

Measurement of the Rheological Properties of Polymer Melts with Slit Rheometer. III. Two-Phase Systems—High-Impact Polystyrene and ABS Resin

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Synopsis

Measurements were made of the rheological properties of commercially available rubber-reinforced two-phase polymer systems. The polymers chosen for study were two high-impact polystyrenes (Union Carbide Corp., TGDB9500 and TGDB2100) and an acrylonitrile-butadiene-styrene (ABS) resin (Monsanto Co., Lustran I240 Natural). For the study, a slit rheometer was used, which was described in part I of this series. The present paper, the third of this series, clearly demonstrates the usefulness of the slit rheometer for characterizing polymer systems of industrial importance by means of their viscous and elastic properties in the molten state.

INTRODUCTION

In recent years some success has been met in producing resins of commercial importance having high-impact strength. Such resins consist of more than one polymer. Specifically, a rubbery component is dispersed in a base component, which can be either a homopolymer or a copolymer. Resins such as high-impact polystyrene, high-impact poly(vinylchloride) (PVC), and acrylonitrile-butadiene-styrene (ABS) are a few of the commercially important polymer systems which give rise to high impact strength.

Interestingly enough, these resins form two phases in the molten state. For instance, molten ABS resin has particles of polybutadiene rubber homogeneously dispersed in a styrene-acrylonitrile copolymer. In other words, the ABS resin consists of a hard medium as the continuous phase and soft particles (rubber component) as the disperse phase. It should be noted that the high-impact polystyrenes and ABS are believed to be grafted copolymers, at least in part, that the rubbery phase is crosslinked, and that the graft copolymer likely is located at the interface with the resin phase. While the resin phase can flow when molten, the rubbery phase is probably only deformable and does not flow in the true sense.

On the other hand, an experimental determination of the rheological properties of two-phase systems in the molten state is of fundamental importance in order to develop resins of better mechanical properties and to rationally design various processing devices (e.g., dies and molds, etc.).

The present paper, the third of this series, reports some measurements of both viscous and elastic properties of two high-impact polystyrenes and an ABS resin, and further demonstrates the usefulness of the slit rheometer, constructed by the author, for the characterization of polymer systems by their viscoelastic properties in the molten state.

EXPERIMENTAL

Materials

Two high-impact polystyrenes (Union Carbide Corp., TGDB9510 and TGDB2100) and an ABS resin (Monsanto Co., Lustran I240 Natural) were used for the present study. Table I shows the rubber content in each sample. The exact content of rubber in ABS resin was not disclosed by the supplier.

TABLE I
Two-Phase Polymer Systems Investigated

Material	Rubber content	K , lb _f /in. ² -sec ⁻ⁿ	n (dimensionless)
High-impact polystyrene (TGDB 9510)	4.5%	2.769	0.288
High-impact polystyrene (TGDB 2100)	24.5%	4.117	0.297
ABS resin (Lustran I240 Natural)	low	3.481	0.378

Apparatus and Experimental Procedure

The apparatus and experimental procedure used has been described in part I of this series.¹ In the present study, only a slit die having an aspect ratio of 20 was used. This was referred to slit die 2 in part I of this series.¹

RESULTS AND DISCUSSION

Representative axial pressure profiles are shown in Figure 1 for high-impact polystyrene (TGDB9510) at 200°C, and in Figure 2 for ABS resin at 200°C. Similar pressure profiles were also obtained for other high-impact polystyrene (TGDB2100). Figures 1 and 2 indicate that wall normal stresses at three positions along the longitudinal direction lie on a straight line at a given volumetric flow rate, and hence at a fixed shear rate.

Using the method described in part I of this series,¹ plots of shear stress versus shear rate are prepared, as shown in Figure 3 for the three samples. It can be seen that all three follow a power law over the range of shear rates encountered. The power law constants of these materials are given in Table I. Figure 4 shows plots of melt viscosity versus shear rate for the three polymers. Figure 4 shows that TGDB2100, which has 24.5% rubbery component, is much more viscous than TGDB9510, which has a 4.5%

