

## Effects of Molecular Weight of PC on Mechanical Properties of PC/ABS Blends using High-Shear Rate Processing

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**Abstract** – Each of the two polycarbonates (PC) of different molecular weights was blended with acrylonitrile-butadiene-styrene (ABS) under high-shear rate processing to afford PC/ABS. Sizes of ABS dispersed phases and mechanical properties of PC/ABS blends were investigated and high-shear rate processing of PC/ABS was carried out by changing screw speed and processing time. Prepared specimens were examined by scanning electron microscope (SEM) to observe morphology changes. Sizes of ABS dispersed phases in PC/ABS blends were observed to decrease gradually as screw speeds increased. Tensile strengths and elongations of specimens were investigated by universal testing method (UTM) to study the influence of molecular weight of PC exerting on PC/ABS blends. As a result, PC1/ABS blends (PC1: higher molecular weight PC) exhibited more strengthened properties than PC2/ABS (PC2: lower molecular weight PC). The tensile strength of PC1/ABS showed an increasing tendency when the screw speed increased, and the elongation did not show a significant decrease, but increased slightly with increasing shear time at a constant screw speed of 1000 rpm.

Key words: High-shear rate processing, Molecular weight of PC, PC/ABS, Mechanical properties, Tensile strength, Elongation

### 1. Introduction

Various methods to prepare polymer blends for better compatibility have been reported; in most cases, mainly to avoid phase separation caused by poor compatibility [1-3]. High-shear rate processing extruders are mainly used for better compatibility. Fig. 1 shows schematically the extruder and its primary functions. One of the extruder functions is plasticization during which materials are mixed and melted (part A of Fig. 1). The other function is the high-shear rate processing by which material blends are efficiently mixed with varied screw speeds and extruding times to manufacture the desired extrudate in Figure 1. In the high-shear rate processing, resins residing in the holes at the center of rotating screws can be maintained and processed until to the desired processing times at appropriated shear-rates. For an instance, PC and PMMA, both transparent, become opaque when mixed due to poor compatibility each other. This can be much improved by high-shear rate processing by which much smaller homogeneous structures can be manufactured, thereby producing blending a mixture much more transparent than PC itself [4-6]. We reported earlier that high-shear rate processing could be applied to incompatible materials, typically such as polycarbonate (PC) and acrylonitrile-butadiene-styrene (ABS) to improve their

compatibility [7-11]. In those studies we found that the dispersed phases became much smaller and that compatibility was much improved. However, mechanical properties of blends could not be improved due to high-shear rate induced degradations [7-9]. Herein, each of the two PCs, different in molecular weight, was used to make PC/ABS blends under high-shear rate processing. In particular, PC/ABS blends made from polycarbonate of higher molecular weight were processed at high-shear rates to observe any change in surface morphology and mechanical properties resulting from much improved compatibility.

### 2. Experimental

#### 2-1. Materials

Two polycarbonates, higher molecular weight (PC1, MW 13,700) and lower molecular weight (PC2, MW 9,700), were obtained from Samyang (Korea) and LG Chem. Co. Ltd (Korea), respectively. Acrylonitrile-butadiene-styrene (ABS) resin containing 15% of polybutadiene was used. Bis(2,4-dicumylphenyl) pentaerythritol diphosphite (Dow Chem. Corp.) was used as an antioxidant. All the materials used in this work are listed in Table 1.

#### 2-2. Preparation of blends and specimens

All the resins were dried at 100 °C for 15 h just before experiments. Dried PC (70%) and ABS (30%) were compounded by twin screw extruder (Toshiba Machine Co. TEM26SS (26φ, 40.4L/D))[7]. Each specimen of PC/ABS was prepared by high-shear processing

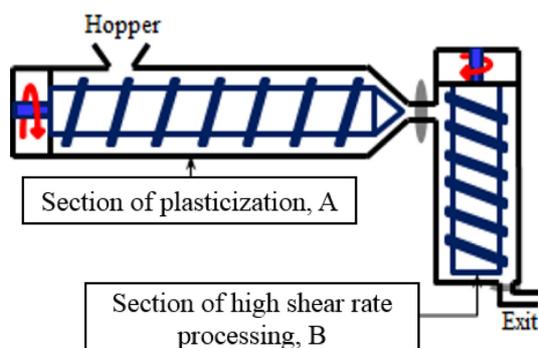
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**Table 1. List of Materials**

