

Rheology of EPR/PP Blends

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Received 20 June, 2000; accepted 27 December 2000

ABSTRACT: The rheological behavior of polypropylene, PP, ethylene-propylene copolymer, EPR, and EPR/PP blends was studied. Zero-shear viscosity and elastic relaxation time were determined by least-squares fits by using a Carreau–Yasuda model with Arrhenius temperature dependency. The effect of PP and EPR molecular weight, ethylene ratio in EPR copolymer (E/EPR), and EPR concentration on the zero-shear viscosity and elasticity of EPR/PP blends was determined experimentally. Molecular weight effects are compared to theoretically expected relationships. EPR concentration effect and E/EPR ratio effects agree well with predictions made by using the Tsenoglou model. © 2001 John Wiley & Sons, Inc. *J Appl Polym Sci* 82: 2113–2127, 2001

Key words: polymer blends; EPR; PP; molecular weight; rheology; viscoelasticity; Tsenoglou model

INTRODUCTION

Addition of ethylene-based elastomers to polypropylene (PP) provides the means of increasing the ductility and impact resistance, thus adjusting the property balance of the PP matrix. Ethylene propylene rubber (EPR) is one of the most common modifiers for PP. In EPR/PP blends, the rubber molecular weight and viscosity are generally higher than those of the PP matrix. The blend viscosity and therefore its processibility can be affected by factors such as the molecular structure of the EPR and its concentration.

Different aspects of the EPR/PP blends have been reported in the literature. Danesi and Porter¹ studied blends of isotactic PP and EPR in terms of their rheology, morphology, and mechanics. The rheological characterization of EPR/PP blends showed a monotonic dependence of blend–melt vis-

cosity on EPR composition. The authors also found that viscosity ratio lower than 1 (viscosity of EPR lower than that of PP) led to finer and more uniform dispersion than in high viscosity ratio blends. Any type of annealing above the melting temperature of PP brought a substantial increase in the domain sizes of the dispersed EPR phase.

D’Orazio et al.² studied the influence of molecular structure of EPR on melt rheology and phase structure of EPR/PP blends. They found that the transition from Newtonian to pseudoplastic flow for EPR/PP blends started at frequencies higher than that for pure PP. The shift toward higher frequencies increased with increasing EPR molecular weight. The elasticity developed in the blend at high frequencies reached that developed in pure PP. The authors also found that size and size distribution of EPR domains were controlled mainly by the EPR/PP viscosity ratio. The EPR number-average particle diameter, \bar{D}_n , increased with increasing viscosity ratio. When the PP matrix phase crystallizes from its blends with EPR under nonisothermal conditions, the phase struc-

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Journal of Applied Polymer Science, Vol. 82, 2113–2127 (2001)
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Table I List of EPR Samples Used in This Study

Polymer	EPR M_w (kg/mol)	E/EPR (wt %)
EPR-1	361	60
EPR-2	708	60
EPR-3	810	60
EPR-4	1017	60
EPR-5	642	80
EPR-6	695	40

ture developed in the blends is characterized by lower lamellar thickness and higher interlamellar amorphous layer thickness than that of pure PP. The crystallization behavior and effect of EPR and PP structure on the properties of EPR/PP blends were also reported.^{3,4,5}

In the present study, we report experimental results on the rheological behavior of PP, EPR, and EPR/PP blends. The objective of this article is to examine the effect of EPR structure and concentration on the rheological behavior of EPR/PP blends and to determine suitable models for prediction of the blends' viscosity from the basic molecular structure of the blend components.

EXPERIMENTAL

Materials

This study was carried out on commercial PP homopolymers (Montell, Canada) and specially synthesized EPR copolymer samples (Mitsubishi Chemicals, Japan). The PP homopolymers were Montell's grades PH-920S (PP-1) with a melt-flow index, MFI = 60 dg/min, SM-6100 (PP-2) with MFI = 12 dg/min, and PP6823 (PP-3) with MFI = 0.5 dg/min. The molecular weights, M_w , and E/EPR fractions of the six batch reactor EPR are presented in Table I. Size exclusion chromatography characterization was made at $T = 140^\circ\text{C}$ by using 1,2,4-trichlorobenzene as solvent for M_w measurements. Calibration curve was constructed from narrow molecular weight polystyrene (PS) standards. No attempt was made to correct differences of hydrodynamic volume of PP, EPR, and PS.

Blending Procedure

To achieve a uniform dispersion of the EPR into PP, two blend preparation methods were tried, as follows:

- (1) Mechanical blends in the melt state obtained by blending for 5 min in an internal mixer (i.e., Brabender mixer) at 60 rpm and 200°C .
- (2) Precipitated blends obtained by dissolving the material in hot toluene followed by precipitation in methyl alcohol.

Typical scanning electron micrographs obtained on fracture surfaces of mechanical and precipitated blends are presented in Figure 1. Figure 1(a) shows a micrograph of a blend containing 30 wt % of EPR-3 in a PP-1 matrix prepared by mechanical blending. A heterogeneous blend with large undispersed EPR particles was obtained. The morphology of the same blend, prepared by the precipitation technique, is shown in Figure 1(b). EPR dispersion was much finer and more homogeneous than that obtained by mechanical blending.

The copolymer EPR-1 is a lower molecular weight EPR and was easier to disperse mechanically, as shown on the micrograph in Figure 1(c) obtained for a 50 wt % EPR-1/PP-1 blend. However, it is clear that finer and more uniform morphologies were obtained by precipitation, as shown in Figure 1(d). The precipitation technique was, therefore, the preferred route for blending.

Rheological Measurements

The rheological properties of the materials were evaluated on a Rheometric Scientific ARES rheometer in plate-plate geometry. The sample preparation and soak time (waiting period before testing) were chosen carefully to allow the samples to relax prior to testing. The preparation technique chosen was to compression mold the materials and to use a soak time of 3 min. Oscillatory frequency ranged from 0.1 to 100 rad/s with deformation amplitude of 10%. All tests were performed under nitrogen atmosphere. Oscillation measurements provide elastic and viscous modulus of the materials, which can be translated into a complex viscosity, analog of the steady-shear viscosity, and into a phase shift, δ .

The phase angle, δ , between the imposed sinusoidal deformation and the measured stress signal is directly related to the material's elasticity. In the following report, the complex viscosity and $\tan \delta$ (the ratio of viscous to elastic forces) will be reported.

