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Complex Modulus of Waste Tires Reinforced Polystyrene

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***Abstract**: In this work, polystyrene/waste tires composites were prepared by incorporating of waste tires into polydisperse commercial polystyrene in a melt-mixing method. The rheological characterization of PS and PS/composite have been studied and compared. These properties were studied using ARES-Rheometer under nitrogen atmosphere in parallel plate geometry with diameter 8 mm. The measurements are carried out over a wide range of temperatures ranged from 120°C to 220°C and frequencies from 100 to 0.1 radians per second. The complex modulus (G*) were evaluated and compared with those of unfilled PS. The dynamic mechanical properties and stability at elevated temperatures were found to increase with the addition of waste tires to PS as confirmed by the results.*

The results showed that the value of G at $\omega = 1.0$ radian/s is 1.8×104 and 4.4×104 Pa for PS and PS/waste tires, respectively. This difference rises at low frequencies-branch to be the value of G* at $\omega = 0.06$ radian/s is 8.8×102 and 7.8×103 Pa for PS and PS/waste tires, respectively. Generally G* increases by the addition of rubber as filler for PS*

Keywords: Polystyrene/waste tires composite, Rheology, Complex modulus

1. INTRODUCTION

The growth rate of the use of particulate filled polymers is very fast in all fields of application Household articles and automotive parts are equally prepared from them. In the early stages, the sole reason for the introduction of fillers was to decrease the price of the polymer. However, as a result of filling all properties of the polymer change, a new polymer is in fact created. Some characteristics improve, while others deteriorate, and properties must be optimised to utilize all potentials of particulate filling. Optimization must include all aspects of the composites from component properties, through structure and especially interactions [1].

Disposal of waste rubber material is a global problem, and used tires constitute the largest volume of scrap rubber. Recycling of waste tires is essential due to economic and environmental reasons. Utilization of ground waste rubber has been reviewed recently. Finely ground waste tire rubber has been used as filler in rubbers and in thermoplastics [2]. Physical properties and processability are reported to be adversely affected when large volumes of waste rubber is added to a rubber compound.

Dynamic mechanical analysis over a wide range of temperature and frequencies permits the determination of the viscoelastic behavior of molten polymers and, in particular, the study the glass transition of reinforced composites. Therefore, the investigations of the polymer composites using the mechanical and the dynamic mechanical analysis are becoming of great interesting [3-18].

The purpose of this work was to characterize in details the complex modulus of rubber filled polystyrene compared to the original material of unfilled polystyrene.

2. EXPERIMENTAL SECTION

Samples preparation and characterization

PS/waste tires composite was prepared by introducing waste tires into commercial PS with molecular weight about 2×10^7 g/mol. The waste tires were shredded into small particles sizes of about 2 mm. The mixture of PS and 12 wt % shredded tires are dry mixed by hand-mixing for around half an hour and heated at 300°C for 2 hours. Followed by preparation the samples of filled and unfilled PS for the rheological measurements under compression-mold at 190°C for 3 hours and 15 bars in a disc form with diameter 8 mm and thickness 2.2 mm.

3. MEASUREMENTS

The dynamic mechanical measurements were performed for PS and PS composite by using an ARES-Rheometer (Rheometric Scientific). The rheometer was operated in the dynamic mode on the plate-plate geometry of 8mm diameter and about 2 mm gap. The gap size changes with the temperatures and is read electronically and allows absolute moduli to be determined. The measurements were performed in this study for the samples under nitrogen atmosphere, strain amplitude 1%, over temperature ranged from 120 to 220°C and angular frequency (ω) varied from 10^2 to10^{-1} radian/s.

4. RESULTS AND DISCUSSION

In this study the experiments data which measured over a wide range of the temperature are shifted into a single log -log curve at a reference temperature T_0 by using of the time-temperature superposition principle which described by Williams-Landel-Ferry [19] 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. a_T shifts the data obtained at different temperatures along the log frequency, ω axis as shown in Fig.1 and in vertical direction is given purely by b_T ($b_T = \rho T / \rho_0 T_0$ [20]). Where ρ is the material density.

Figure 1 shows the shear complex modulus (G*) as a function of frequency at temperatures ranged from 120 to 220°C. By choosing the reference temperature at 180°C, the horizontal shift factor shifts the high temperatures data of G* toward right side at low frequencies-branch along of G* which measured at 180°C and those at the low temperatures are shifted at high frequencies-branch as shown in Figure 1. The vertical shift factor rises G* of the high temperatures to G* of 180°C and decreases those at low temperatures to reach G* of 180°C as shown in Figure 3. Because G* modulus decreases with increasing the temperatures as it is clear from Fig.1 .

The master curves of the shear complex modulus, G* for PS and PS/waste tires at 180°C are logarithmically plotted against the angular frequency as seen in Figure 2. This quantity of G* is a combination of the storage modulus (G') and loss modulus (G") as, G*= G' + i G" [21] .

