

Toughening Modification of PBT/PC Blends with PTW and POE

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Received 27 April 2004; accepted 15 March 2005

DOI 10.1002/app.22436

Published online 5 April 2006 in Wiley InterScience (www.interscience.wiley.com).

ABSTRACT: New toughened poly(butylene terephthalate) (PBT)/bisphenol A polycarbonate (PC) blends were obtained by melt blending with ethylene–butylacrylate–glycidyl methacrylate copolymer (PTW) and ethylene-1-octylene copolymer (POE) in a twin-screw extruder. The mechanical properties of PBT/PC blends were investigated. The presence of PTW or POE could improve the mechanical properties except for the tensile strength and flexural properties of the PBT/PC blends. However, a combination use of PTW and POE had a strong synergistic effect, leading to remarkable increases in the impact strength, elongation at break, and Vicat temperature and some reduction of the

tensile strength and flexural properties. The relationship between mechanical properties and morphology of the PBT/PC/PTW/POE blends was studied. The morphology was observed by scanning electron microscopy and the average diameter of dispersed phase was determined by image analysis, and the critical interparticle distance for PBT/PC was determined. © 2006 Wiley Periodicals, Inc. *J Appl Polym Sci* 101: 54–62, 2006

Key words: poly(butylene terephthalate); polycarbonate; ethylene–butylacrylate–glycidylmethacrylate copolymer; ethylene-1-octylene copolymer; modification

INTRODUCTION

Polymer alloys or blends are important engineering materials whose properties may be tailored by taking advantage of the properties of the constituent polymers. Bisphenol A polycarbonate (PC)/poly(butylene terephthalate) (PBT) blend is a typical polymer alloy.

PBT is one of the most important engineering polymers used in various applications, because of its outstanding properties including high tensile strength and flexural modulus, good dimensional stability and high resistance to hydrocarbonates. However, it has relatively low impact strength, low heat deflection temperature, low melt viscosity, and poor optical properties.

PC is a widely used engineering thermoplastic, because it has several distinct properties such as transparency, dimensional stability, flame retardant, high heat distortion temperature, and high impact strength. However, PC is known to exhibit poor solvent resistance, poor processability, and notch sensitivity.

Blending of two or more polymers is proved to be a useful way to overcome some drawbacks of a material without significantly compromising their advantages. Usually, PBT/PC blends have excellent solvent resis-

tance, good dimensional stability, and easy processability.

The structure–property relationships of PBT/PC blends have been studied.^{1–9} It was found that^{5,6} the impact toughness of PBT/PC blends was low, which limits their applications. PBT and PC are partially miscible polymers,⁸ thus, simple melt blending of PBT and PC will most probably produce a phase-separated PBT/PC mixture with low mechanical strength. Transesterification between PBT and PC during processing can create some PBT–PC copolymers. Initially, these copolymers may act as interfacial agents to improve the interfacial bounding strength, but, ultimately, transesterification will lead to an amorphous random copolymer without the desired chemical resistance or heat distortion of a phase-separated blend.¹⁰ Therefore, to improve fracture toughness, especially impact toughness, of PBT/PC blends, toughening by incorporation of modifiers is often required. Among these modifiers, methyl methacrylate–butadiene–styrene copolymer (MBS)^{11–13} as an impact modifier demonstrated a significant impact-modifying effect at low temperatures. Chacko et al.¹⁴ reported that the addition of 20 wt % MBS as an impact modifier could obtain the acceptable impact strength. William et al.¹⁵ used functional MBS to improve impact strength of PBT/PC blend.

Ethylene–glycidyl methacrylate copolymer (EGMA) has epoxy groups (glycidyl) and can react with carboxyl (preferentially) or hydroxyl functional groups.

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Because of its elastomeric nature and reactivity, EGMA was used as an impact modifier for engineering thermoplastics and thermoplastic/polyolefin blends, such as poly(ethylene terephthalate),¹⁶ PBT,¹⁷ PBT/polypropylene (PP)¹⁸, and PBT/ethylene-1-octylene copolymer (POE) blends.¹⁹

POE is a polyolefin elastomer with a narrow molecular weight distribution and homogeneous octene distribution that exhibits the advantage of thermoplastic processability; its elastomeric nature has allowed it to be used as an impact modifier for PBT²⁰ and PP.²¹

To improve the toughness of PBT/PC blends without significantly compromising the other properties, ethylene-butylacrylate-glycidyl methacrylate copolymer (PTW) and POE were used as modifiers in this study.

Nowadays, the interparticle distance (or matrix ligament thickness) (τ) is widely accepted as the parameter that controls toughness which should appear when τ is below a critical value (τ_c). It was first indicated by Wu²² on polyamide/ethylene-propylene rubber blends that the brittle-ductile transition has correlation with a critical interparticle distance. The following studies showed that this critical value was affected by the extrinsic parameters such as the test temperature and deformation rate, and the intrinsic parameters such as crystallinity, type and modulus of the rubber, the ratio between the modulus of the matrix and that of the rubbery dispersed phase (E_m/E_d).²³

However, PBT/PC/PTW/POE blends have not been studied, to our knowledge, till now. For this reason, the purpose of this study was to examine the possibility of increasing the notched impact strength of PBT/PC blends using both PTW and POE via melt extrusion. First, the best formulation for the blends was chosen. Subsequently, the blends with PTW/POE content from 0 to 14 wt % were prepared by extrusion and subsequent injection molding. The mechanical properties were measured. The relationship between mechanical properties and morphology of the PBT/PC/PTW/POE blends was explored. The morphology of the PBT/PC/PTW/POE blends was observed by scanning electron microscopy and the dispersed phase average diameter was determined by image analysis. The brittle-ductile transition of notched Izod specimens was investigated and the critical ligament size was evaluated.