The viscosity of three EPR/PP blends (30, 50, and 60 wt % of EPR-1 in PP-1) obtained by the

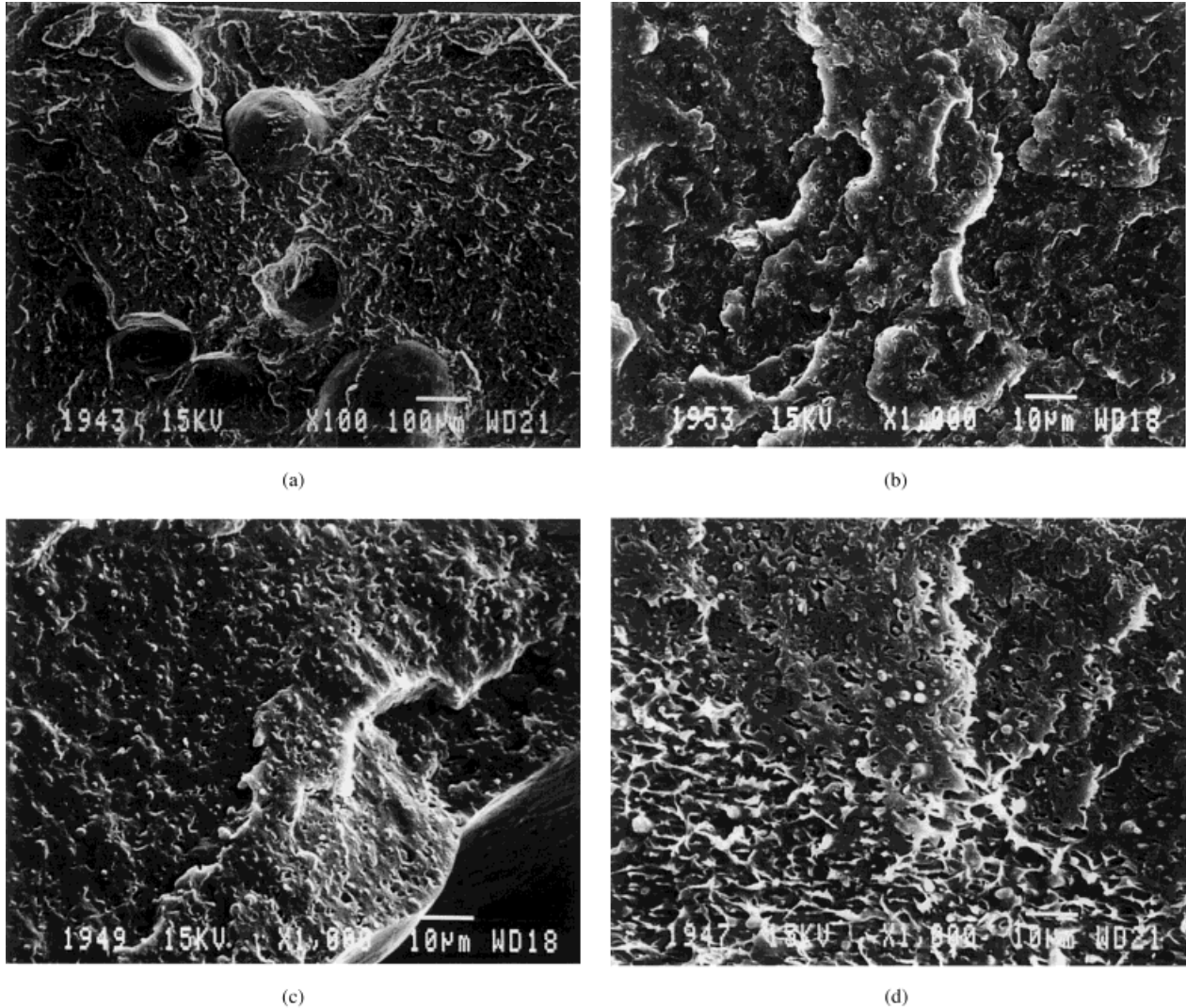


Figure 1 SEM micrographs of (a) mechanical blend, 30 wt % EPR-3/PP-1; (b) precipitated blend, 30 wt % EPR-3/PP-1; (c) mechanical blend, 50% EPR-1/PP-1; (d) precipitated blend, 50% EPR-1/PP-1.

two blending techniques described in the last section is presented in Figure 2. Even though the morphologies are different, the viscosities of precipitated and mechanical blends are similar. The slight difference observed for low shear rates may be due to a change in the initial entanglement density. The rheological data provide evidence that the precipitation technique used in this study does not cause chain scission.

THEORETICAL ASPECTS ON POLYMER MELT RHEOLOGY

Process Effects

This theoretical section presents an overview of the different models used in this work and ex-

plains the equations used to describe the PP, EPR, and EPR/PP blend rheology.

The Carreau–Yasuda model⁶ and Arrhenius–temperature dependency were used to describe shear rate and temperature dependency of blend viscosity. The model equation is given by:

$$\eta = b_T \eta_0 (1 + (b_T \lambda \dot{\gamma})^\alpha)^{(n-1)/\alpha} \quad (1a)$$

with

$$b_T = e^{-E_a/R((1/T_{ref}) - (1/T))} \quad (1b)$$

where η_0 is the zero-shear viscosity, λ is a characteristic elastic time for the fluid, and n is the power-law index in the high-frequency range. The param-

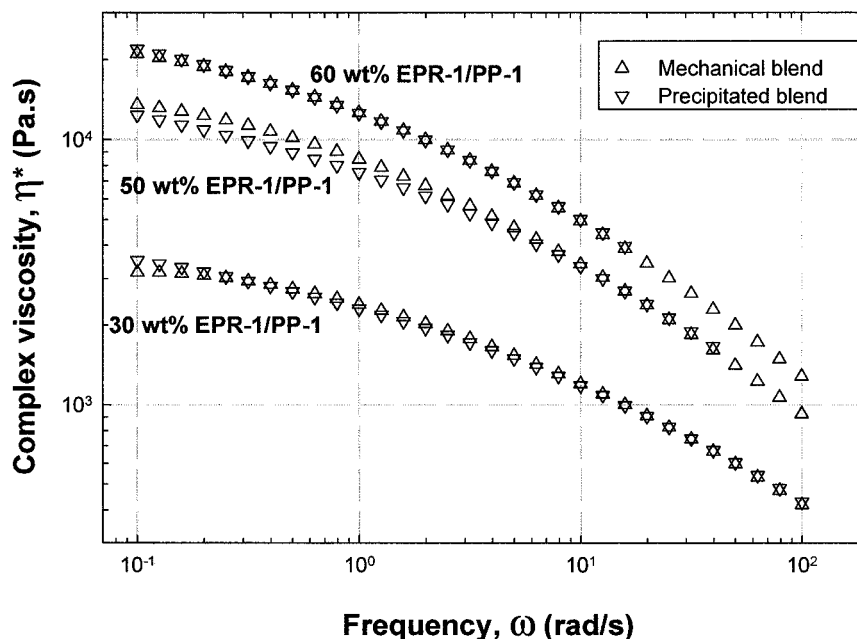


Figure 2 Viscosity of precipitated and mechanical blends of similar composition at 190°C.

eter a adjusts the breadth of the transition region between the viscosity plateau and the power-law region. The parameters of the Arrhenius eq. (1b) are as follows: E_a , the activation energy; R , the gas constant; and T and T_{ref} respectively, the measurement and reference absolute temperatures.

Molecular Weight Effects

The zero-shear viscosity is molecular weight dependent. For molecular weight, M_w , greater than the critical molecular weight for entanglement, M_c , the general relationship is given by:

$$\eta_0 = K \times (M_w)^d \quad (2)$$

where the parameters K and d are constants.⁷ This relationship was found to apply for the vast majority of polymer melts. The generally agreed interpretation is that above M_c , the polymer–polymer entanglements exert an overriding effect. This would seem reasonable intuitively because at low values of M_w , with short polymer chains, the lifetimes of those entanglements which do form will be very short. Above M_c , the increasingly long lifetime of junction points (entanglements) can be shown, by using several molecular flow models, to give rise to a power relationship with a power law slope, d , of 3.5.⁷ In this study, the molecular weight of the materials is much higher than the critical values,

which are reported around 1500 and 7000 g/mol for PE and PP, respectively.