Materials	Abbreviation	Note
Polycarbonate	PC1	Molecular Weight ( $M_n$ ): 13,700 g/mol
	PC2	Molecular Weight ( $M_n$ ): 9,700 g/mol
Acrylonitrile-butadiene-styrene	ABS	Portion of Polybutadiene = 15%
Bis(2,4-dicumylphenyl) pentaerythritol diphosphite	-	Antioxidant

**Fig. 1. Schematic main functions of high-shear rate processing extruder.**

extruder (NHSS2-28, Niigata Machine Techno. Co. Ltd) whose brief schematic diagram is shown in Fig. 1. Two processing parameters were considered at a fixed temperature of 220 °C, i.e., by changing screw speeds (1000, 2000 and 3000 rpm) as shown in part B of Fig. 1 and processing times (10, 20, 30 and 40 sec) [12].

### 2-3. Morphology analysis

Scanning electron microscopy (SEM, JSM-7000F) was used to observe and measure the surface of blends. Samples were fractured after cooling under liquid nitrogen and were etched with aqueous chromic acid solution (H<sub>2</sub>O 30 mL, H<sub>2</sub>SO<sub>4</sub> 120 mL, and Cr<sub>2</sub>O<sub>3</sub> 5 g) for 5 min at 80 °C [8].

### 2-4. Measurements of mechanical properties

Universal testing method (UTM, Instron 4467) was used to measure the mechanical properties of PC/ABS blends after processing under high-shear rate conditions.

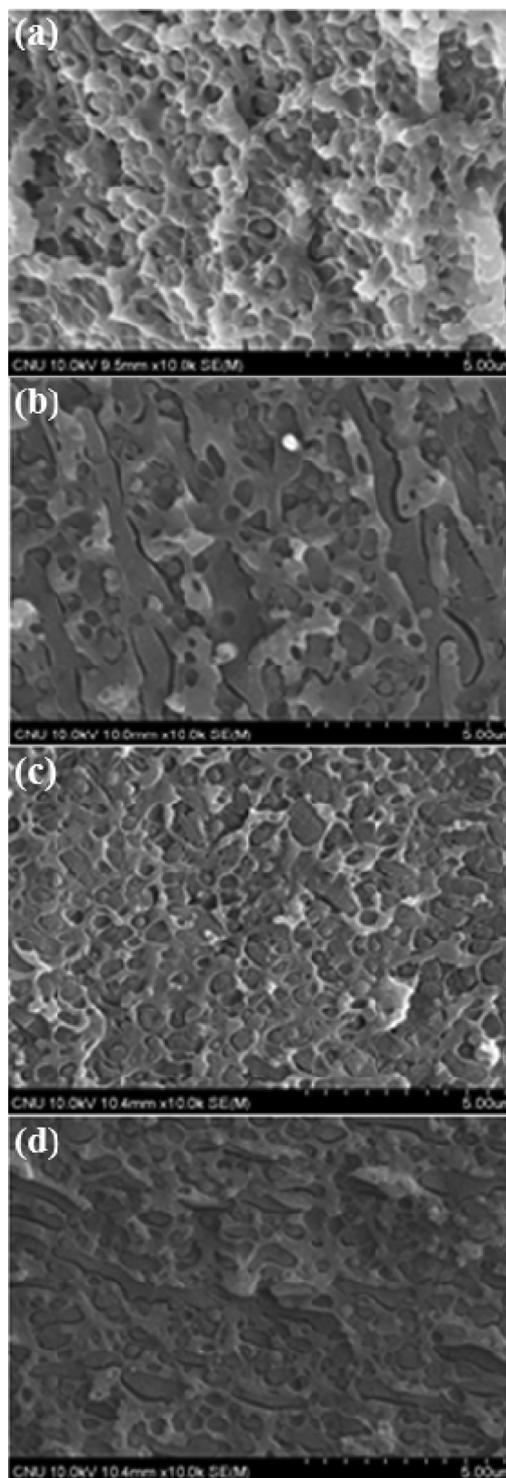
Each specimen for mechanical testing was prepared according to press molding process described in the JIS K6251-8 method at 200 °C, i.e., preheated for 10 min, pressed for 5 min under 3000 psi, and followed by rapid cooling.

## 3. Results and Discussion

### 3-1. Effect of screw speed on morphology of blends

Influences of PC matrices exerting on domain sizes of ABS were studied by SEM images of PC/ABS blends obtained by high-shear rate processing as shown in Figs 2 and 4.