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* for PS and PS/waste tires display three distinct regions of behavior and that is typically for flexible-chain monodisperse homopolymer. These region are : the dynamic glass transition, rubbery plateau, and flow zones from the right side to the left side. At the flow regime, G* decreases further as shown in Figure 2. This corresponding to the complete relaxation of polymer chains at low shear rate, where the time allowed for relaxation is longer than the longest relaxation time in the polymer. The dynamic glass transition zone is located at high frequencies at which the shear rate is higher than the average relaxation time of the polymer chain. Therefore, the chains can not adjust quickly enough to dissipate the applied stress as a result, the observed modulus is high. As the deformation shear rate decreases, G* decreases 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 over the frequency range from about 1×103 to 10 radians/s as shown in Figure 2. This rubber like behavior reflects the elasticity of the polymer and it is due to the entanglement of the chains, this entanglement depends on the type and the long of the chains. From the beginning of this regime of the rubber-like, G* is observed to rise for PS/waste tires composite than this of the original PS and this increase is significantly continued over the flow regime too at low frequencies as shown in Figure 2. As an example, the value of G* at ω = 1.0 radian/s is 1.8×104 and 4.4×104 Pa for PS and PS/waste tires, respectively. But this difference rises at low frequencies-branch to be the value of G* at ω = 0.06 radian/s is 8.8×102 and 7.8×103 Pa for PS and PS/waste tires, respectively. Generally this increase in G* by the addition of rubber as filler for PS is may be because the interaction between the rubber particles and the PS chains which increases the stiffness of the chains. The significant increase at low frequencies (means at long time and high temperature) may be due to the formation of the rubber-PS network. Since the formation of this matrix increases with the time at high temperature.

5. CONCLUSION

In this study the PS/waste tires composite were prepared. The Rheological properties for PS composite are evaluated and compared to those of the original material of unfilled PS. These properties are determined by ARES Rheometer under nitrogen atmosphere in parallel plate geometry with diameter 8 mm. The measurements are carried out over a wide range of temperatures, ranged from 120°C to 220°C and frequencies from 100 to 0.1 radians per second.

The results showed that the value of G* at ω = 1.0 radian/s is 1.8×104 and 4.4×104 Pa for PS and PS/waste tires, respectively. This difference rises at low frequencies-branch to be the value of G* at ω = 0.06 radian/s is 8.8×102 and 7.8×103 Pa for PS and PS/waste tires, respectively. Generally G* increases by the addition of rubber as filler for PS

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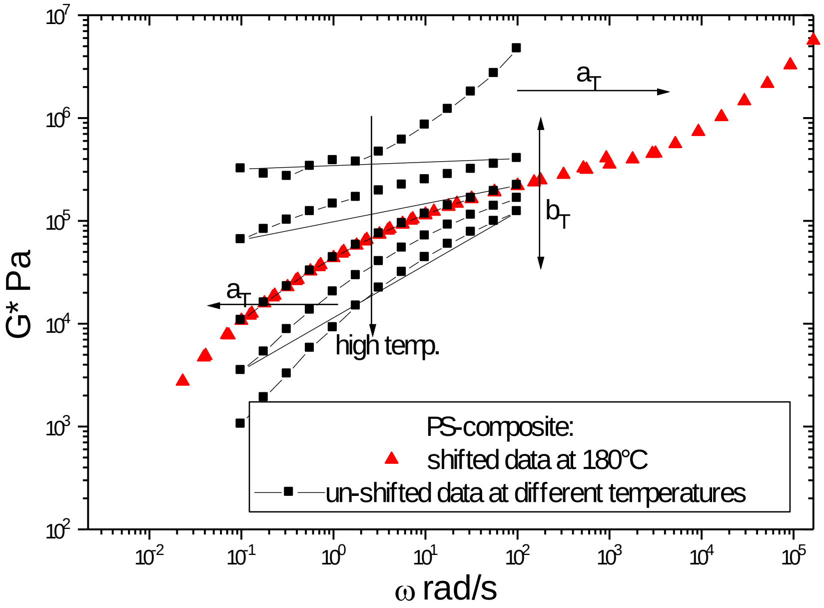

Figure 1:Experiments data of G were measured at different temperature as a function of ω for PS and PS composite and shifted at T_0 = 180°C by using a_T and b_T .*

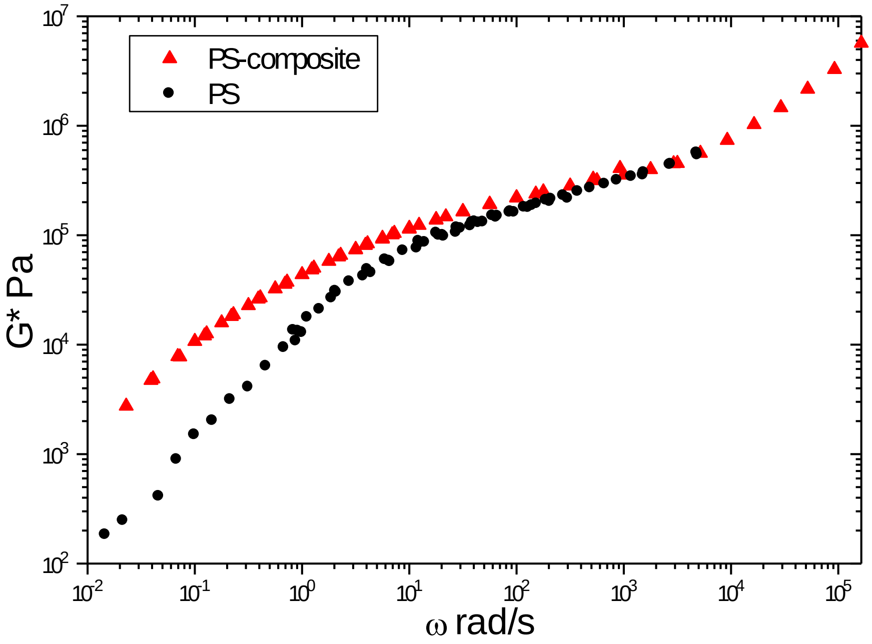

Figure 2: Master curve of G as a function of ω for PS and PS composite at T_0 = 180°C.*