The theoretical predictions for the characteristic elastic time, λ , indicate that, for a constant temperature, λ increases linearly with η_0 ,⁷ for instance,

$$\lambda = (K/T)\eta_0 \quad (3)$$

where K is a constant and T is the absolute temperature. Thus, the characteristic elastic time has the same molecular weight dependence as the zero-shear viscosity, η_0 .⁸

Concentration Effects

A model for polymer emulsion rheology was successfully developed by Paliarne.⁹ The model takes into account particle size and interfacial tension but is limited to spherical droplet morphology (low concentration) and small deformation (linear viscoelasticity). There is no available model for high concentration or cocontinuous blends. In the current study, interfacial tension in the melt state is very low, around 0.8 J/m².¹⁰ Therefore, it was thought that the Tsenoglou or double-reptation model,¹¹ derived for miscible blends without interaction, might be able to predict EPR/PP blend viscosity over a wide range of concentrations. It was also commented by the authors as

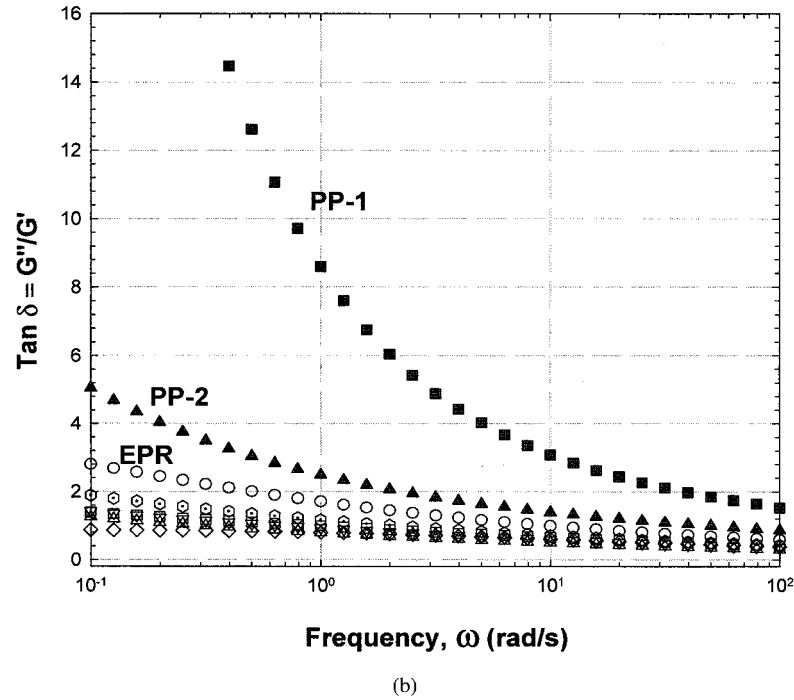
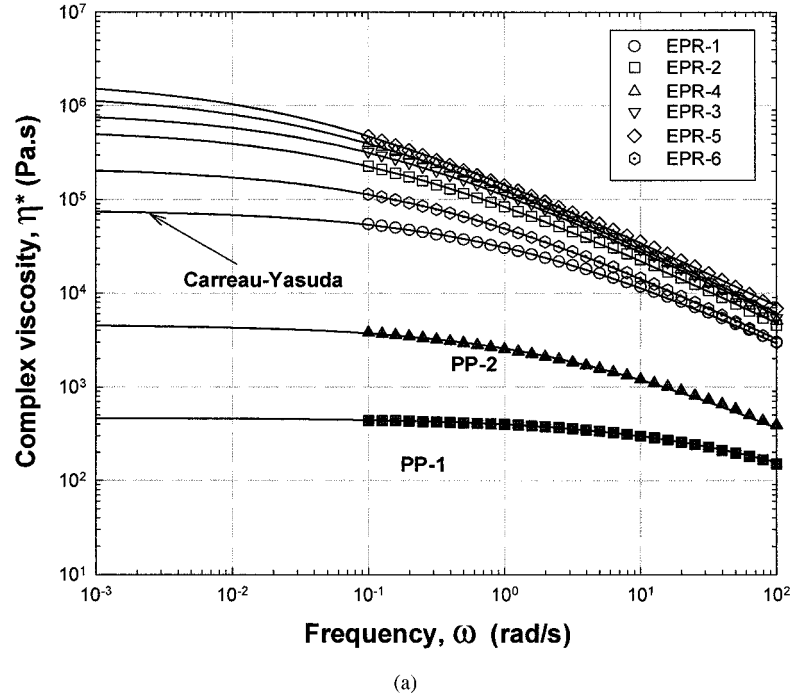


Figure 3 Rheological properties of pure EPR and PP materials at 190°C. (a) Viscosity and corresponding Carreau–Yasuda model fits; (b) $\tan \delta$ of pure materials at 190°C.

useful for partly miscible or compatible systems and was derived by combining reptation and constraint-release concepts. The basic equations of the model are

$$(G_N^0)_{\text{blend}}^{1/2} = \sum \phi_i (G_N^0)_i^{1/2} \quad (4)$$

and

$$(\eta_0)_{\text{blend}} = \phi_1^2(\eta_0)_1 + \phi_2^2(\eta_0)_2 + \frac{4\phi_1\phi_2(\eta_0)_1(\eta_0)_2(G_N^0)_1^{1/2}(G_N^0)_2^{1/2}}{(G_N^0)_1(\eta_0)_2 + (G_N^0)_2(\eta_0)_1} \quad (5)$$

Table II Weight Average Molecular Weight and Carreau–Yasuda Model Parameters (base materials)

Polymer	M_w (kg/mol)	Carreau–Yasuda Model Parameters			
		η_0 (kPa s)	λ (s)	a	n
EPR-1	361	77	0.879	0.5	0.3
EPR-2	708	562	8.44	0.5	0.3
EPR-3	810	864	10.3	0.5	0.3
EPR-4	1017	1350	18.9	0.5	0.3
EPR-5	642	1890	29.2	0.5	0.3
EPR-6	695	221	3.77	0.5	0.3
PP PH920S	215	0.465	0.0142	0.5	0.3
PP SM6100	375	4.59	0.265	0.5	0.3
PP 6823	794	82.4	2.23	0.5	0.3

where ϕ_i is the weight fraction of the component i of the blend and G_N^0 is the plateau modulus, which is independent of the molecular weight. The plateau modulus is usually calculated from dynamic mechanical data of monodisperse polymers where a well-defined plateau in the G' plot or a maximum in G'' appears.⁷

The advantage of the Tsenoglou model is that all rheological properties of the blend are related to the corresponding properties of the individual components without any need for introducing additional molecular parameters or physical assumptions other than that of randomness in interchain associations.¹²