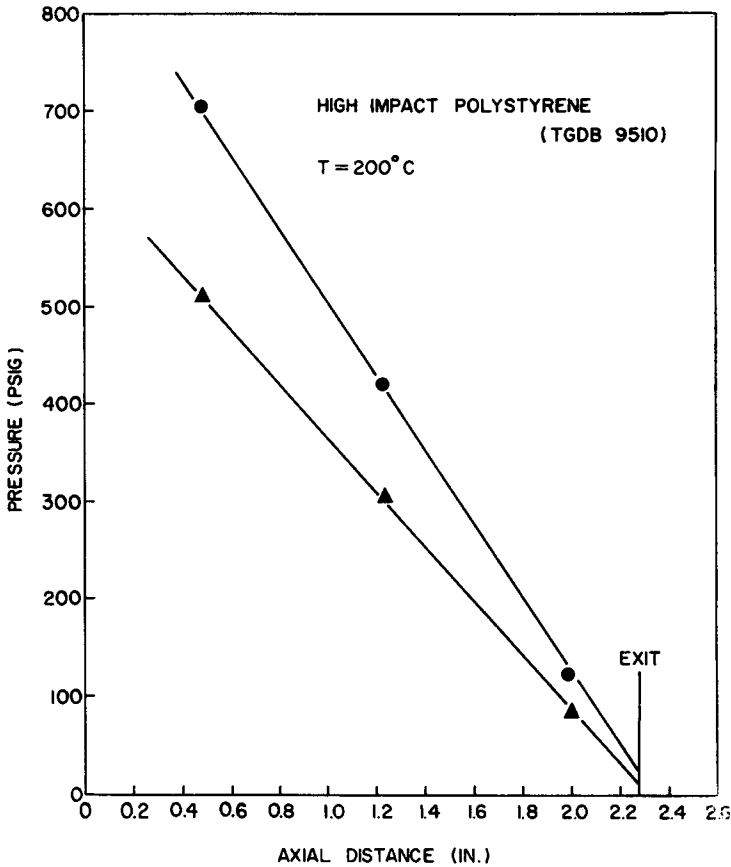


Fig. 1. Axial pressure profiles for high-impact polystyrene (TGDB9510) at 200°C: (●) $\dot{\gamma} = 143.5 \text{ sec}^{-1}$; (▲) $\dot{\gamma} = 43.8 \text{ sec}^{-1}$.

rubbery component. This indicates that melt viscosity increases as more polybutadiene is added to the base component, which, in this case, is polystyrene.

Figure 5 shows plots of exit pressure versus shear rate for the three polymers investigated. Again, it is seen from Figure 5 that TGDB2100 gives rise to higher exit pressures than TGDB9510, at fixed values of shear rate. However, as has been pointed out in previous studies by the author,^{1,2} exit pressure should be plotted versus shear stress instead of shear rate if one wishes to determine the relative values of melt elasticity of different materials. Figure 6 shows plots of exit pressure versus shear stress for the three polymers.

It is interesting to note from Figure 6 that, at a fixed shear stress, TGDB9510 gives a higher value of exit pressure than does TGDB2100, indicating that the sample which contains a higher percentage of rubbery component is indeed less elastic than the sample containing a lower per-

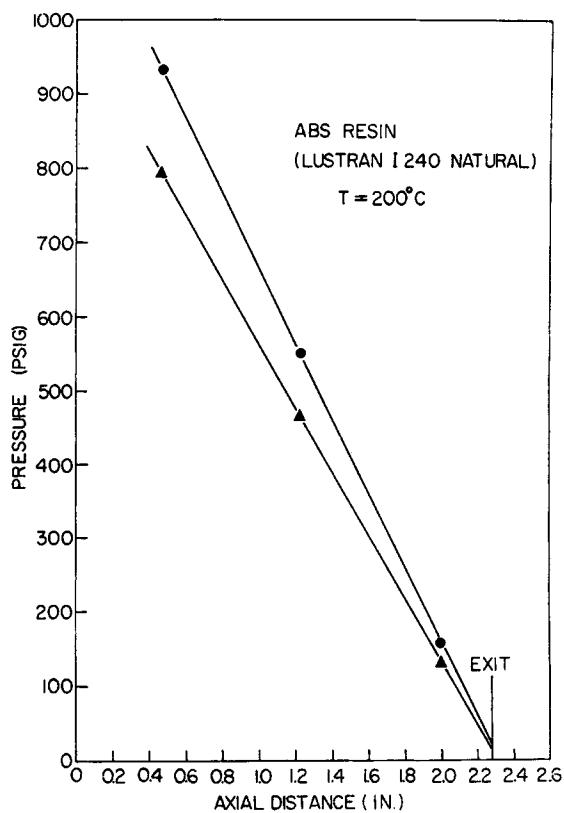


Fig. 2. Axial pressure profiles for ABS resin at 200°C: (●) $\dot{\gamma} = 47.9 \text{ sec}^{-1}$; (▲) $\dot{\gamma} = 31.9 \text{ sec}^{-1}$.

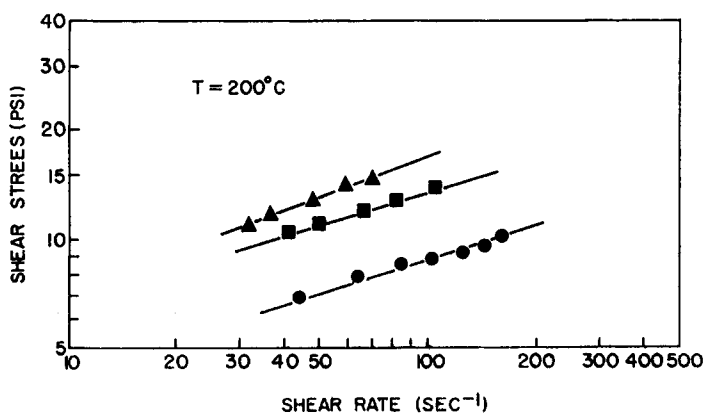


Fig. 3. Shear stress vs. shear rate: (▲) ABS; (■) HIPS (TGDB2100); (●) HIPS (TGDB9510).