EXPERIMENTAL

PBT was L2100G (Yizheng Chemical Fiber Group Corp., Jiangsu, China). PC was PC110 (Chimei-Asahi Corp., Taiwan, China). PTW was Elvaloy PTW (DuPont). POE was Engage 8180 (DuPont-Dow).

PBT and PC particulates were dried at 120°C for 4 h in a vacuum oven before processing to avoid possible moisture-degradation reactions. The blends comprised 50 phr PBT and 50 phr PC by weight.

The blends were extruded using a Berstoff twin-screw extruder (type ZE25, L/D ratio 41, screw diameter 25 mm) at a screw speed of 300 rpm and torques of 50–70%. The temperature profiles of the barrel were 40–230–230–235–235–240–240–245–250°C from the hopper to the die. The extruded rods were cooled in a water bath, palletized, and dried in an air oven for 4 h at 80°C. Injection molding was carried out in a plastic injection molding machine (HTB110X/1, China) to obtain tensile (ISO R527, thickness 4 mm), flexural (ISO 178, thickness 4 mm) and impact (ISO 180, thickness 4 mm) specimens. The barrel temperature profiles of the injection molding were 240–250–250–250–259°C, and the mold temperature was 50°C.

The tensile and flexural tests were carried out at room temperature using an Instron 4465 at speeds of 50 mm/min and 2 mm/min, respectively. The Izod impact tests were carried out on Ray-Ran testing equipment. The notches (depth 2.54 mm, mean radius 0.25 mm) were machined after injection molding. A minimum of five specimens were tested for each reported value of tensile, flexural and impact strength.

The dynamic mechanical properties of the samples were measured with a dynamic mechanical thermal analyzer (Rheometrics Scientific DMTA IV). The scans were carried out in single cantilever mode at a constant heating rate of 2 K/min and at a frequency of 1 Hz from –80°C to about 200°C.

Differential scanning calorimetry (DSC) measurements were conducted using a Perkin-Elmer DSC (Pyris 1, USA). The samples were first heated at a rate of 20 K/min from 0 to 250°C, maintained for 2 min to remove thermal history, and cooled at a rate of 10 K/min to 0°C to obtain the crystallization temperature (T_C). The cooled samples were then reheated at a rate of 20 K/min to 250°C, to obtain the melting temperature (T_m).

The surfaces of cryogenically fractured specimens were observed by scanning electron microscope (SEM, Hitachi-S-2150, Japan) after gold coating. The rubber particle diameter was measured in representative zones of the cryogenically fractured impact specimens. The number-average particle diameter (d_n) was calculated from a minimum of 200 particles as $d_n = \frac{\sum n_i d_i}{\sum n_i}$, where n_i is the number of particles with a diameter d_i .

RESULTS AND DISCUSSION

Mechanical properties

Typical stress-strain curves of PBT/PC blends were shown in Figure 1. The PBT/PC blends containing PTW and POE as tougheners have lower yield stress and higher elongation at break than that of the PBT/PC blend without modifiers. In particular, when PTW and POE were added together, the elongation at break had a significant increase.

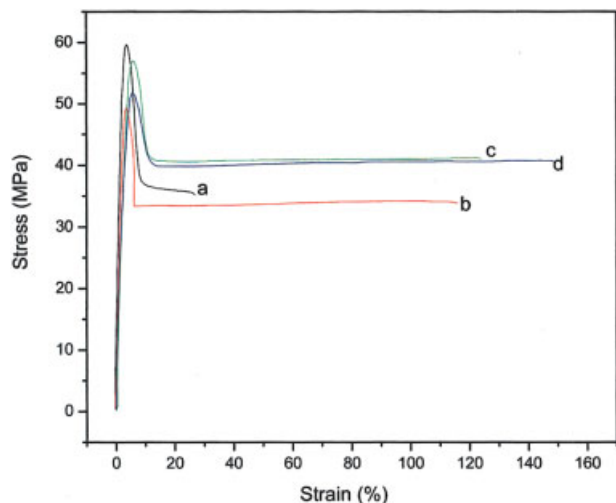


Figure 1 Typical stress–strain curves of PBT/PC 50/50 (a), PBT/PC/PTW 50/50/7 (b), PBT/PC/POE 50/50/7 (c), PBT/PC/PTW/POE 50/50/3.5/3.5 (d) blends. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

Tensile deformation of all the blends was characterized by formation of a macroshearband at the yield point, followed by propagation of a neck from one side of the macroshearband. The engineering stress dropped as the neck formed, the neck then propagated at a constant engineering stress.²⁴ The major effect of PTW or POE in the PBT/PC blends was the enhanced stability of the propagating neck. A typical PBT/PC blend was fractured at one end of a neck after the neck had propagated only a short distance. In contrast, the necks in the PBT/PC/PTW, PBT/PC/POE, and PBT/PC/PTW/POE blends propagated at constant stress from one side of the macroshear band all the way to the end of the gauge section. When the entire gauge section became necked, there was a region of uniform strain hardening at one end of the neck, as reported by Tanrattanakul.²⁵

The stress–strain behavior in Figure 1 indicates that the addition of both PTW and POE was effective to toughen the PBT/PC blend.

Figure 2 shows the flexural strength and flexural modulus as functions of POE, PTW, and PTW/POE modifier content in the blends. As can be seen, both the flexural strength and modulus decreased with increase in modifier content.