Effect of E/EPR Ratio (ϕ_E) on EPR Viscosity

The viscosity of EPR will not depend only on its molecular weight but also on the ethylene content in the copolymer. A function $f(\phi_E)$ was defined as the viscosity of EPR over that of pure PP for a given molecular weight. The Tsenoglou equation, used to describe the concentration effects, was also used to describe the effect of the ethylene content in the EPR copolymer. By using the Tsenoglou functional form given by eqs. (4) and (5), the following relation between the ethylene content, ϕ_E , and the zero-shear viscosity in the EPR copolymer was developed:

$$f(\phi_E) = \frac{\eta_{\text{EPR}}}{\eta_{\text{PP}}} = A\phi_E^2 + B\phi_E + 1 \quad (6)$$

with

$$A = \frac{(\kappa + 1)[(G_N^0)_{\text{PE}} + \kappa(G_N^0)_{\text{PP}}] - 4\kappa(G_N^0)_{\text{PE}}^{1/2}(G_N^0)_{\text{PP}}^{1/2}}{(G_N^0)_{\text{PE}} + \kappa(G_N^0)_{\text{PP}}}$$

and

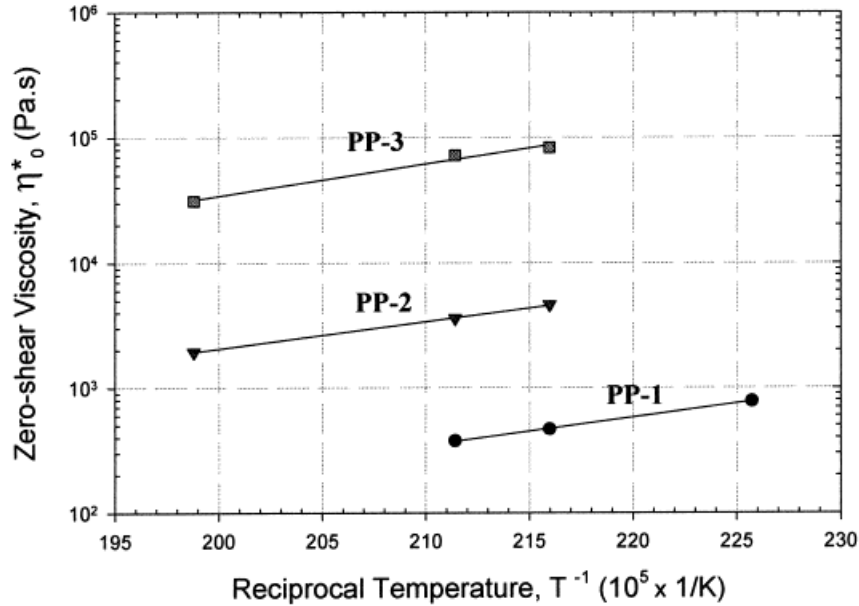
$$B = \frac{4\kappa(G_N^0)_{\text{PE}}^{1/2}(G_N^0)_{\text{PP}}^{1/2} - 2[(G_N^0)_{\text{PE}} + \kappa(G_N^0)_{\text{PP}}]}{(G_N^0)_{\text{PE}} + \kappa(G_N^0)_{\text{PP}}}$$

ϕ_E is the ethylene fraction in the EPR copolymer; η_{PP} is the viscosity of PP evaluated at the EPR molecular weight; and κ is the theoretical ratio between the zero-shear viscosity of PE and PP of the same molecular weight as given by eq. (2). The values of the PP and PE plateau modulus, G_N^0 , can be found in the literature and are, respectively, 800 and 2600 kPa.¹³

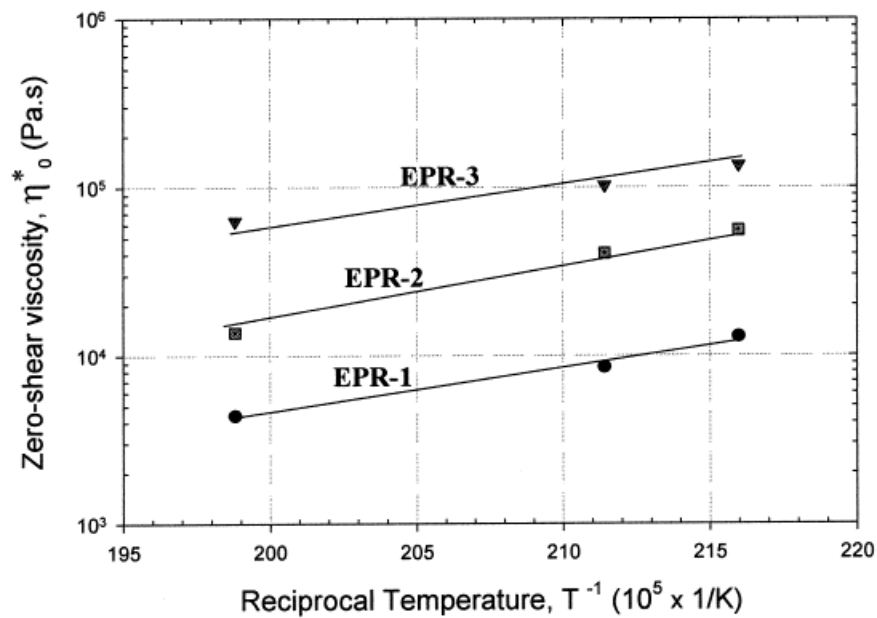
EXPERIMENTAL RESULTS AND ANALYSIS

Rheology of Pure Materials

Figure 3 presents the complex viscosity and loss tangent for the pure materials. In Figure 3(a), the measured complex viscosity (symbols) is compared with the Carreau–Yasuda model fits (solid lines). The viscosity of EPR copolymers is much higher than that of PP. The Newtonian plateau of PP extends to much higher frequencies than for EPR copolymers. In fact, the Newtonian plateau for EPR materials cannot be directly measured in the probed deformation rate range. All investigated PP and EPR materials show approximately the same degree of shear thinning at high deformation rate. The slope of the viscosity versus frequency plot ($=n - 1$) is approximately equal to -0.7 . This yields a power-law index n around 0.3 for all studied materials. The Carreau–Yasuda model was used to extrapolate the viscosity data to its zero-shear limit. All model parameters for



(a)



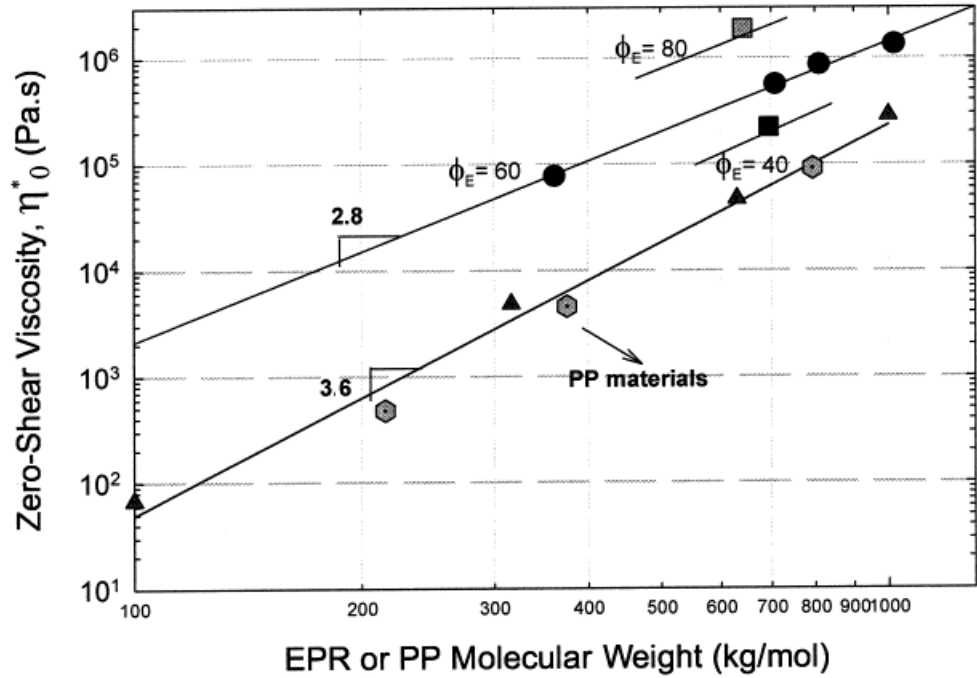
(b)

Figure 4 Temperature effect on the (a) PP and (b) EPR zero-shear viscosity.

