Rheological properties of blends of polycarbonate with poly(acrylonitrile–butadiene–styrene)

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Blends of polycarbonate (PC) and poly(acrylonitrile–butadiene–styrene) (ABS) of compositions ranging between 10 and 90% ABS have been investigated to study the effect of addition of ABS on the flow properties of polycarbonate. Torque data have been collected for these blends at temperatures in the range of 210–230°C and speed in the range of 40–80 rpm, on a Haake Torque Rheometer System 90. The recorded data have been interpreted in terms of shear rate, shear stress and viscosity. The viscosity of the blend has been found to decrease with shear rate, and the decrease is greater for compositions that are rich in ABS. The viscosity decreases with increase in temperature, although the activation energies show higher values for PC-rich compositions and relatively lower values for ABS-rich blends. Thus, the addition of small amounts of ABS to PC could result in materials having good properties along with improved processability.

(Keywords: polycarbonate; PC/ABS blends; rheological properties)

INTRODUCTION

Blends of polycarbonate (PC) and poly(acrylonitrile–butadiene–styrene) are characterized for their useful combination of mechanical and thermal properties and good flowability. Because of these properties, blends of PC and ABS have been widely investigated for their mechanical properties[1], thermal properties, viscoelastic properties and morphology[2,3].

The study of the rheological properties of polymer blends is important in order to study the mechanism by which addition of one polymer to another influences the original polymer and to determine those combinations in which such effects occur[4]. These studies can then be utilized to establish optimal processing conditions and to develop optimal morphology to maximize product performance[5].

There are a variety of instruments used in rheological studies of polymers[6]. The torque rheometer is an efficient instrument that can provide a basis for developing quantitative indices of processability as a function of mixing time. The fundamental work in the area of torque rheometry has been based on using a mixer with roller-type mixing heads as a sensor, on the basic measuring instrument. The torque data can be interpreted in terms of shear force, shear rate and viscosity. The torque is related to the concept of shear stress and the speed of the rheometer is related to shear rate. The relation of shear stress to shear rate is the apparent viscosity.

Various methods have been suggested for converting data obtained by a torque rheometer to fundamental units such as apparent viscosity of the polymers without additional data from other techniques[7–9].

In this investigation polymer melts of blends of PC and ABS have been studied. Seven compositions of PC/ABS blends were studied on a torque rheometer at various speeds and temperatures. On the basis of a method suggested by Laguna *et al.*[7], an attempt has been made to convert these data in terms of shear stress, shear rate and apparent viscosity. An approximate value of activation energy of flow has been determined by using the Arrhenius equation.

EXPERIMENTAL

Polymers

The bisphenol A based polycarbonate used in this study is a commercial product of the General Electric Co., designated as Lexan 141-R-111 (Transparent) and supplied by IPCL, Baroda (India), having a relative density of 1.20. The ABS used has been supplied by Polychem Ltd, Bombay (India), and is designated as Polylac 100 GP-1 (rubber 16.5%, acrylonitrile 24% and styrene 59.5%); the relative density and MFI of ABS are 1.04 and 3.0 g/10 min, respectively.

Measurement of torque

A Haake Torque Rheometer with mixing head Rheomix 600 was used to measure the torque required for polymer melts at three temperatures, viz. 210, 220 and 230°C, and five speeds, viz. 40, 50, 60, 70 and 80 rpm.

The measurements were taken for polycarbonate, ABS and five compositions of their blends containing PC and ABS in the ratios of 90/10, 70/30, 50/50, 30/70 and 10/90. The granules of polymers of different compositions were weighed on the basis of 70% filling of the chamber having a volume of 69 cm^3 and the densities of the blends.

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The weighed granules were premixed by tumbling and dried in an oven for 2 days at 80°C to remove moisture. The temperature and speed of rotation were set on the microprocessor attached to the rheometer. The tests were controlled and processed by the software of the Haake System 90. The residence time of the polymer inside the mixing chamber was 10 min in all cases.

