Capillary Flow Behavior of Polycarbonate (PC)/Acrylonitrile–Butadiene–Styrene (ABS) Blends

Mosab Kaseem[1,*] and Kotiba Hamad[2]

[1]*Plasticity Control and Mechanical Modeling Laboratory, School of Materials Science and Engineering, Yeungnam University, Gyeongsan 38541, South Korea*

[2]*School of Advanced Materials Science and Engineering, Sungkyunkwan University, Suwon 440-746, South Korea*

Abstract: In this work, the flow behavior of polycarbonate / acrylonitrile-butadiene-styrene (PC/ABS) was investigated. The present blends with different ratios of PC and ABS were prepared by means of internal bath mixer. From the results of capillary rheometer, apparent shear rate, apparent shear stress, apparent viscosity, power law index, and flow activation energy at a constant shear rate and shear stress were determined. The results showed that the blends are pseudo plastic in behavior, and PC behaves in a relatively Newtonian manner but ABS exhibited significant shear thinning. In addition, the flow activation energy of the blends decreases with increasing shear rate while it increases with increasing shear stress.

Keywords: Polycarbonate, acrylonitrile -butadiene -styrene, capillary rheometer, rheology.

1. INTRODUCTION

Polycarbonate / acrylonitrile-butadiene-styrene (PC/ ABS) blends are high impact resistant materials with good ductility, durability and high dimensional stability [1-2]. PC can contribute towards improvements in strength, dimensional stability, and impact resistance of the blends. In addition, ABS provides processing advantages, chemical resistance besides cost reduction with respect to PC [3]. The PC/ABS blends are widely used in the automotive industry and also for making computer and equipment housings. The investigation of flow behavior of PC/ABS blend is an important characteristic for the processing properties of polymers and polymer blend melts under technological conditions so, extensive works have been carried out to investigate the flow behavior of PC/ABS blends. For example, Khan *et al*. [4] performed rheological study of various PC/ABS blends demonstrating improvement of PC processability by addition of ABS. Hausnerova *et al*. [5] used a rotational rheometer with parallel plate's geometry to determine viscoelastic properties of PC/ABS blend. They reported that the viscoelastic properties of the blend prepared using a counter twin rotating twin screw extruder differed from those obtained with a single screw extruder as well as co rotation twin screw blending. Unfortunately, a lack of studies used the capillary rheometer for determining the melt rheology of this kind of materials where the on-line measurements during the extrusion process were used. Generally, on-line measurement needs a large amount of the sample to be tested whereas the capillary rheometer is simpler and less cost as compared with other testing methods. In this study, an internal mixer was used to fabricate the PC/ABS blends and, then, the flow behavior of the prepared blends was investigated using a capillary rheometer.

2. EXPERIMENTAL

2.1. Materials

PC with molecular weight of 245000g/mol was obtained from GB Plastics, ABS (Kumho ABS 750SW) was supplied by Korea Kumho Petrochemical Co., Ltd. (Korea) [MFR = 50g/10min (200°C = 21.6Kg), density = 1.04g/cm^3].

2.2. Blends Preparation

PC/ABS blends were prepared using an internal mixer (co-rotating twin-screw brabender plastograph-Germany) at 220°C and screw speed of 30 rpm for 20min in various compositional ratios of PC as shown in Table **1**.

2.3. Rheology

Rheological properties of the composites were studied using a capillary rheometer (Davenport 3/80), it consists of a barrel into which material was loaded before begin pushed by a plunger through a capillary, the load in the plunger provide the total pressure drop in the barrel and capillary and the volume flow rate. The rheological experiments were carried out at 220,

*Address correspondence to this author at the Plasticity Control and Mechanical Modeling Laboratory, School of Materials Science and Engineering, Yeungnam University, Gyeongsan 38541, South Korea; Tel: +8201025998205; E-mail: mosabkaseem@gmail.com

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Table 1: The Composition of the Prepared Blends

Blends	0/100	10/90	20/80	30/70	40/50	50/50	60/40	70/30	80/20	90/10	100/0
PC	0	10	20	30	40	50	60	70	80	90	100
ABS	100	90	80	70	60	50	40	30	20	10	0

226, 232, 238 and 244°C and by using *L/R* =15, no end corrections were applied. The apparent viscosity (η_a) was given by;

$$\eta_a = \frac{\tau_a}{\gamma_a} = \frac{\pi r^4 \Delta P}{8LQ} \quad (1)$$

where γ_a and τ_a are the apparent shear rate and the apparent shear stress, respectively. *r* is the capillary radius, ΔP is the pressure at the capillary entrance, *L* is the capillary length, *Q* is the volumetric flow rate.