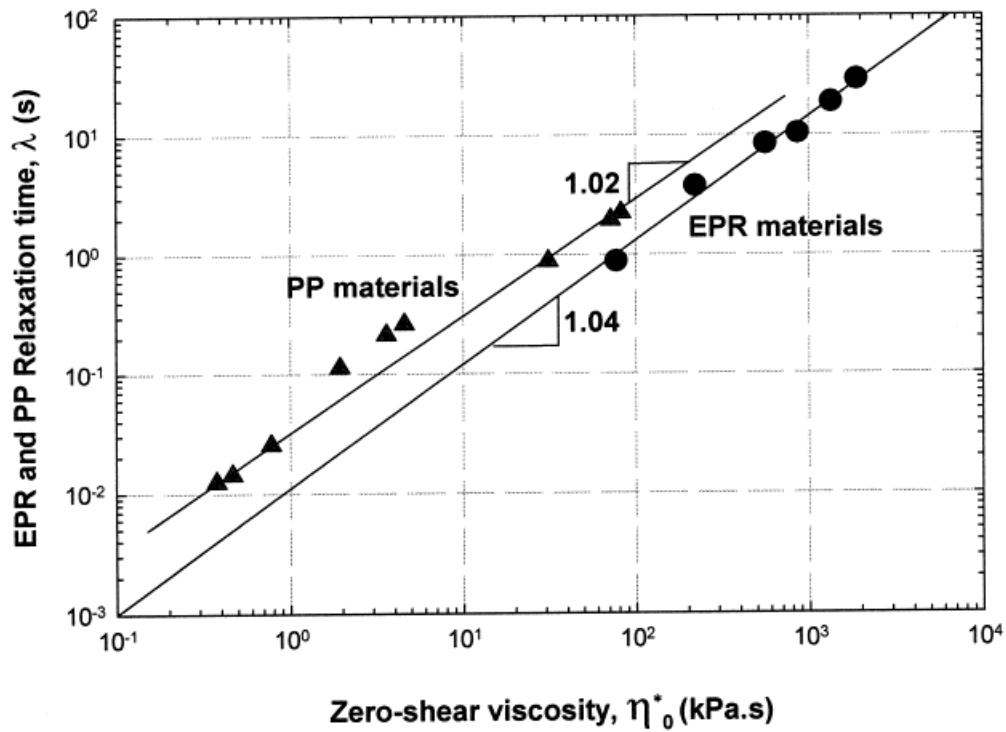
the PP and EPR material are reported in Table II, together with the corresponding weight-average molecular weight.

Figure 3(b) presents the loss tangent ($\tan \delta$) as a function of oscillation frequency. Perfectly viscous fluids have $\tan \delta = \infty$, whereas elastic solids would have $\tan \delta = 0$. The figure shows that

the EPR materials are much more elastic than the PP materials, especially at low frequency. The elasticity increases with increasing frequency, and, for the same ethylene weight fraction, the EPR elasticity increases with an increase in its weight-average molecular weight. Such behavior results from the molecular structure of the mate-



(a)



(b)

Figure 5 Molecular effects on (a) the zero-shear viscosity and (b) the characteristic elastic time of EPR and PP materials. Triangular symbols in Figure 5(a) correspond to PP data obtained from the literature.¹³

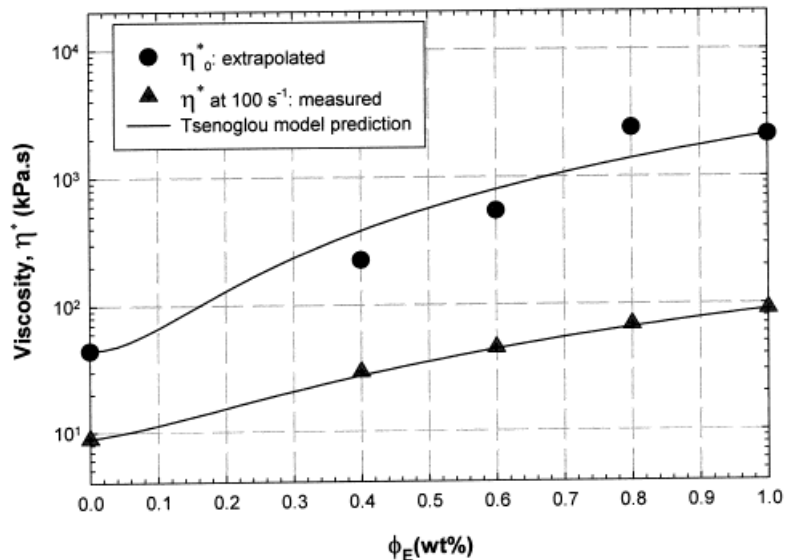


Figure 6 E/EPR ratio effects on EPR viscosity and comparison with the Tsenoglou model predictions.

rials. The difference in the elasticity becomes smaller with increasing frequency.

Temperature Effects on Viscosity

The EPR and PP rheology was measured at three different temperatures (190, 200, and 230°C) to evaluate the material's activation energy, E_a . Figure 4(a,b) presents a log-linear representation of the zero-shear viscosity as a function of the reciprocal of temperature for PP and EPR materials, respectively. The linear relationship found in these plots indicates that the Arrhenius eq. 1(b) is valid for both PP and EPR. The activation energies, given by the slopes in Figure 4(a,b) plots, were found to be 48 and 50 kJ/mol for PP and EPR, respectively, with no significant effect of M_w .

Molecular Effects on η_0 and λ

Figure 5(a,b) presents, respectively, the effect of M_w on zero-shear viscosity, η_0 , and characteristic elastic time, λ , at 190°C for EPR and PP. The EPR copolymers have an E/EPR ratio of 60 wt % and different molecular weights ($M_w = 361, 708, 810,$ and 1017 kg/mol). Additional data for PP taken from the literature¹³ were also used for calculations. As expected for high molecular weight materials, the EPR and PP zero-shear viscosity were found proportional to the molecular weight at a power, d , of approximately 2.8 and 3.6, respectively. The value of 2.8 obtained for the EPR copolymers is smaller than 3.5, the typical value reported for poly-

mer melts. If we consider that the EPR entanglement molecular weight is intermediate between that of polyethylene and that of polypropylene, the molecular weight for the EPR used in this study ranges approximately from 200 to 600 times the entanglement molecular weight, M_e . For high molecular weight polymers, Colby et al.¹⁴ found evidence for a systematic decrease of the power law exponent from the 3.4 to 3.6 value for linear polymers of $M_w \geq 200M_e$. A value of 3.0, instead of 3.5, has also been observed by Graessley⁸ for some systems with high molecular weights. Graessley also suggested that the exponent of 3.0 is correct for high molecular weight and that the deviation is due to contributions to relaxation from other mechanisms than reptation, which become more important with decreasing molecular weight. Therefore, the power-law index of 2.8 found in this study is consistent with past observations on high molecular weight systems.