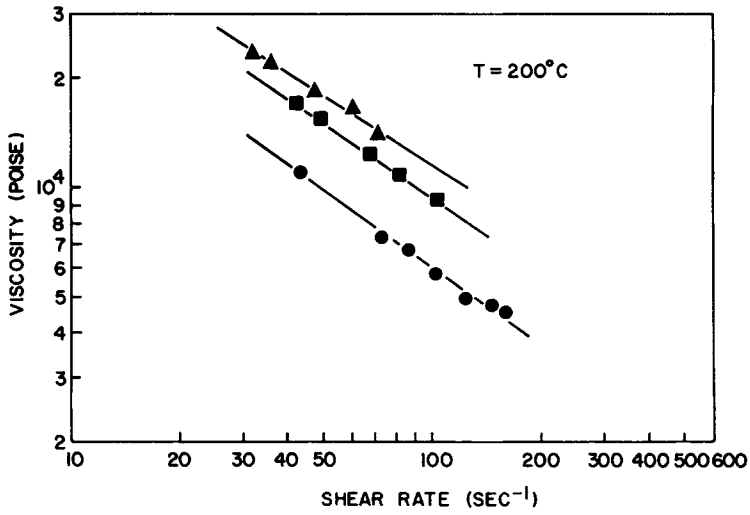


Fig. 4. Melt viscosity vs. shear rate. Symbols same as in Fig. 3.

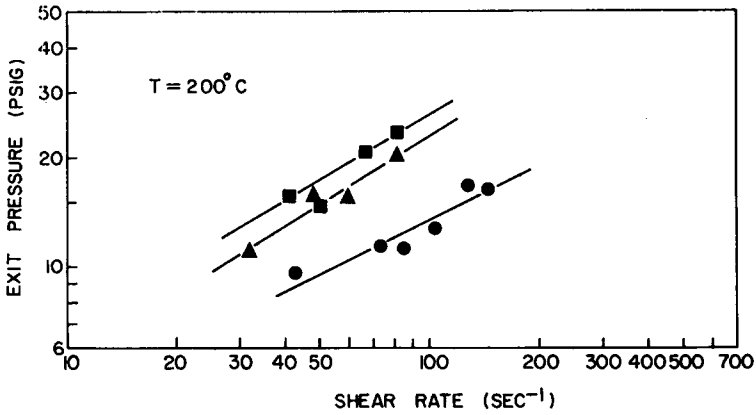


Fig. 5. Exit pressure vs. shear rate. Symbols same as in Fig. 3.

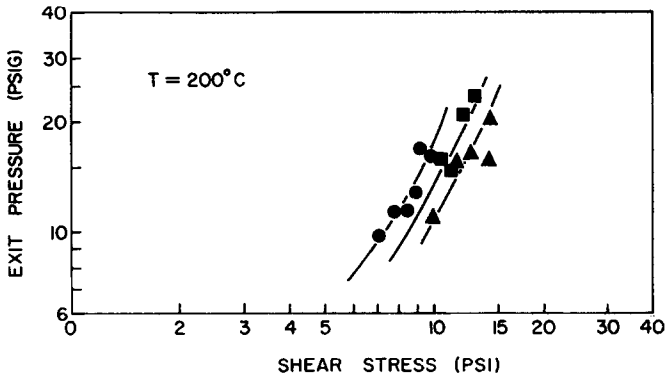


Fig. 6. Exit pressure vs. shear stress. Symbols same as in Fig. 3.

centage. This result seems to indicate that melt elasticity goes through a minimum at a certain blending ratio, whereas the result shown in Figure 4 appears to indicate that melt viscosity goes through a maximum as the rubbery component is increased in the two-phase system of high-impact polystyrene. This apparently unusual rheological behavior of two-phase systems has already been shown in an earlier paper³ and in part II of this series,⁴ in which blends of polystyrene and polyethylene and blends of polystyrene and polypropylene were investigated for several different blending ratios.

CONCLUSIONS

Three polymers of commercial importance, which form a two-phase system in the molten state, have been characterized by means of their viscous and elastic properties at a melt temperature of 200°C. The polymers investigated were two high-impact polystyrenes and an ABS resin.

The results of the present study show rather unusual rheological behavior both in melt viscosity and elasticity as the composition ratio of two components in a given resin varies. Interestingly enough, rheological behavior of commercially available two-phase systems follows a similar trend to that of blend systems of polystyrene with polyethylene and polystyrene with polypropylene.

The present study, the third of this series, together with previous studies described in parts I and II, clearly demonstrates the usefulness of the slit rheometer for characterizing polymer systems by their viscous and elastic properties in the molten state.

An advantage of using a slit rheometer over a capillary rheometer lies in that use of a slit die permits *flush-mounting* of melt pressure transducers and thus eliminates any *dead space* between the tip of the transducer and the flow channel. This feature of die design is essential for characterizing thermosetting resins by their viscous and elastic properties, because thermosetting resins form crosslinkage in any dead space and hence will make wall normal stress measurements difficult at that point.

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