SEM images of morphological characteristics of PC1/ABS blends influenced by screw speeds are shown in Fig. 2. Dispersed phase sizes of PC1/ABS became smaller as screw speeds increased. Similar trends were also observed for PC2/ABS, as was reported previ-

**Fig. 2. SEM images (X1000) of PC1/ABS blends depending on screw speed for a fixed processing time (20 sec); (a) 'compounded', (b) 1000 rpm, (c) 2000 rpm, (d) 3000 rpm.**

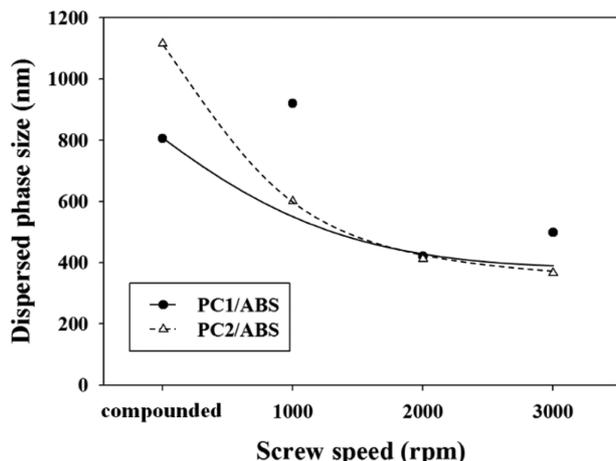


Fig. 3. Correlation of average size of dispersed phase in PC/ABS blends with screw speed for a fixed processing time (20 sec).

ously [9]. Here, 'compounded' stands for the specimen prior to high-shear rate processing. The average dispersed phase sizes of PC/ABS blends were measured from SEM images (Fig. 2) by using Image J software and are shown in Fig. 3 as a function of screw speed for a fixed processing time. In Fig. 3, average dispersed phase sizes of PC1/ABS (present work) are compared with those of PC2/ABS reported in this laboratory [9]. For PC1/ABS (Fig. 3), the dispersed size of 'compounded', specimen prior to high-shear rate processing, was about 810 nm initially; however, decreasing to 420 nm at 2000 rpm and then to 498 nm at 3000 rpm.

For PC2/ABS, size of 'compounded' specimen was about 1115 nm, gradually decreasing to 600 nm at 1000 rpm, 412 nm at 2000 rpm, and 380 nm at 3000 rpm.

The results from Fig. 3 obviously indicate that the drop size of dispersed phases of ABS became smaller as screw speed increased. Noteworthy was that under high-shear rate processing the drop size of dispersed phases in PC2/ABS decreased more steeply than those in PC1/ABS. Under increasing high-shear rate processing, this phenomenon was similar to the thermal behavior observed in the magnitudes of  $T_g$ s ( $T_g$  stands for glass transition temperature)[8].

### 3-2. Effect of processing times on morphology

The morphological changes were dependent upon the varied processing time at a fixed screw speed (1000 rpm) of NHSS2-28. Fig. 4 displays SEM images of PC1/ABS, providing an information that the sizes of dispersed phases of ABS were decreased upon increasing the processing time. Similar results were also observed when high-shear rates were increased for a fixed shear time.

The average size of dispersed phases of ABS versus processing times is displayed in Fig. 5 wherein the data of PC2/ABS were from our previous study [9]. The average size of dispersed phases of 'compounded', specimen (PC1/ABS) without shear force, was 810 nm. Then the size became smaller to be 685 nm, 408 nm and 398 nm at 10, 30, and 40 sec of the processing time, respectively. Similar behavior was observed in PC2/ABS, i.e., the average dis-