As shown in Figure 5(b), the EPR and PP characteristic elastic time, λ , increased linearly with η_0 on the logarithmic plot with a power-law exponent of 1.02 and 1.04, respectively, close to the theoretical value of 1.0 expected from eq. (3). Exponents of 1.0 will be used for the predictive model.

Effect of E/EPR Ratio (ϕ_E) on EPR Viscosity, η

The zero-shear viscosity and viscosity at 100 rad/s as a function of the ethylene weight fraction, ϕ_E , are presented in Figure 6. The data was obtained from EPR-2, EPR-5, and EPR-6 and from the

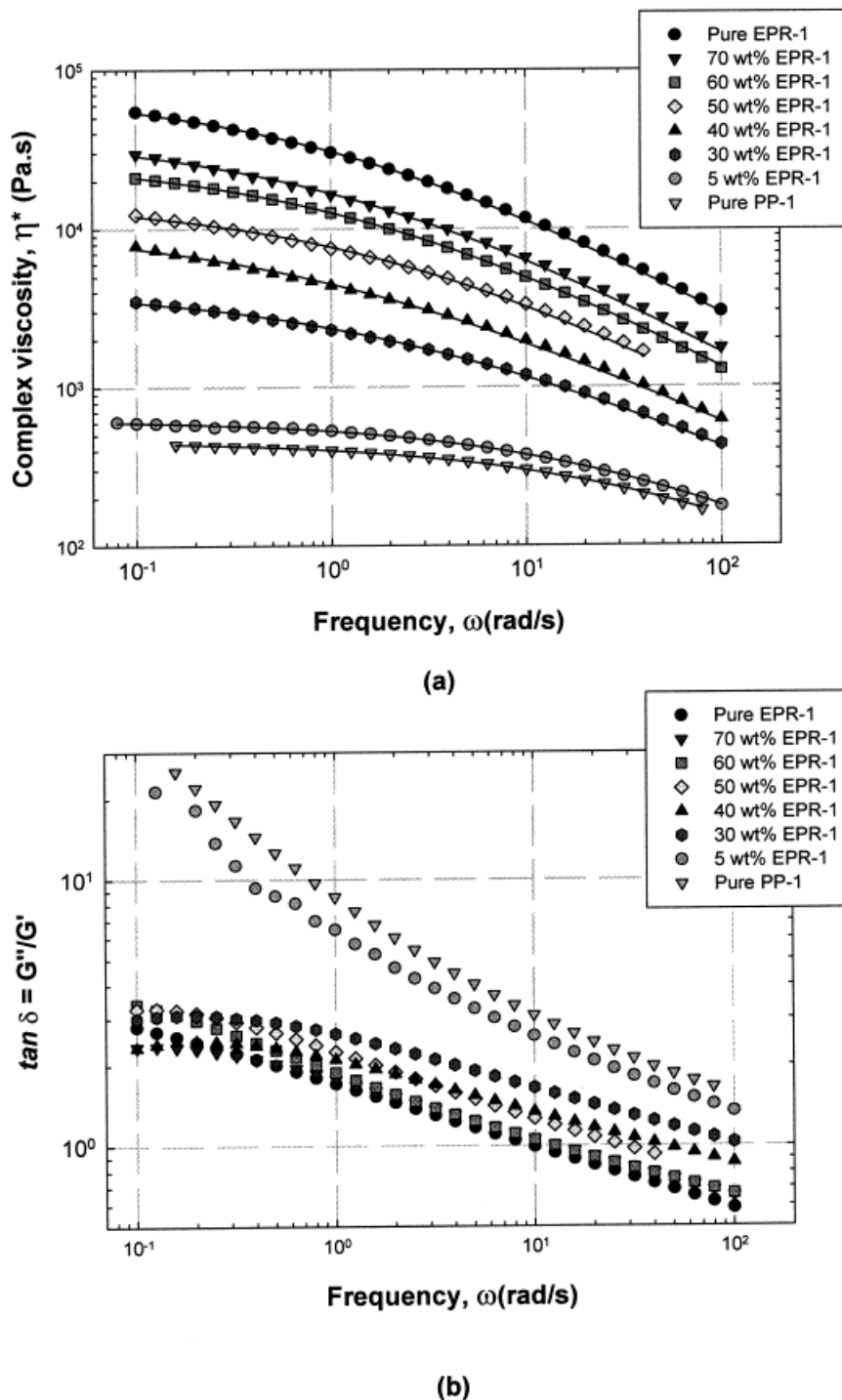


Figure 7 (a) Viscosity and (b) loss tangent of EPR-1/PP-1 blend at 190°C, as a function of oscillation frequency and EPR weight fraction.

theoretical values of polyethylene and polypropylene viscosity for a molecular weight of 700 kg/mol. To take into account the slight molecular weight difference for the three EPR materials,

their viscosity were normalized to $M_w = 700$ kg/mol by using the molecular weight dependency given by eq. (2). The theoretical ratio, κ , between the zero-shear viscosity of PE and PP of $M_w = 700$