Interpretation of torque data

In order to convert the torque data in terms of fundamental units, the method suggested by Laguna *et al.*[7] was followed. According to that method, the torque M was plotted as a function of speed (rpm) Ω at constant temperature T on log–log scale, so that:

$$M = C_0 \Omega^b \tag{1}$$

where C_0 is a constant depending on machine geometry and temperature, and b is a constant characteristic of the polymer melt. Since in all cases the plots of $\log M$ vs. $\log \Omega$ were straight lines, b is equivalent to the slope of the corresponding straight lines. According to the method applied, b can be taken as equivalent to an index giving the degree of non-Newtonian behaviour of any fluid that follows the familiar power law given by:

$$\tau = K \dot{\gamma}^n \tag{2}$$

where τ is the shear stress and $\dot{\gamma}$ is the shear rate. The constant of the chamber was determined by using the results of calibration as reported by Goodrich *et al.*[9]. The effective instrument dimensions considered for the Rheomix 600 were: radii of the inner and outer cylinders, $R_i = 1.64$ cm, $R_e = 1.94$ cm, respectively; average radius, $R_m = 1.79$ cm; and cylinder length, $h = 4.78$ cm. Thus, the following correlations were used to calculate shear stress τ, shear rate $\dot{\gamma}$ and viscosity η of polymers from torque and speed data:

$$\tau = K_1 M \tag{3}$$

$$\dot{\gamma} = K_2 \Omega \tag{4}$$

where

$$K_1 = \frac{1}{2\pi R_m^2 h} \tag{5}$$

$$K_2 = \frac{2}{n R_m^{2/n} (R_i^{-2/n} - R_e^{-2/n})} \tag{6}$$

The apparent viscosity can be calculated by dividing shear stress by shear rate, or by the expression:

$$\eta = \frac{n R_m^{2(1/n - 1)}}{4\pi h} \left(\frac{1}{R_i^{2/n}} - \frac{1}{R_e^{2/n}} \right) \frac{M}{\Omega} \tag{7}$$

In expressions (3), (4) and (7), M and Ω are expressed in dyn cm and s^{-1}, respectively. Consequently, τ is given in dyn cm^{-2}, $\dot{\gamma}$ is given in s^{-1} and η is given in P.

The activation energy of flow at constant shear rate of all compositions of PC/ABS blends was determined by using the Arrhenius equation for the flow of non-Newtonian fluids:

$$\eta = A_{\dot{\gamma}} \exp(E_{\dot{\gamma}}/RT) \tag{8}$$

where $A_{\dot{\gamma}}$ is the Arrhenius constant and $E_{\dot{\gamma}}$ is the activation energy of flow at constant shear rate and R is the gas constant.

RESULTS AND DISCUSSION

Shear stress vs. shear rate plots

The torque and speed data as obtained from the Haake Torque Rheocord System 90 for polycarbonate, ABS and their blends have been plotted on log–log scale at three different temperatures of 210, 220 and 230°C as shown in *Figures 1a, 1b* and *1c*, respectively. The correlation coefficients in most of the cases were higher than 0.98, and therefore the shear stress and shear rate were determined by substituting corresponding values of n, M and Ω in expressions (3) and (4).

The shear stress vs. shear rate plots were obtained on log–log scale for polycarbonate, ABS and their blends at 210, 220 and 230°C and are shown in *Figures 2a, 2b* and *2c*, respectively. As is obvious from these plots, the slope, which represents the power-law index, decreases with increasing amount of ABS in the blend, and is lowest for ABS polymer. This shows that the non-Newtonian behaviour of melts increases with the addition of ABS. This result is in accordance with the results given by Kim and Burns[3], who have obtained shear stress vs. shear rate plots from volumetric flow rate data and melt densities of the mixture. There is a very minor change in slope with increase in temperature for all compositions, although it decreases on increasing the temperature. This could be attributed to the effect of temperature on the physicomechanical properties of polymer melts.