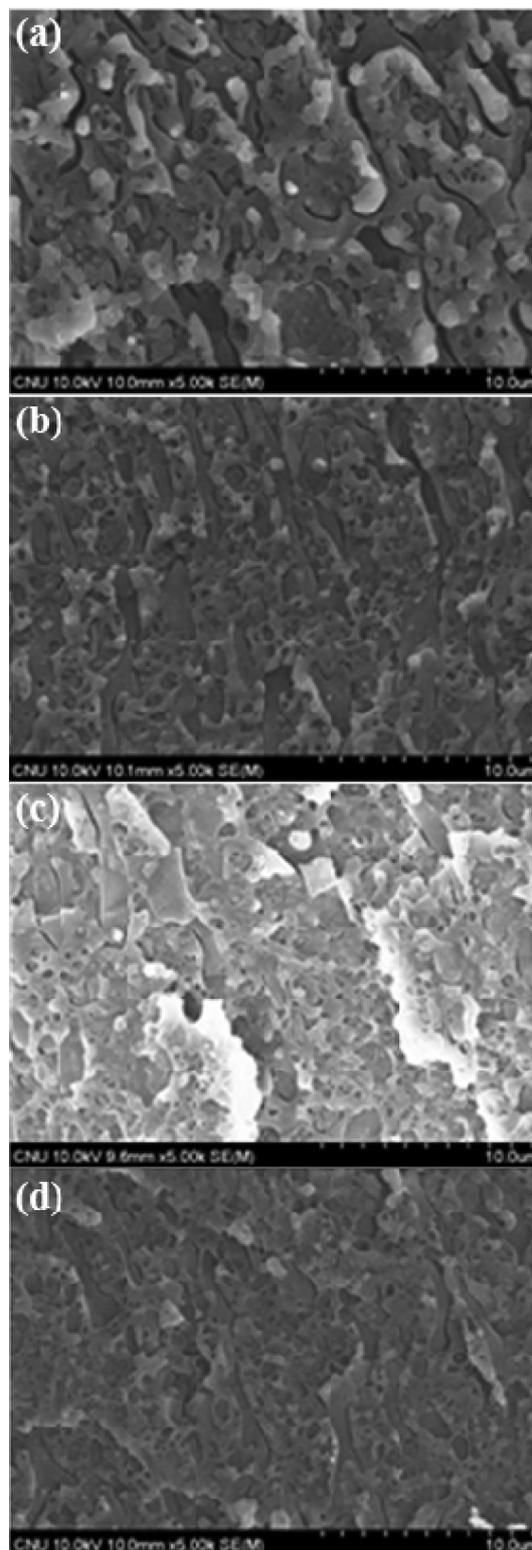


Fig. 4. SEM images (X5000) of PC1/ABS blends depending on processing time at a fixed screw speed (1000 rpm); (a) 10 sec, (b) 20 sec, (c) 30 sec, (d) 40 sec.

persed sizes of phases for ABS were 1100 nm, 601 nm, 512 nm, and 498 nm at 10, 20, 30, and 40 sec, respectively. Therefore, we could observe that the size of dispersed phases of ABS in PC2 blends decreased gradually from 1115 nm of 'compounded' as processing

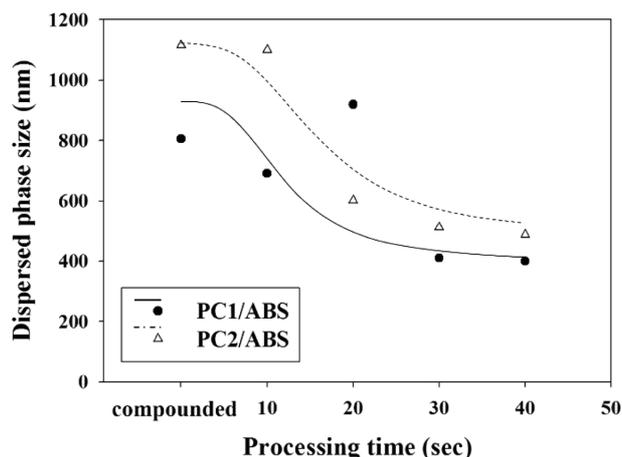


Fig. 5. Correlation of average size of dispersed phase in PC/ABS blends with processing time at a fixed screw speed (1000 rpm).

time increased. Noteworthy in Fig. 5 is that the effect of shear time was negligible for PC2 or small for PC1 until 10 sec, and the drop sizes of PC2/ABS were larger than those of PC1/ABS as the processing time increased at a fixed speed rate.