Figure 3 shows the plots of notched impact strength versus modifier content for the PBT/PC/PTW, PBT/PC/POE, and PBT/PC/PTW/POE blends. The PBT/PC blend has low impact strength of 58 J/m. The addition of modifiers resulted in an impressive jump of the Izod impact strength. All the blends presented a brittle to ductile transition with increasing modifier content. The PBT/PC/PTW/POE blend showed an earlier brittle–ductile transition leading to high toughness. For all the blends, adding 3 wt % or less modifier did not significantly affect the impact strength.

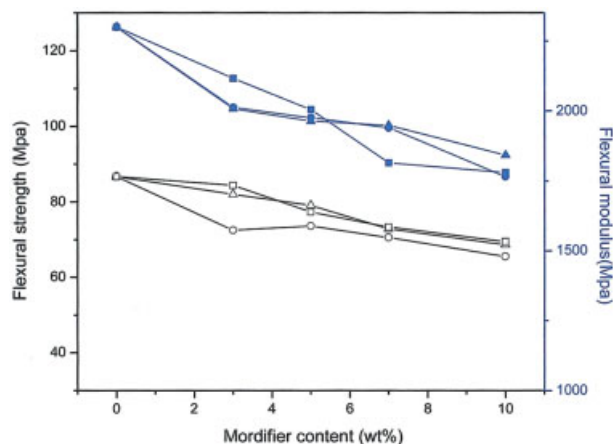


Figure 2 The flexural strength and flexural modulus as a function of POE (\square), PTW (\circ) and PTW/POE 1/1 (\triangle) modifiers content for PBT/PC 50/50 blends open symbols are for flexural strength. Filled symbols are for flexural modulus. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

Figure 4 shows the changes in notched impact strength with variation in weight ratio of the PTW and POE content at the same amount of total modifiers (7 wt %). As can be seen, a maximum Izod impact strength occurred at a PTW/POE weight ratio of 50/50 for the PBT/PC/PTW/POE blend. In the presence of 3 wt % PTW/POE, the impact strength of the blends increased from 58 to 166 J/m shown in Figure 3. The impact strength increased sharply as the PTW/POE content approached to 7 wt %. Further increasing PTW/POE content up to 10% did not affect the impact strength.

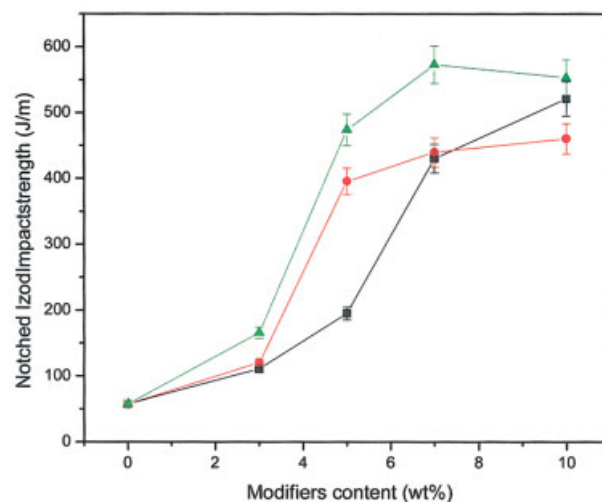


Figure 3 The plots of notched impact strength versus modifier content for the PBT/PC/POE (\blacksquare), PBT/PC/PTW (\bullet), and PBT/PC/PTW/POE (\blacktriangle) blends, respectively. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

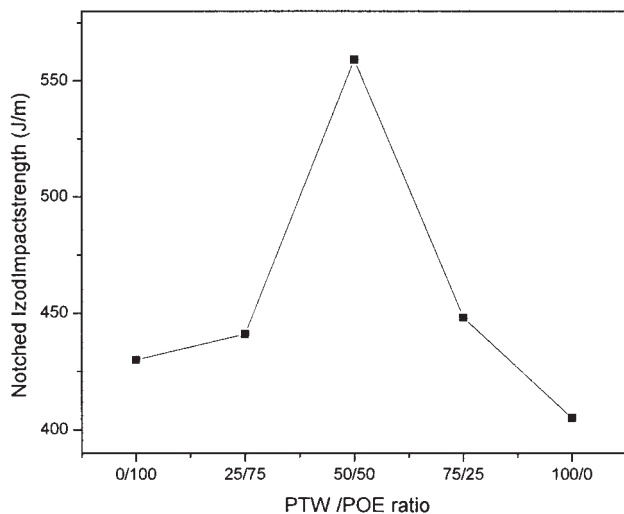


Figure 4 The plots of notched impact strength versus the ratio of PTW and POE.

Figure 5 demonstrates the effects of PTW and POE on the Vicat temperature of PBT/PC blends. As can be seen, the addition of either PTW or POE to the PBT/PC blends resulted in a dramatic increase in the Vicat temperature. The addition of both PTW and POE led to a further increase in the Vicat temperature. Thus, it was worth mentioning that a combination of PTW with POE was effective to increase the Vicat temperature for the toughened PBT/PC blends.

As mentioned earlier, a proper selection of modifier, that is, a combination of PTW with POE can lead to dramatic increases in the impact strength, elongation at break, and Vicat temperature.