The values of flow activation energy at a constant shear rate (E_γ) and shear stress (E_τ) were determined by using Arrhenius form equation:

$$\eta_a = Ae^{\frac{E_{\gamma,\tau}}{RT}} \quad (2)$$

where η is the viscosity for Newtonian melt flow of polymers (Pa s), *A* is the consistency related to structure and formulation, *R* is the gas constant (8.314J/mol K).

3. RESULTS AND DISCUSSION

3.1. Flow Curves

Figure **1** shows flow curves presenting the relationship between apparent shear stress and apparent shear rate, for PC/ABS (50/50) at 220, 226, 232, 238, and 244°C. The flow curves are very important in the evaluation of the processing behavior of materials. It could be noted from Figure **1** that the linearity of these curves is good and they obey a power law at a certain range of shear rate as following:

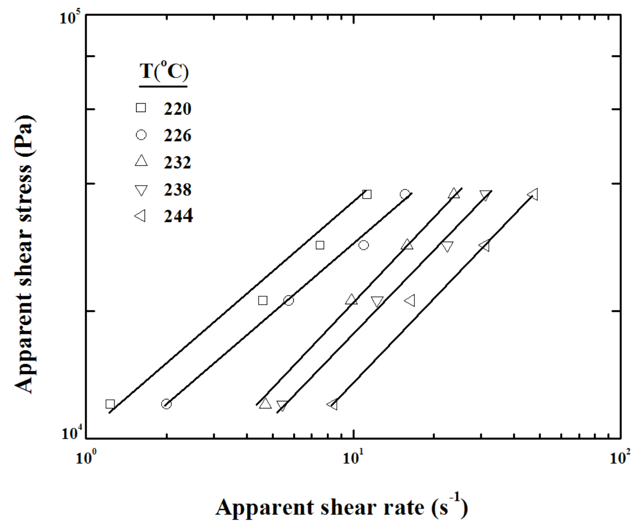


Figure 1: Flow curves of the PC/ABS (50/50) blend at different temperatures of 220, 226, 232, 238, and 244°C.

$$\tau = K.\gamma^n \quad (3)$$

The power law index (*n*) were determined from the slope of these lines, and the values of *n* are listed in Table **2**, the values of *n* were all less than 1, implying that PC, ABS and their blends are pseudo plastic materials [6-14]. The value of *n* describes the deviation from the Newtonian fluids about flow behavior, so it is also called the flow behavior index. A higher value of *n* reveals less influence of shear rate on flow behavior, so it could be said that, PC behaved in a relatively Newtonian manner because (*n*=0.82) and ABS exhibited significant shear thinning (*n*=0.59) [4]. The *n* value would reflect the shear rate sensitivity of viscosity in the range of shear rates. Thus, the low *n* value indicated the strong shear rate sensitivity of viscosity. The blends containing 10 and 20wt. % ABS, exhibited high values of *n* (0.77), indicating that the melt

Table 2: *n*-Values of PC/ABS Blends

	PC/ABS	0/100	10/90	20/80	30/70	40/60	50/50	60/40	70/30	80/20	90/10	100/0
n	220ºC	0.59	0.71	0.75	0.73	0.72	0.68	0.51	0.65	0.77	0.77	0.82
	226ºC	0.65	0.61	0.76	0.70	0.63	0.61	0.72	0.75	0.59	0.76	0.81
	232ºC	0.62	0.70	0.74	0.61	0.71	0.70	0.67	0.84	0.73	0.59	0.86
	238ºC	0.60	0.71	0.69	0.61	0.76	0.63	0.67	0.77	0.59	0.76	0.76
	244ºC	0.54	0.73	0.62	0.69	0.75	0.64	0.73	0.70	0.73	0.75	0.76

viscosities of those blends were stable over a wider range of shear rates at a given temperature.

3.2. Viscosity Curves

Figure **2** shows the relationship between apparent viscosity and apparent shear rate for the PC/ABS (50/50) blends at 220, 226, 232, 238, and 244°C. It could be noted from Figure **2**, that the viscosity of the composite samples decreased with increasing shear rate showing a typical shear thinning behavior over the range of the investigated shear rate. This behavior was attributed to the alignment or arrangement of chain segments of composite components in the direction of applied shear stress [6-9]. Figure **3** shows the effect of PC content on the viscosity of PC/ABS blends at constant shear rates and shear stresses.