### 3-3. Effect of screw speeds on mechanical properties

Tensile strength and elongation were determined by UTM in order to investigate the changes in mechanical properties of PC/ABS blends under high-shear rate processing. Fig. 6 shows behaviors of both tensile strength and elongation as a function of screw speed under high-shear processing. For PC1/ABS tensile strength of 'compounded' was about 52 MPa, increasing to about 64 MPa at 1000 rpm. However, it decreased to 59 MPa as screw speed increased to 3000 rpm. For PC2/ABS tensile strength of 'compounded' was about 50 MPa, followed by increasing to 56 MPa and decreasing to 50 MPa at 1000 rpm and 3000 rpm respectively. Elongation of PC1/ABS increased to 190% at 1000 rpm; however, it decreased to 105% and 90% as screw speed increased. On the other hand, elongation of PC2/ABS decreased to 108% at 1000 rpm and then decreased to 46% and 22%

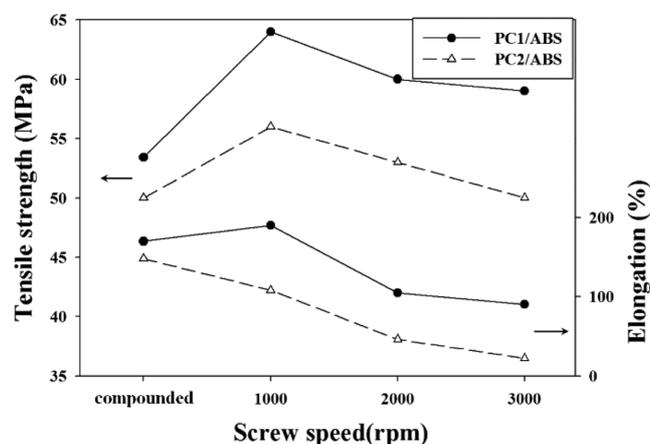


Fig. 6. Correlation of tensile strength and elongation with screw speed for a fixed processing time (20 sec) for PC1/ABS and PC2/ABS blends.

at 2000 and 3000 rpm, respectively. Based on these results (Fig. 6) elongation of PC1/ABS at 3000 rpm was more than four-times superior to that of PC2/ABS. Overall, tensile strength and elongation of PC1/ABS were greater than those of PC2/ABS. At low-shear rate of 1000 rpm both tensile strength and elongation increased to a certain degree. However, when the screw rates were higher, i.e., at 2000 and 3000 rpm, tensile strength and elongation of PC2/ABS decreased rapidly [8]. However, those of PC1/ABS either remained unchanged or decreased relatively a little.

Overall, the physical properties were greatly dependent on PC of different molecular weight, i.e., PC1/ABS showed larger elongation than that of PC2/ABS by four-times. Also, both tensile strength and elongation decreased obviously by degradation, well corroborating our previous results [8], when screw speed was higher than 2000 rpm for processing time of 20s.

### 3-4. Dependence of mechanical properties on the processing times

Tensile strength and elongation of PC/ABS blends as a function of processing time at a fixed screw speed (1000 rpm) are graphed in Fig. 7. Tensile strengths of PC1/ABS under shear force were greater than 62 MPa, while those of PC2/ABS were in the range of 56–58 MPa. Elongation of PC1/ABS for 10 sec of shear time showed the highest value of about 225%, then decreased to 190% for 20 sec and 151% for 30 sec, and increased to about 170% for 40 sec.

Similar trend was also observed for PC2/ABS, i.e., 141% (10 sec), 108% (20 sec), 109% (30 sec), and 139% (40 sec). The results (Fig. 7) appear to indicate that the enhanced improvement of mechanical properties was due to high-shear force at 1000 rpm during which negligible damage to blends was made by thermal degradation, unlike

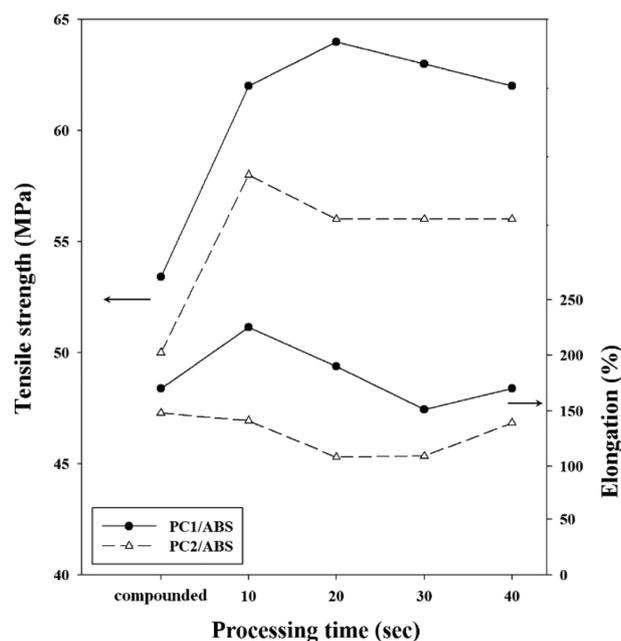


Fig. 7. Correlation of tensile strength and elongation with processing time at a fixed screw speed (1000 rpm) for PC1/ABS and PC2/ABS blends.