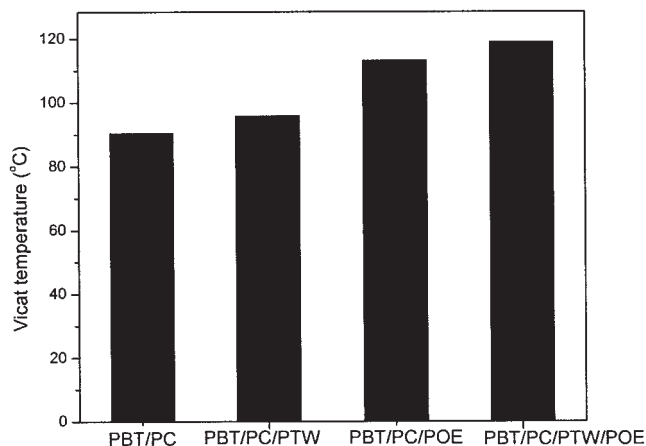


Figure 5 The effect of PTW and POE on the Vicat temperature of PBT/PC 50/50 wt % (a), PBT/PC/PTW 50/50/7 wt % (b), PBT/PC/POE 50/50/7 wt % (c), PBT/PC/PTW(POE) 50/50/3.5/3.5 wt % (d) blends.

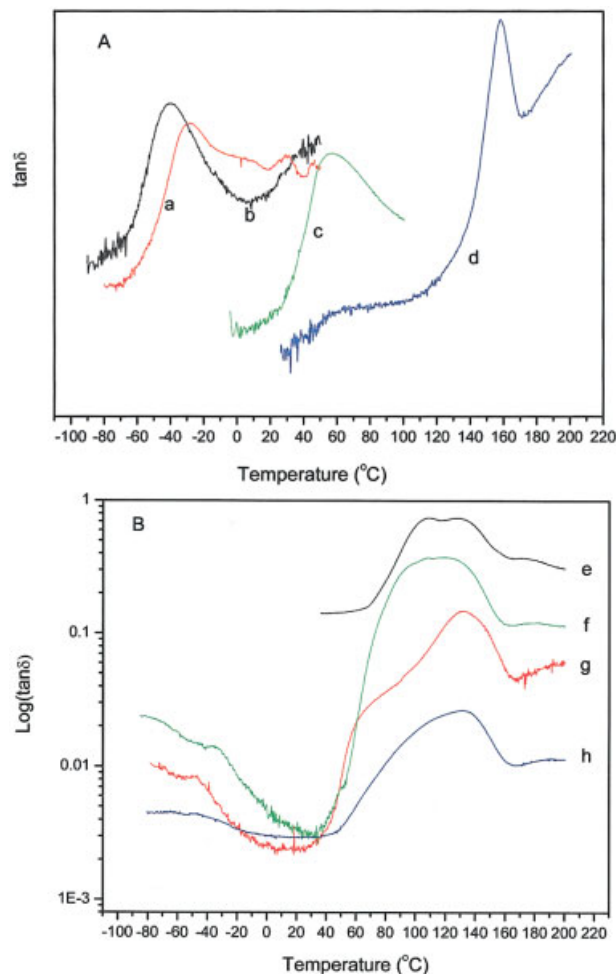


Figure 6 The DMTA spectra of PTW (a), POE (b), PBT (c), PC (d) (A) and PBT/PC 50/50 (e), PBT/PC/PTW 50/50/7 (f), PBT/PC/POE 50/50/7 (g), PBT/PC/PTW/POE 50/50/3.5/3.5 (h) blends (B). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

DMTA analysis

Figure 6(A, B) shows the DMTA spectra of PC, PBT, PTW, POE, and PBT/PC, PBT/PC/PTW, PBT/PC/POE, PBT/PC/PTW/POE blends. As can be seen in Figure 6(A), over the experimental temperature range (0~200°C), PC exhibited a glass transition temperature at 158°C, and PBT showed a glass transition peak at 56°C. In the temperature range of -80~50°C, PTW showed two glass transition peaks with low temperature at -30°C and high temperature at 30°C. POE exhibited one glass transition at -40°C. As can be seen in Figure 6(B), PBT/PC/PTW, PBT/PC/POE, PBT/PC/PTW/POE blends exhibited different low temperature behavior. For the PBT/PC/PTW blend [Fig. 6(B), curve f], the T_g of PTW could be accurately determined. The T_g appeared at -35°C close to the T_g of PTW, indicating the presence of a PTW amorphous phase in the PBT/PC/PTW blend. For the PBT/PC/POE blend [Fig. 6(B), curve g], the T_g of POE could be

accurately determined. It appeared at -50°C close to the T_g of POE, indicating the presence of a POE amorphous phase in the PBT/PC/POE blend. However, for the PBT/PC/PTW/POE blend [Fig. 6(B), curve h], the glass transition peaks of PTW and POE could not be identified. It may be due to their low intensity not to be detected. As seen in Figure 6(B), the high temperature behavior showed interesting trends, dependent on the various modifiers. For the PBT/PC blend [Fig. 6(B), curve e], two high temperature peaks appeared at 130 and 105°C , respectively. The peak higher than that of pure PBT could be attributed to the PBT-rich phase, and the other peak lower than that of pure PC could be attributed to the PC-rich phase. These results clearly indicate that the PBT/PC blend has a partial miscibility resulting from the transesterification between PBT and PC in the melt mixing. The earlier results are consistent with those of other studies.^{8,26,27} For the PBT/PC blend modified by PTW alone, the two peaks at 130 and 105°C merged into a broad peak, indicating that the addition of PTW led to an increase in phase mixing. The epoxide groups in the PTW can react with the terminal carboxylic acid and/or hydroxyl groups of PBT,⁷ and as a consequence the miscibility of PBT and PC is improved in the PBT/PC/PTW blend. For the PBT/PC blend modified by POE alone, a peak and a shoulder appeared at 130 and 85°C , respectively. The peak at 105°C in the PBT/PC blend shifted to a shoulder at 85°C , indicating that the addition of POE could suppress the transesterification to some extent. For the PBT/PC blend modified by PTW and POE together, the peak at 130°C appeared and the shape of the peak at 105°C showed a change resulted from two overlapping peaks (it could be a peak of the PBT-rich phase at about 90°C and the peak of the PC-rich phase at about 130°C), indicating the improved miscibility of PBT and PC.