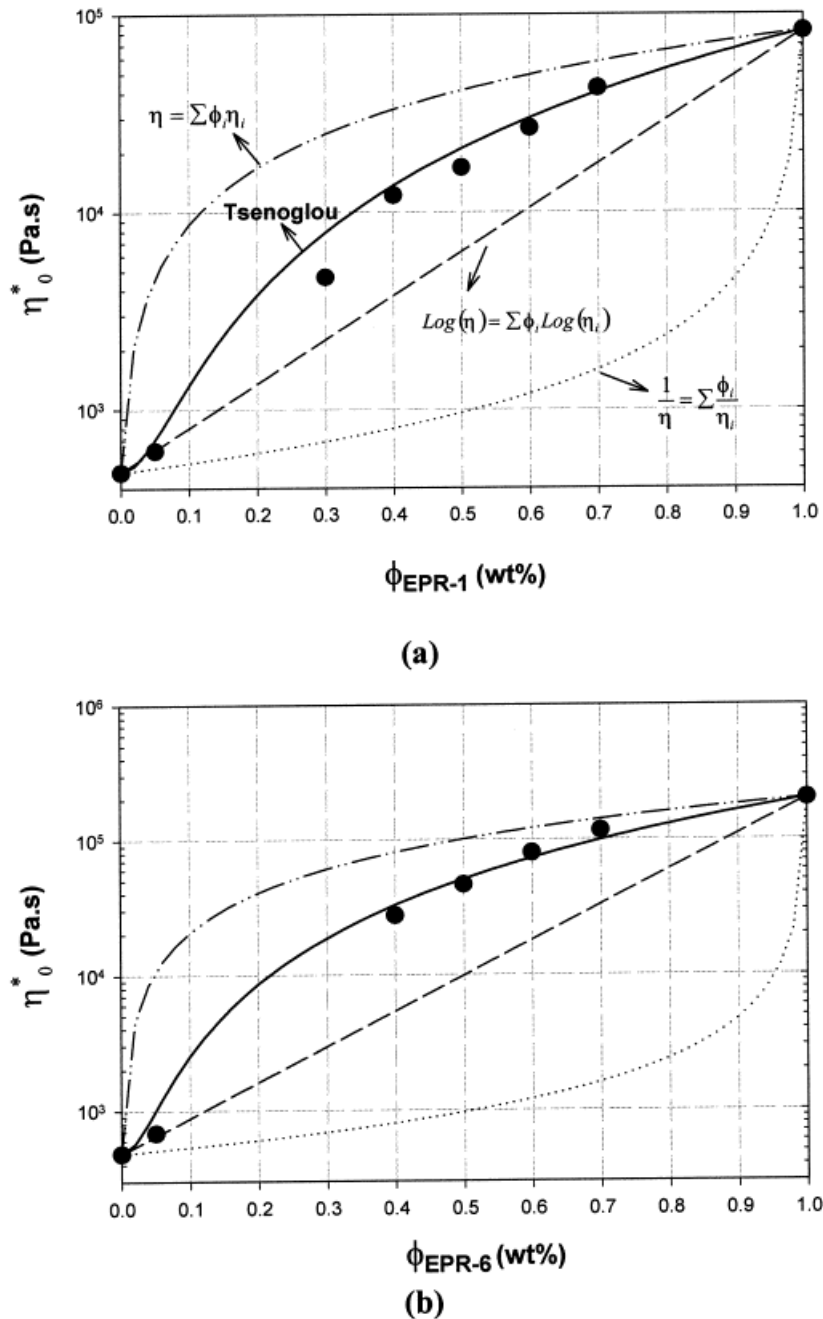


Figure 8 Blend zero-shear viscosity, η_0 , as a function of EPR weight fraction.

kg/mol was 41.8. It is worth noting that in calculating κ , additional previous experimental results, taken from the literature,¹³ were used. After final calculations, eq. (6) leads to the following correlation:

$$f(\phi_E) = 29.96\phi_E^2 + 10.83\phi_E + 1 \quad (7)$$

The limiting values of $f(\phi_E)$ are 1.0 if $\phi_E = 0$ (by definition) and 41.8 for $\phi_E = 1$. The last limiting

case corresponds the ratio between the zero-shear viscosity of a linear PE over that of PP for a given molecular weight.

The viscosity of the EPR copolymer increases dramatically with the weight fraction of ethylene, E/EPR. The effect of the weight fraction of ethylene, E/EPR, on viscosity is reasonably well described by eq. (6), developed from the Tsenoglou model. The deviation from the Tsenoglou model prediction for the extrapolated zero-shear viscos-

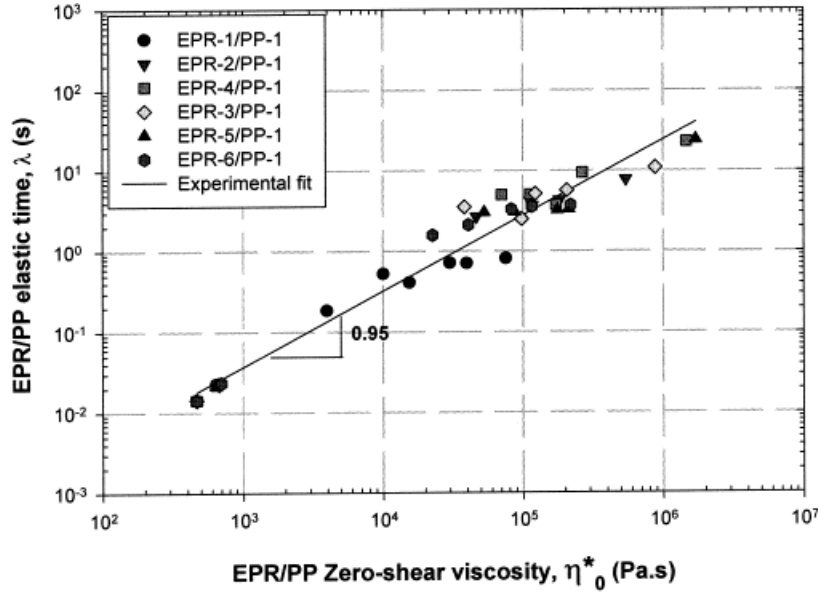


Figure 9 Blend characteristic elastic time, λ , as a function of zero-shear viscosity, η_0 .

ity may be caused by the required extrapolation. As shown in Figure 6, a better agreement between the model and the measured viscosity data was found for an oscillatory frequency of 100 rad/s.

Rheology of EPR/PP Blends

Figure 7 presents the complex viscosity and the loss tangent ($\tan \delta$) for blend EPR-1/PP-1 at various concentration at 190°C. In Figure 7(a), the solid lines are the Carreau–Yasuda fits used to determine the zero-shear viscosity and elastic time. The viscosity of the EPR/PP blends lies between the viscosity of the PP and that of the EPR copolymers. The blends have approximately the same degree of shear thinning at high deformation rate as the PP and EPR base materials. The use of a power-law index, n , around 0.30 is, therefore, well suited for the blends as well as for the pure PP and EPR. Other EPR/PP blends presented similar behavior. Figure 7(b) shows that the blend's loss tangent lies between that of PP and that of EPR copolymers and increases with increasing frequency. At low frequencies, the blend elasticity is more controlled by EPR elasticity (for EPR weight fractions higher than 30%, i.e., the blend elasticity approaches much more EPR elasticity than that of the PP). With increasing frequency, the influence of the PP on the blend elasticity is more important. These results are similar to those obtained by D'Orazio et al.² with EPR/PP blends.

Concentration Effects on EPR/PP Blends Zero-Shear Viscosity, η_0

The effect of EPR concentration, ϕ_{EPR} , on EPR/PP blend zero-shear viscosity, η_0 , is presented in Figure 8 together with the Tsenoglou model predictions and those of three other common mixing rules: additivity, log-additivity, and fluidity models, given, respectively, by the following equations:

$$\eta_{\text{blend}} = \sum \phi_i \eta_i \quad (8)$$

$$\log(\eta_{\text{blend}}) = \sum \phi_i \log(\eta_i) \quad (9)$$

$$\frac{1}{\eta_{\text{blend}}} = \sum \frac{\phi_i}{\eta_i} \quad (10)$$

Figure 8(a,b) presents data obtained, respectively, with EPR-1 and EPR-6 blended with PP-1. The other blends obtained with EPR-2 to EPR-5 in PP-1 present similar behaviors. In all PP/EPR blends, the zero-shear viscosity presents a positive deviation from the log-additivity and the fluidity rules, and negative deviation from the additivity rule of pure PP and EPR zero-shear viscosities. The extent of such deviation increases with an increase in the EPR weight-average molecular weight. In all cases, the Tsenoglou model prediction is in much better agreement with the data. The best agreement is observed for blends containing EPR-1, -2, and -6. Some discrepancies are observed for the blends with EPR-3 and -5 and to

