitumen. But the increase in G'' indicates
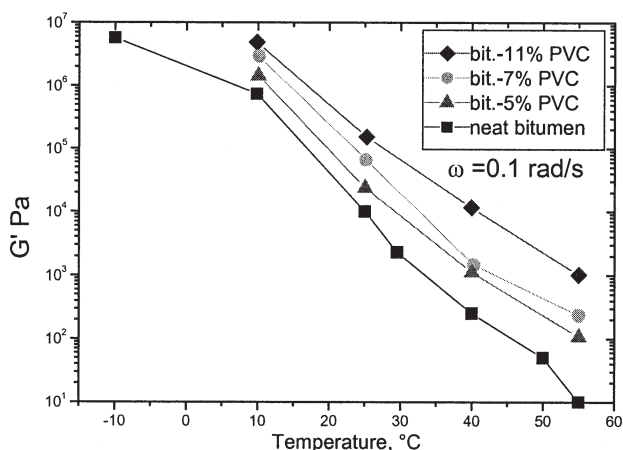
an increase in the viscous response. That evidences the existence of molecular association among the constituents, compared with that of neat bitumen, and this interaction increases the stiffness. The interaction between polymer and bitumen is mostly due to the interaction between polymer with saturate resins, owing to their closer solubility.[5]

Figure 6 presents tan δ of bitumen blends and pure bitumen at a reference temperature of 25°C. Tan δ indicates the relative degree of viscous to elastic dissipation of the material and it is related to the loss modulus by, tan δ = G''/G''; therefore, tan δ is called the loss factor. In Figure 6, tan δ decreases with increasing frequency until it reaches the minimum value at high-ω. This minimum in tan δ is associated to the high elasticity of the material at this regime, which leads to a minimum in the loss energy per cycle of the deformations. As shown in Figure 6, tan δ of blends are lower than that of neat bitumen, and the values of tan δ decrease with increasing PVC content, in particular, at high frequency. This reflects mostly the devel-
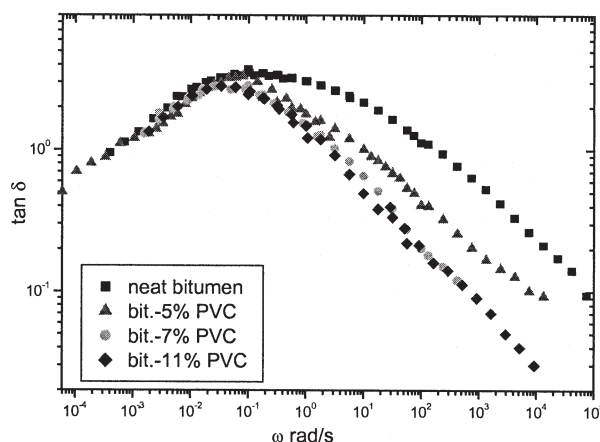

Figure 4 G'' for bitumen and bitumen blends as a function of temperature at $\omega = 0.1$ rad/s.

Figure 6 Master curves of tan δ for bitumen and bitumen blends as a function of ω at $T_0 = 25$°C.

opment of elasticity in the blends melt at high frequency, which leads to decrease the loss energy (decrease in tan δ), and this elasticity rises with the PVC content.

In Figure 7, the master curves of dynamic viscosity, $\acute{\eta}$, of bitumen blends and neat bitumen is plotted versus ω at 25°C. $\acute{\eta}$ is related to the loss modulus, G'' as, $\acute{\eta} = G''/\omega$; therefore, $\acute{\eta}$ decreases with increasing ω, as shown in Figure 7. At high frequencies ($\omega \leq 100$ rad/s), $\acute{\eta}$ of neat bitumen is higher than those of bitumen blends and decreases with PVC content, as shown in Figure 7, due to the elasticity as discussed before. At $\omega \leq 50$ rad/s, the viscosity increases by the addition of PVC and is found to rise with PVC content.

At low frequencies ($\omega \sim 0.1$ rad/s), $\acute{\eta}$ is somewhat flat and nearly independent on the frequency, and in this branch $\acute{\eta}$ is called the melt viscosity, η_0 (zero-shear viscosity). In the case of bitumen-11wt % PVC, the viscosity becomes independent on ω at $\omega \sim 10^{-3}$ rad/s (Fig. 7), due to the network formation as mentioned earlier.

The melt viscosity can be obtained also from G'' and ω as, $\eta_0 = \lim\limits_{\omega \to 0} \dfrac{G'(\omega)}{\omega}$.[27] η_0 is plotted (semilog) against temperatures in Figure 8. This Figure shows an increase in η_0 by the addition of PVC to bitumen over the temperatures range. As shown in Figure 8, at 25°C, the values of η_0 are 8.4×10^4, 7.2×10^5, 2.3×10^6, and 5.5×10^6 Pa s for neat bitumen, bitumen-5% PVC, bitumen-7% PVC, and bitumen-11% PVC, respectively. At 55°C, the bitumen blends are more viscous than the neat bitumen, and the increase in the values of η_0 is more significant because the bitumen flows readily above 40°C.[1] This effect of the incorporation of PVC in bitumen results in reducing tendency for permanent deformation, therefore produces extended pavement life.
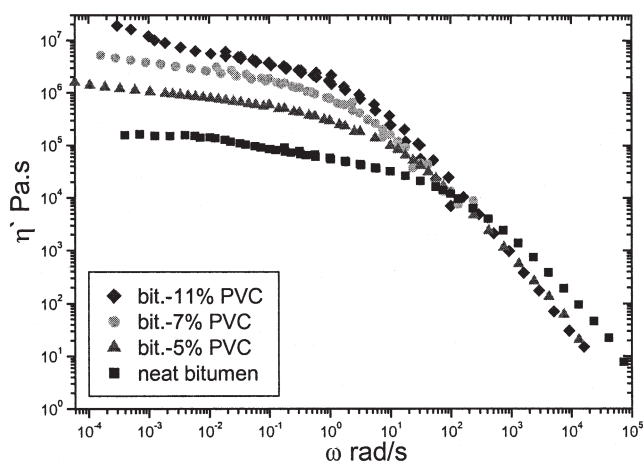

Figure 7 Master curves of $\acute{\eta}$ for bitumen and bitumen blends as a function of ω at $T_0 = 25$°C.
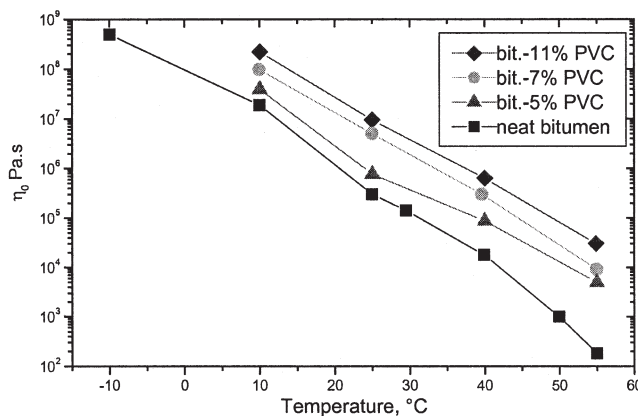

Figure 8 η_0 for bitumen and bitumen blends as a function of temperature.

CONCLUSIONS

In this study, the waste PVC pipes were successively reused in production of modified bitumen. The results evidence that the dynamic mechanical moduli and viscosity are enormously enhanced when waste PVC are added to the bitumen, and they are found to rise with the PVC content.

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