DSC analysis

Figure 7(A, B) shows DSC curves of PBT, PBT/PC, PBT/PC/PTW, PBT/PC/POE, and PBT/PC/PTW/POE blends. The curves in Figure 7(B) clearly demonstrate the melting temperature (T_m) of pure PBT and the crystalline phase of the blends. Pure PBT exhibits one main melting phase at higher temperature together with a small melting peak at lower temperatures that could be attributed to secondary infilling crystallization.^{28–31} As reported by Huang,³² the nature of fast crystallization rate of PBT could result in a small fraction of less perfect crystals. The first small peak could be attributed to the partial melting of these less perfect crystals. The second large peak could be attributed to the melting of original and recrystallized crystallites. As can be seen in Figure 7(B), this behavior has also been found in the PBT/PC, PBT/PC/PTW, PBT/PC/POE, and PBT/PC/PTW/POE blends. The small melting peaks showed different intensity, and the main

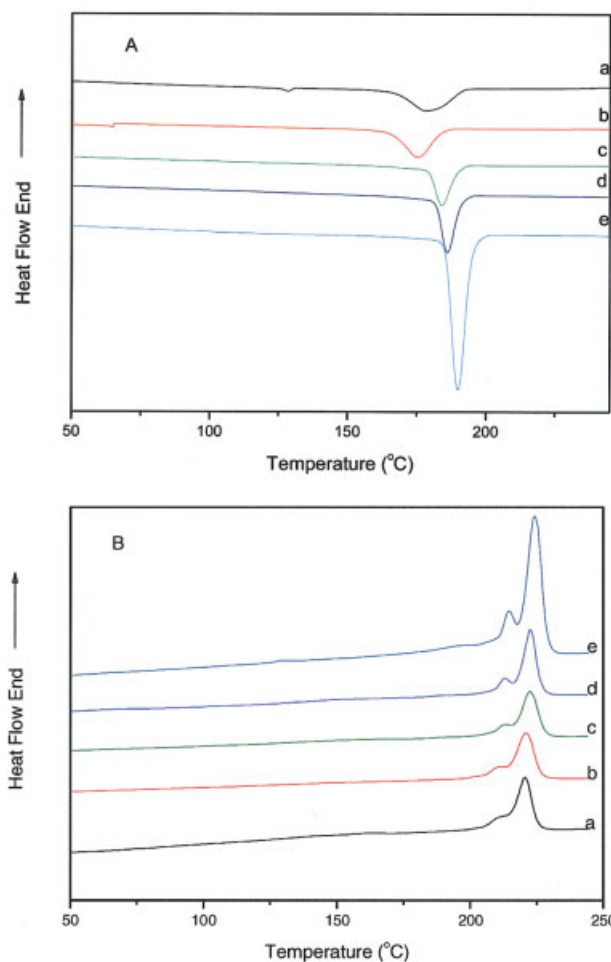


Figure 7 DSC cooling thermograms (A) and second heating thermograms (B) of PBT/PC 50/50 (a), PBT/PC/PTW 50/50/7 (b), PBT/PC/POE 50/50/7 (c), PBT/PC/PTW/POE 50/50/3.5/3.5 (d) blends and pure PBT (e). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

melting points remained almost constant, dependent on the various modifiers. The small melting peaks became a shoulder for the PBT/PC/PTW blend, similar to the PBT/PC blend. However, the intensity of the small melting peak increased for the PBT/PC/POE blend, and further increased for the PBT/PC/PTW/POE blend. The curves in Figure 7(A) clearly demonstrate the crystallization temperature (T_c) of PBT. As can be seen, the addition of PTW alone to the PBT/PC blend decreased the T_c of PBT for the PBT/PC/PTW blend, whereas the addition of POE alone to the PBT/PC blend increased the T_c of PBT for the PBT/PC/POE blend and the incorporation of both PTW and POE to the PBT/PC blend increased the T_c of PBT further for the PBT/PC/PTW/POE blend, compared with T_c of PBT for the PBT/PC blend.

For the PBT/PC blend [Fig. 7(A, B), curve a], a shift in T_c to lower temperature and a change in the low temperature peak from a small melting peak to a shoulder were observed, compared with pure PBT