The ordinates of the torque vs. rpm and shear stress vs. shear rate plots decrease with increase in ABS content. The ordinates in these plots represent yield point for shear stress. Thus the blends of PC and ABS show pseudoplastic behaviour along with yield stress. This pseudoplasticity is due to intermolecular interactions between entangled and randomly oriented molecules. With addition of ABS, the interaction of molecules decreases and consequently pseudoplasticity increases.

Apparent viscosity

The apparent viscosities of blends have been determined by equation (7). For all compositions of blends, the viscosity was found to decrease with shear rate according to the notion of pseudoplastic character, as shown in *Figures 3a, 3b* and *3c*. The apparent viscosity of blends was found to be lower than that of polycarbonate and was found to decrease gradually with increase in ABS content in the blend. This is evident from *Figures 3a, 3b* and *3c*. The decrease in viscosity by adding 10% and 30% ABS is about 13–15% and 20–27%. Thus, power utilization would improve when ABS is added to polycarbonate. The reason for the decrease in viscosity of polycarbonate with addition of ABS may be solvation of the highly entangled structure of molecules of polycarbonate due to the presence of ABS molecules. Thus, with increase of shear rate, solvated layers may be sheared away, resulting in decrease in intermolecular interaction and consequent reduction in apparent viscosity[10].

Activation energy

The activation energy was determined from the slopes of $\log \eta$ against inverse temperature at five shear rates corresponding to five different speeds and at the lowest experimental shear rate ($\dot{\gamma}_0$), using equation (8), and have been given in *Table 1*. The activation energy was first found to decrease with increase in ABS content. The decrease on adding 10% ABS is about 9–13%, while for

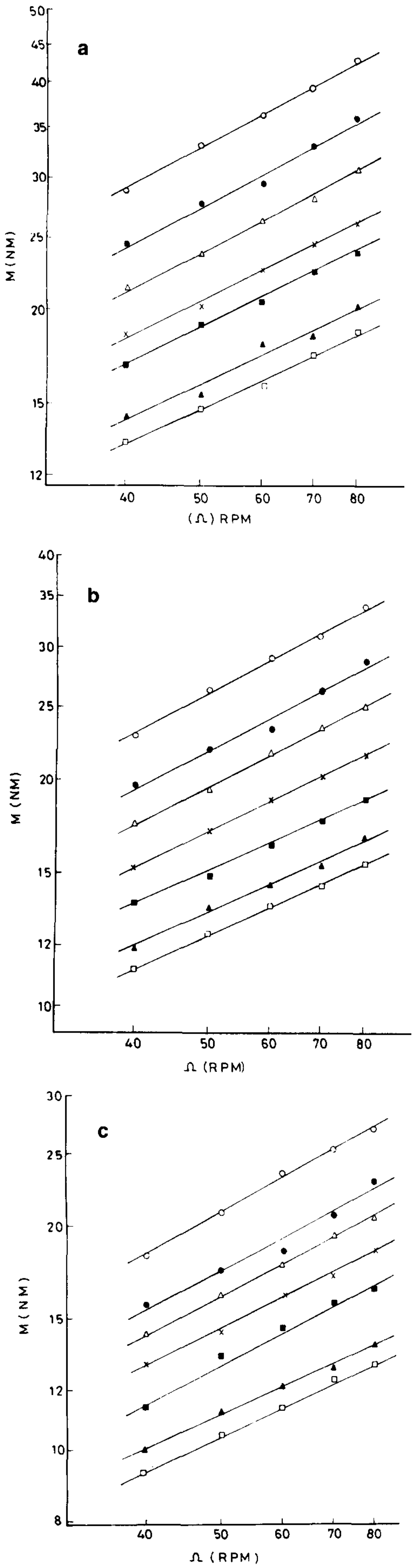

Figure 1 Log–log plot of torque vs. rpm for PC/ABS blends of compositions 100/0 (○), 90/10 (●), 70/30 (△), 50/50 (×), 30/70 (■), 10/90 (▲) and 0/100 (□) at (a) 210°C, (b) 220°C and (c) 230°C