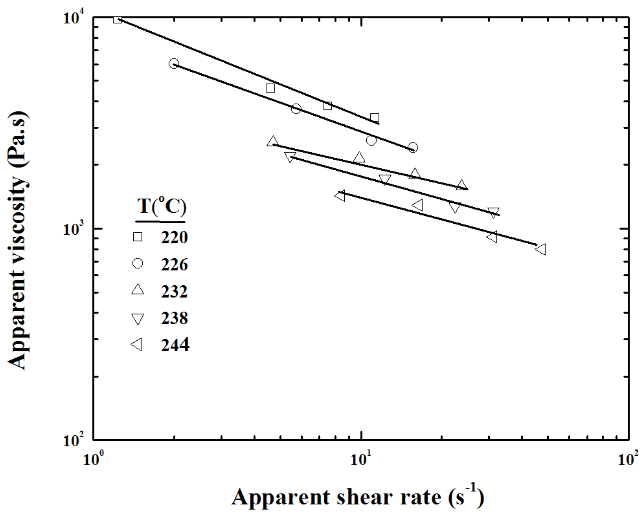


Figure 2: Viscosity curves of the PC/ABS (50/50) blend at different temperatures of 220, 226, 232, 238, and 244°C.

It could be noted from Figure **3**, that the addition of a relatively small amount of one homopolymer to the other homopolymer, for example (10% PC to 90% ABS) or (10%ABS to 90% PC), leads to a large drop in viscosity, in comparison with pure homopolymer (PC or ABS). This phenomenon could be attributed to a lubricating role of the small quantity homopolymer in the blend [15]. It can be concluded that the small amount component in blend seems to play the role of an additive material. In addition, the viscosity of the blend (50/50) was almost lower than that of the other compositions; this phenomenon could be attributed to the incompatibility between the blend components (PC and ABS) which cause negative deviation from the line of the mixing rule [10, 16].

3.3. Flow Activation Energy

Figure **4** shows the relationship between the viscosity of the composites and temperature at several shear rates (1, 5, 10, and 20s^{-1}) and several shear stresses (10, 20, 40, and 80kPa). It could be noted from Figure **4** that the viscosity of the composites decreased with increasing temperature at different shear stresses. The motion abilities of various chains in the composites tended to be enhanced with increasing temperature and the resistance between the melt layers decreased leading to reduction of the melt viscosity. It is observed that the linearity for all plots in Figure **4**, was good, which indicated that the relationship between viscosity and *1/T* obeyed by Arrhenius equation form (Eq. 4), so the flow activation energy at a constant shear rate (E_γ) and shear stress (E_τ) could be determined from the slope of these lines.

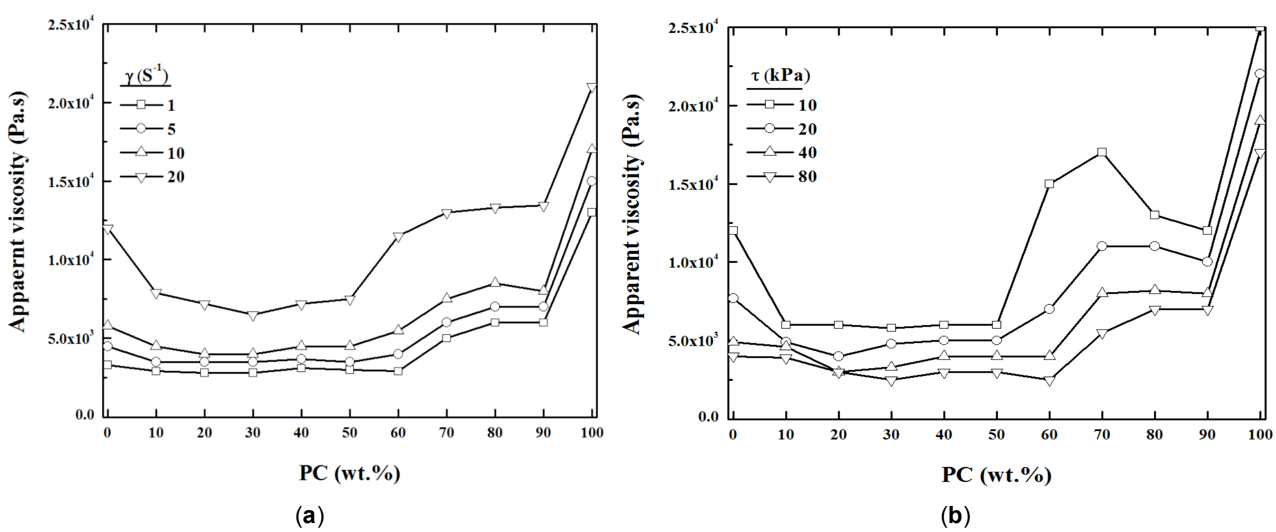
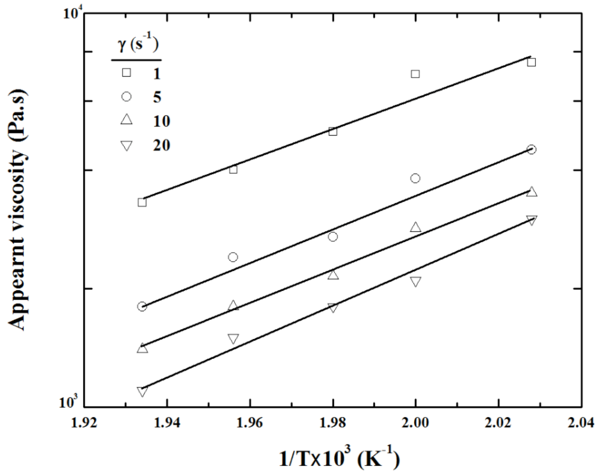
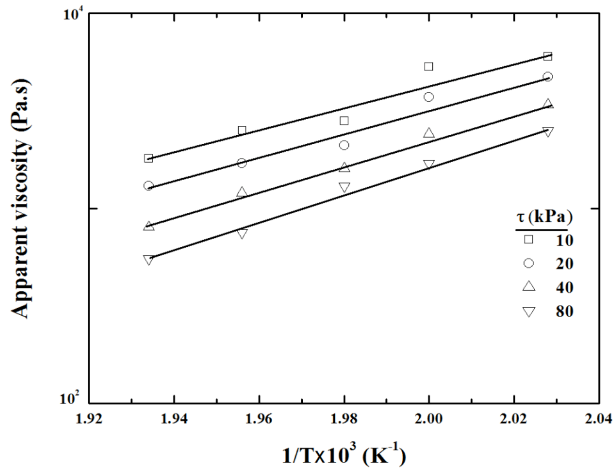