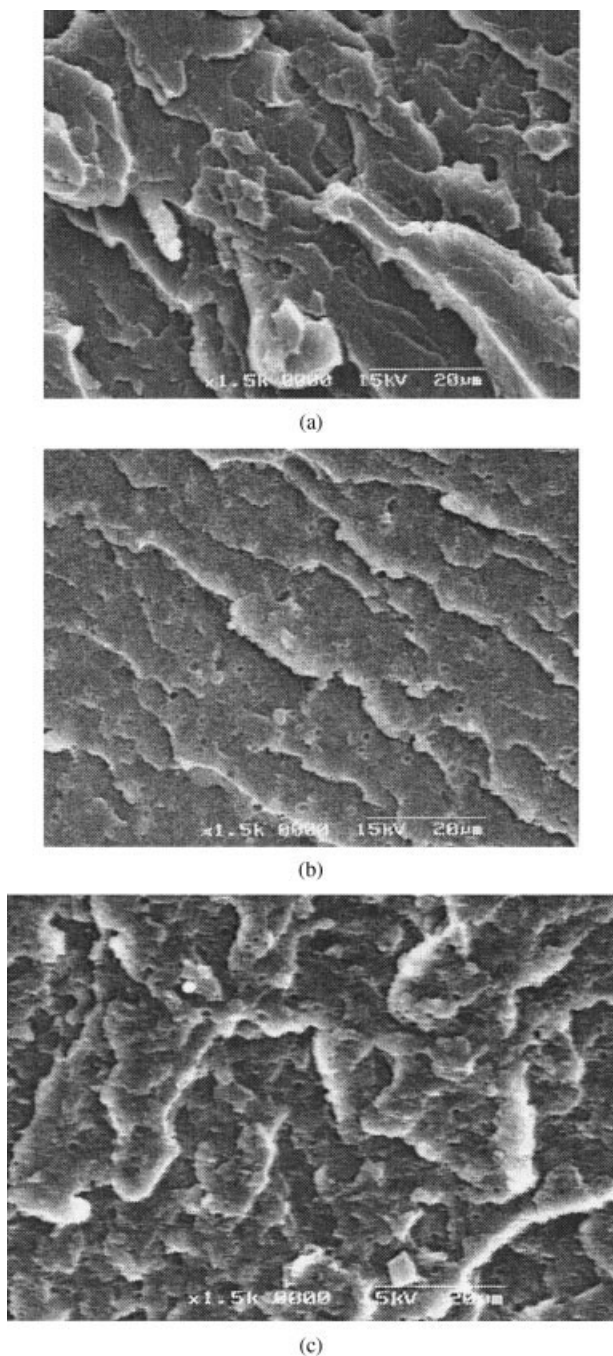


Figure 8 The morphology of PBT/PC 50/50 (A), PBT/PC/POE 50/50/3.5 (B), and PBT/PC/PTW/POE 50/50/3.5/3.5 (C) blends.

[Fig. 7(A, B), curve e]. These results indicated that PC could hinder PBT crystallization in PBT/PC blend during mixing in the melt, as reported by Runt et al.³³ and Tattum et al.³⁴ For the PBT/PC/PTW blend [Fig. 7(A, B), curve b], the PTW could interfere with PBT crystallization and cause a greater fraction of amorphous PBT. Those tightly linked amorphous PBT segments were difficult to crystallize at low temperatures. This is probably the reason why the smaller peak became a shoulder and the crystallization rate of PBT

decreased in the PBT/PC/PTW blend. A similar behavior was observed in PBT/ethylene-glycidyl methacrylate copolymer (EGMA) blends.¹⁷ For the PBT/PC/POE blend [Fig. 7(A, B), curve c], the increase in the T_c of PBT and the intensity of the small melting peak indicated the dispersed POE particles can promote crystallization of PBT during the melt mixing. For the PBT/PC/PTW/POE blend [Fig. 7(A, B), curve d], further increase in the T_c of PBT and the intensity of the small melting peak was due to the nucleation efficiency of very small size POE particles. As shown in Figure 8, the POE particles dispersed as smaller sizes in the PBT/PC/PTW/POE blend than in the PBT/PC/POE blend, which will be discussed in next section. It has been reported that very small size of the particle leads to high nucleation efficiency.³⁵ From the DSC analysis, it may be concluded that the addition of both PTW and POE has little effect on the integrity of the PBT crystals, and as a consequence is favorable for the preservation of the crystallization nature and the improvement in the mechanical and chemical properties.

Morphology

Figure 8 shows the SEM fractographs of PBT/PC (50/50), PBT/PC/POE (50/50/3.5), and PBT/PC/PTW/POE (50/50/3.5/3.5) blends. As can be seen, the POE particles dispersed as very large sizes in the PBT/PC/POE blend. However, in the PBT/PC/PTW/POE blend, the POE particles dispersed as small sizes because of the presence of PTW. It was evident that PTW was effective to compatibilize the PBT/PC/POE blend. The fact that PTW can improve the miscibility of POE and PBT/PC blends is in agreement with DMTA results. The improved miscibility of PBT/PC blends and POE leads to a marked increase in both elongation at break and notched Izod impact strength as discussed previously.

Figure 9 shows the morphology of the PBT/PC/PTW/POE blends with different PTW/POE content. The morphology of the PBT/PC/PTW/POE blends with 3.5, 4, and 4.5 wt % PTW/POE has not been shown in this article because the morphologies of blends with 3.5, 4, and 4.5 wt % PTW/POE are similar to those shown in Figure 9(b–d), respectively. As can be seen, the particle size changed with increasing PTW/POE content.

The mean interparticle distance (τ) has been proposed as a parameter that controls toughness. τ is defined as

$$\tau = d_n \left[k \left(\frac{\pi}{6\phi_r} \right)^{\frac{1}{3}} - 1 \right] \quad (1)$$

where d_n is the number-average particle size, ϕ_r is the volume fraction of rubber, and K denotes a geometric