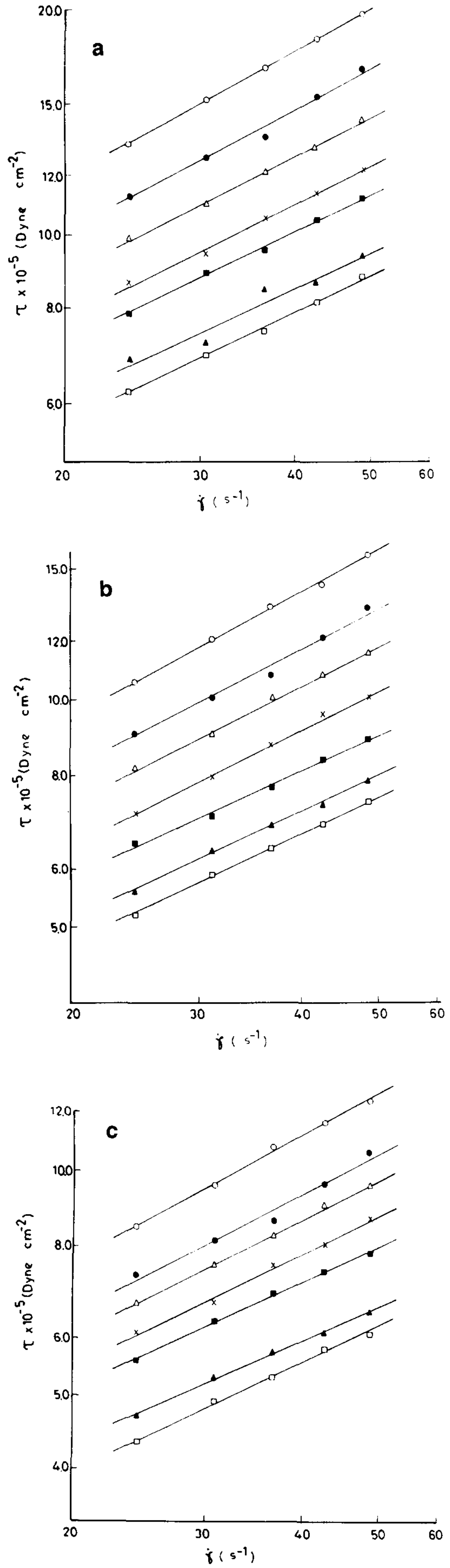

Figure 2 Log–log plot of shear stress vs. shear rate for PC/ABS blends of compositions 100/0 (○), 90/10 (●), 70/30 (△), 50/50 (×), 30/70 (■), 10/90 (▲) and 0/100 (□) at (a) 210°C, (b) 220°C and (c) 230°C