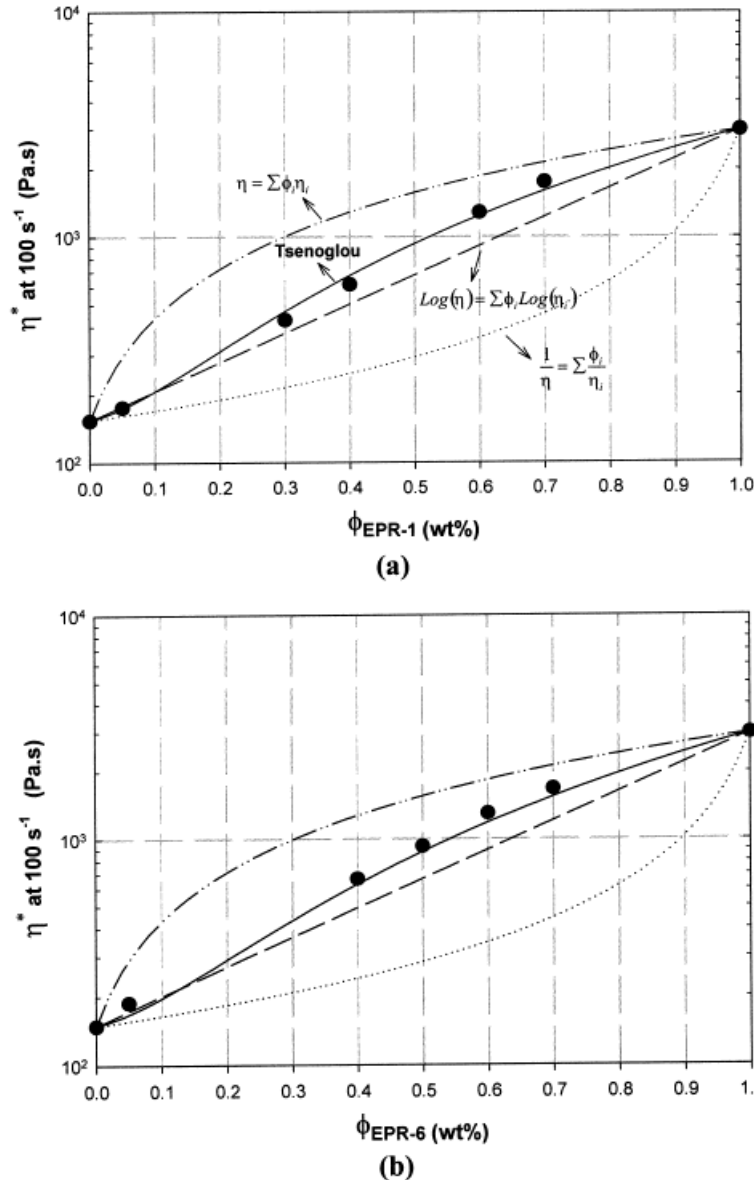


Figure 10 Blend viscosity, at constant shear rate of 100 s^{-1} , as a function of EPR weight fraction.

a lesser extent to the EPR-4/PP blend. It should be noted that the best results correspond to the less viscous systems. Thus, it is possible that the deviation from the Tsenoglou model prediction may originate from extrapolation of the zero-shear viscosity in the higher viscosity systems rather than from theoretical limits in the Tsenoglou model.

Figure 9 presents the characteristic elastic time, λ , for different EPR/PP-1 blends as a function of the zero-shear viscosity, η_0 . For each blend, data for different EPR concentrations of 5, 30, 40, 50, 60, and 70 wt % is presented. The blend characteristic elastic time increases linearly with

η_0 on the logarithmic plot. The value of the power-law exponent, obtained by linear regression, is 0.95, close to the theoretical value of 1.0 expected for pure materials.

By combining the Tsenoglou model to the molecular weight and temperature-dependency models presented above, one is able to determine the Carreau–Yasuda model parameters and thus predict the zero-shear viscosity and elastic relaxation time for blends of EPR and PP of a given molecular structure.

Molecular information is not, however, always readily available and for practical reasons, viscos-

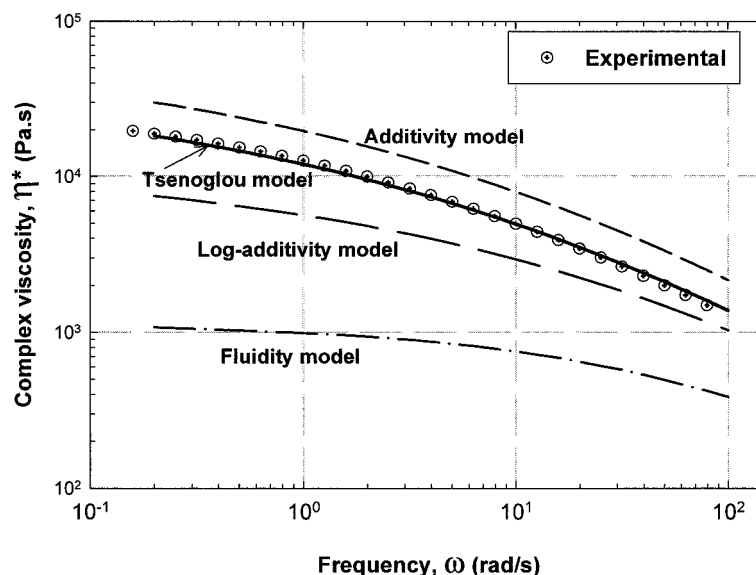


Figure 11 Viscosity of EPR-1/PP-1 blend at 190°C as a function of oscillation frequency.

ity of the base materials may be easier to collect. It is thus of interest to determine if the Tsenoglou model could be used at processing deformation rate. This was verified by replacing the zero-shear viscosity in eq. (5) by the viscosity at a fixed deformation rate. Figure 10(a,b) presents the different model predictions for the viscosity at a constant oscillation rate of 100 s^{-1} . The Tsenoglou model remains fairly accurate over a wide range of EPR concentrations. In fact, the predictions are closer to the experimental data than for the zero-shear viscosity, because extrapolation is not necessary.

Figure 11 reports the complex viscosity of 60 wt % EPR-1/PP-1 blend, together with the predictions in the whole range of the investigated frequencies (0.1–100 rad/s). As in the preceding figure, the blend model predictions for each oscillation rate are based on the pure component viscosity at the same oscillation rate. The fluidity additivity and viscosity additivity model severely under- and overpredict the blend viscosity. The log-additivity remains a good first approximation but the use of the Tsenoglou model predictions are clearly more adequate to predict the blend viscosity over the whole range of deformation rate.

CONCLUSION

The rheological behavior of PP, EPR, and EPR/PP blends has been studied. The viscosity and elastic

relaxation times were found proportional to the molecular weight at a power close to 2.8 and 3.6 for EPR and PP, respectively. Flow activation energies of 48 and 50 kJ/mol were found for both PP and EPR, respectively, with no relation to molecular weight. For EPR, the Tsenoglou model, based on double-reptation, was found adequate to predict the effect of the ethylene content of EPR on shear viscosity, specifically for high shear rates. The Tsenoglou model was also used to predict the EPR/PP blend viscosity at the zero-shear limit or at fixed nonzero frequency. In the first case, agreement was good, especially for the lower viscosity systems, where the zero-shear viscosity values are easier to extrapolate both for the blend and for its components. When using the component viscosity in the 0.1–100 rad/s range, excellent agreement between Tsenoglou predictions and blend viscosity was found for all studied blend systems.

The authors thank H el ene Roberge and Pierre Sammut for the blends preparation and rheological characterization.

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