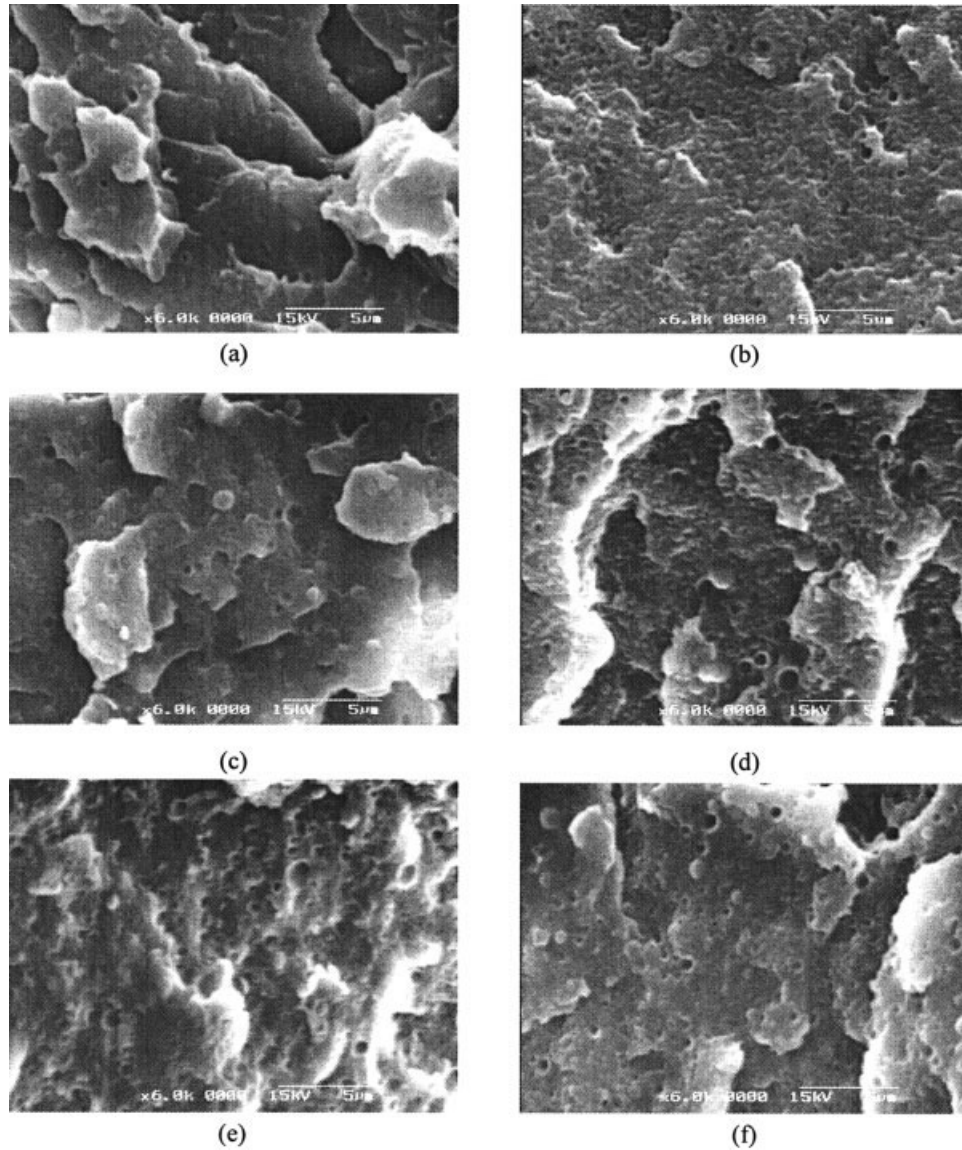


Figure 9 The morphology of the blends with (A) 0, (B) 3, (C) 5, (D) 7, (E) 10, (F) 14 wt % PTW/POE, respectively.

constant which depends on the lattice type. In a cubic lattice K equals 1, in a body centered lattice K equals $2^{1/3}$ and in a face centered lattice K equals $4^{1/3}$. The relationship between the brittle–ductile transition and

the τ was established based on a cubic lattice.³⁶ The average particle sizes were determined by image analysis based on micrographs taken on sections perpendicular to the flow. The values are shown in Table I. To

TABLE I
The Parameter of d_n , ϕ_r , τ and Notched Izod Impact Strength (σ) for PBT/PC/PTW/POE^a Blend as a Function of Content of PTW/POE

PTW/POE (wt %)	d_n (μm)	ϕ_r	τ	σ (J/m)
3	0.620 ± 0.119	0.0379	0.860 ± 0.66	166.0 ± 8.3
3.5	0.499 ± 0.130	0.0440	0.639 ± 0.166	169.8 ± 11.4
4	0.476 ± 0.105	0.0499	0.566 ± 0.124	168.1 ± 10.8
4.5	0.477 ± 0.106	0.0558	0.529 ± 0.117	479.8 ± 21.2
5	0.506 ± 0.136	0.0616	0.527 ± 0.141	493.3 ± 23.7
7	0.452 ± 0.182	0.0842	0.379 ± 0.152	573.0 ± 28.7
10	0.434 ± 0.123	0.1160	0.283 ± 0.080	553.0 ± 27.6
14	0.430 ± 0.125	0.1550	0.215 ± 0.062	600.7 ± 30.1

^a Formulation: PBT 50, PC 50, PTW/POE 1/1.

find out whether the critical value (τ_c) limits the impact strength behavior of these blends, the notched Izod impact strength as a function of τ is shown in Figure 10. It should be noted that, because of their complex morphology, we dealt with this system as follows. The PBT/PC blend was the matrix and the PTW and POE were dispersed phase. As shown in Figure 10, at a τ around $0.52 \mu\text{m}$, a sharp change in the impact strength took place. Thus, the blends with τ values greater than $0.52 \mu\text{m}$ have low impact strength, whereas the blends with composition with a τ less than $0.52 \mu\text{m}$ are tough, and have high impact strength. Therefore, $0.52 \mu\text{m}$ was considered as the τ_c for the toughened PBT/PC blend, and τ appeared to be the parameter that controlled toughness in these blends. To our knowledge, this is the first time the critical interparticle distance is reported for the PBT/PC blend. In agreement with Wu's theory, τ should be a characteristic of PBT/PC blends, because the PBT/PC blends have the properties of pseudoductile polymers, such as high unnotched impact strength and low notched impact strength. When τ was below τ_c , the impact strength should increase. Shear yielding should occur in those ligaments which were thinner than the τ_c .