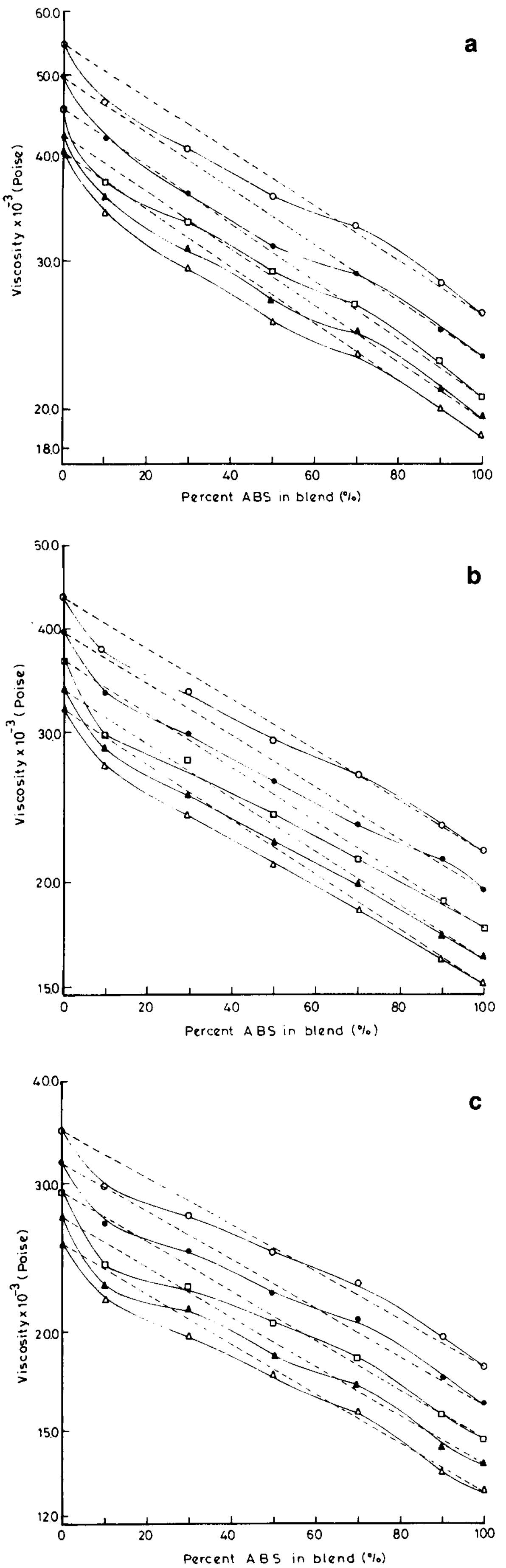

Figure 3 Log viscosity vs. composition plot for PC/ABS blends at shear rates $24\,s^{-1}$ (○), $30\,s^{-1}$ (●), $36\,s^{-1}$ (□), $42\,s^{-1}$ (▲) and $48\,s^{-1}$ (△) studied at (a) 201°C, (b) 220°C and (c) 230°C

Table 1 Activation energy of flow at constant shear rates of 24 to $48\,s^{-1}$ for different compositions of PC/ABS blends as estimated from the Arrhenius equation

ABS in blend (%)	Activation energy of flow (kcal mol^{-1}) at constant shear rate (s^{-1})					
	24	30	36	42	48	Lowest exp. shear rate
0	11.37	11.36	11.10	11.24	11.66	11.05
10	11.07	11.33	11.08	11.05	11.34	10.01
30	9.91	9.51	9.90	9.53	10.05	9.39
50	8.85	8.76	8.50	9.01	9.73	8.62
70	8.61	8.69	8.32	8.51	9.10	6.88
90	9.03	8.70	9.67	8.62	9.15	6.72
100	9.00	8.64	8.37	8.38	9.14	8.96

30% ABS the decrease is about 15%. The lowest value is for the composition containing 70% ABS. This behaviour of activation energy of flow suggests that the compositions containing 70% or more than 70% ABS are more sensitive to temperature effects compared to other compositions.

This behaviour of activation energy of flow can be explained on the basis of miscibility of components in the blend. The ABS-rich compositions have better interphase miscibility and thus are more sensitive to temperature. This is also evident from plots of log viscosity vs. composition in *Figures 3a, 3b* and *3c*, where ABS-rich compositions show nearly additive behaviour or slightly positive deviation from additivity.

CONCLUSIONS

The data obtained from the torque rheometer for different compositions of polycarbonate and poly(acrylonitrile–butadiene–styrene) blends could be interpreted in terms of shear rate, shear stress and apparent viscosity. The viscosity of blends depends on the ratio of PC and ABS in the blend and decreases with increase in ABS content in the blend. Thus the addition of ABS to polycarbonate improves the processability of PC. Viscosity reduces on increasing the shear rate, indicating shear-thinning behaviour of blends.

The viscosity of blends decreases on increasing the temperature. The temperature dependence of viscosity of all blend compositions has been compared in terms of activation energy of flow, and the ABS-rich compositions are found to be more sensitive to temperature compared to PC-rich compositions.

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