Figure 3: Viscosity versus blending ratio at, (**a**) constant shear rates and (**b**) constant shear stresses.



(a)



(b)

Figure 4: Viscosity versus *1/T* of PC/ABS (50/50) at (**a**) constant shear rates and (**b**) constant shear stresses.

$$E_{\gamma,\tau} = R\left(\frac{\ln\eta}{1/T}\right)_{\gamma,\tau} \qquad (4)$$

It could be noted from Tables **3** and **4** that the E_γ decreased with increasing shear rate while E_τ increased with increasing shear stress. The flow activation energy represented the effect of the temperature on the flow behavior of material. Also, it can be seen from Tables **2** and **3** that the PC/ABS (9/10) blend had the highest activation energy at shear rate of $20s^{-1}$ as compared to the other compositions at the same shear rate ($20s^{-1}$). In general, the high activation energy of polymer materials is required in injection molding applications, where low viscosities of the processed materials can be achieved by a slight change in the processing temperature. Accordingly, PC/ABS (90/10) blend with higher value of activation energy as compared to the other blends, can be suitable to be used in injection molding applications, where the low viscosity achieved at low processing temperature enables low injection pressure, high injection speed and less time of the injection cycle [17]. On the other, it can be noted that the viscosity of the PC/ABS (50/50) blend which has the smallest value of both (E_τ) and (E_γ) will be stable over a wider range of temperature, at a given shear rate and shear stress. This blend will be the easiest to process among the other blends and homopolymers (PC, ABS).

Table 3: Flow Activation Energy of PC/ABS Composites at Constant Shear Rates E_γ (KJ/mol)

	PC/ABS	0/100	10/90	20/80	30/70	40/60	50/50	60/40	70/30	80/20	90/10	100/0
E_γ (KJ/mol)	$\gamma = 1s^{-1}$	63	92	65	70	106	78	147	144	127	153	127
	$\gamma = 5s^{-1}$	61	75	63	67	92	76	112	131	124	145	125
	$\gamma = 10s^{-1}$	60	64	62	67	91	75	103	121	122	143	124
	$\gamma = 20s^{-1}$	59	60	61	66	88	74	101	117	121	140	124

Table 4: Flow Activation Energy of PC/ABS Composites at Constant Shear Stress E_τ (KJ/mol)

	PC/ABS	0/100	10/90	20/80	30/70	40/60	50/50	60/40	70/30	80/20	90/10	100/0
E_τ (KJ/mol)	τ = 10 kPa	104	98	69	108	141	112	169	193	163	187	151
	τ = 20 kPa	117	101	101	110	149	119	180	195	167	191	165
	τ = 40 kPa	129	104	118	122	151	128	185	198	176	196	181
	τ = 80 kPa	134	108	132	130	152	138	194	205	186	200	204

CONCLUSIONS

The rheological properties of PC/ABS blends were investigated using a capillary rheometer, the blends were prepared by means of internal bath mixer. All PC/ABS blends showed a decrease in shear viscosity with increasing shear rate indicating shear-thinning behavior. In addition, the plots of viscosity versus blending ratio go through a minimum at blending ratio PC/ABS of (50/50). The flow activation energy of the blend decreased with increasing shear rate while it increases with increasing shear stress. In addition, some blends were suitable to be used in injection molding applications.

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