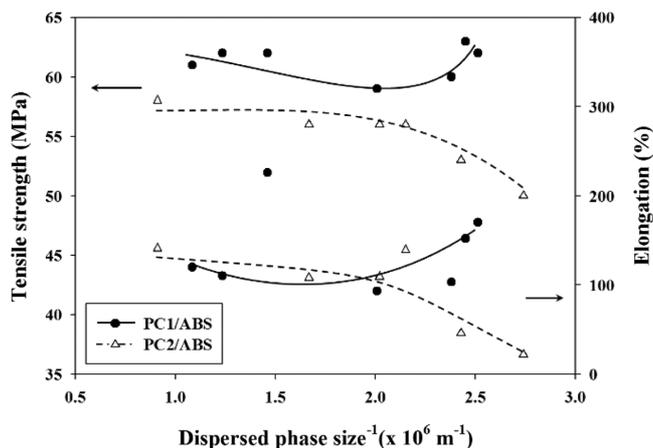


Fig. 8. Correlation of tensile strength and elongation with reciprocal of dispersed phase size for PC1/ABS and PC2/ABS blends.

the results in Fig. 6. Thus, the results in Fig. 7 show that elongation did not decrease significantly and tensile strength was almost maintained when the processing time was increased to 40s. For high molecular weight PC (PC1), the maximum increase in physical properties was observed for processing time of 20s.

### 3-5. Dependence of mechanical properties on dispersed phase size

Fig. 8 shows mechanical properties depending on drop size of dispersed phases under high-shear rate processing. Here, mechanical properties are graphed as a function of reciprocal of size of dispersed phase, following the general theory that the mechanical properties would be proportional to the reciprocal of the size. The results of Fig. 3 and 5 show that the drop size of dispersed phases of ABS decreased as screw speed increased (Fig. 3) and as processing time was prolonged (Fig. 5). Noteworthy in Fig. 8 is that mechanical properties of PC1/ABS increased again when the size of dispersed phases reached to about 520 nm, while those of PC2/ABS decreased steeply as the dispersed phases became smaller. It was imagined for PC2/ABS that increase in high-shear force could make the drop size smaller accompanied by shear-induced degradation at the same time, which makes mechanical properties worse. Therefore, use of PC1 in blending with ABS under high-shear processing could not only enhance compatibilities, but also make size smaller to greatly improve mechanical properties, reducing the degradations caused by high-shear force. Similar trends were also observed in the previous study on thermal properties of PC/ABS [7-9].

## 4. Conclusions

Two kinds of polycarbonates were blended with ABS for PC/ABS blends: PC1 ( $M_n=13,700$ ) and PC2 ( $M_n=9,700$ ). Dispersed phase sizes of ABS in PC1/ABS became smaller to 398 nm from 810 nm as screw speed and shear time increased, while those in PC2/ABS decreased to 380 nm from 1115 nm based on SEM images. The best mechanical properties of PC1/ABS, 64 MPa of tensile strength and

190% of elongation, were observed at 1000 rpm for 20 sec, while those of PC2/ABS, 56 MPa of tensile strength and 108% of elongation, were observed at 1000 rpm for 10 sec. However, when screw speed and shear time increased to a great extent, both tensile strength and elongation were reduced, mainly due to shear-induced degradation. Therefore, we could confirm that it would be most important to find the optimum conditions of high-shear processing to avoid possible thermal degradation.

In a graph of the mechanical properties versus reciprocal of drop size of dispersed phases, PC2/ABS showed steeper decline. However, mechanical properties PC1/ABS were improved. The results clearly indicated that high-shear processing could improve the mechanical properties of PC/ABS blends.

It was also imagined that reduction in size of dispersed phases, lowering of  $T_g$ s, one step thermal degradation curve, and improvement of mechanical properties could be well corroborated with compatibilities of PC and ABS. Overall, the choice of PC having optimum molecular weight and control of high-shear processing condition to avoid possible degradation would be most important factors to improve mechanical properties of PC/ABS blends.

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