Figure 11 shows the fractured surface of blends containing (a) 0, (b) 3, (c) 7 wt % PTW/POE following Izod impact. In Figure 11(c), the surface of PBT/PC/PTW/POE (7 wt %) blend was rough and the strands of highly deformed PBT/PC matrix could be observed. The corresponding impact strength was 573 J/m. However, the surface morphology of the PBT/PC/PTW/POE (3 wt %) blend indicates no shear yielding occurred, as shown in Figure 11(b). This was similar to that observed on the fracture surface of PBT/PC blend in Figure 11(a). The PBT/PC/PTW/POE blend with 3 wt % PTW/POE exhibited brittle behavior. Furthermore, the blend containing 3 wt %

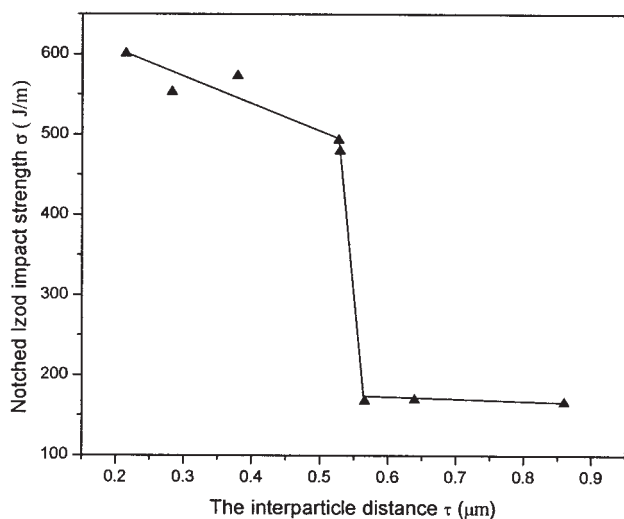
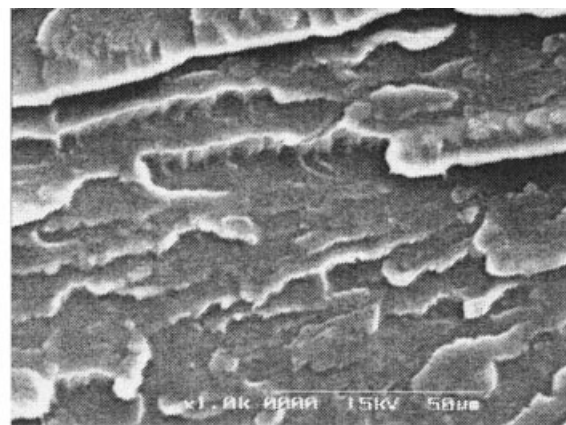
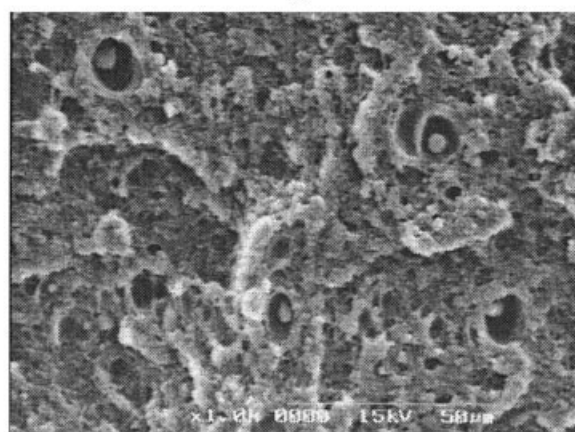


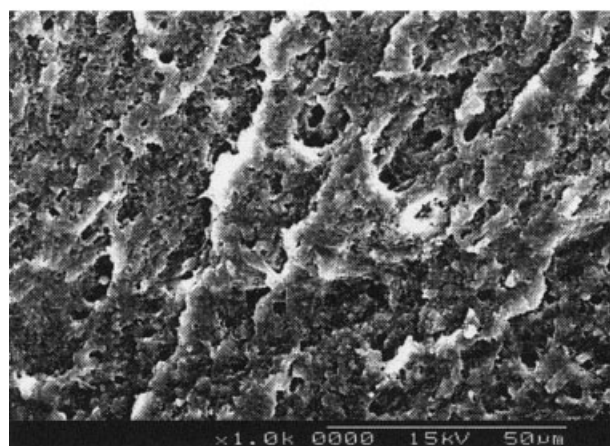
Figure 10 The dependency of the impact strength on the calculated interparticle distance.



(a)



(b)



(c)

Figure 11 The fractured surface of blends containing (A) 0, (B) 3, (C) 7 wt % PTW/POE following Izod impact.

PTW/POE with low impact strength after fracture and around the notch showed a stress-whitening zone, and the toughened blend containing 7 wt % PTW/POE with high impact strength showed a stress-whitening zone that extended to the whole fracture surface.

CONCLUSIONS

Adding either PTW or POE alone to a brittle PBT/PC blend could result in increases in the impact strength,

elongation at break, and Vicat temperature and decreases in the tensile strength, flexural strength, and flexural modulus. When the PTW and POE were used in combination in the PBT/PC blend, a prominent synergistic effect existed leading to significant increases in impact strength, elongation at break, and the Vicat temperature and some reduction of the tensile strength and flexural properties. The best synergistic effect occurred at a PTW/POE weight ratio of 50/50 for the PBT/PC/PTW/POE blend. DMTA analysis indicated that the presence of PTW improved the miscibility of PBT and PC and the presence of POE resulted in a phase change. DSC analysis indicated that the presence of PTW tended to interfere with the crystallization of PBT, the presence of POE promoted the crystallization of PBT, and both PTW and POE promoted PBT crystallize further.

The brittle–ductile transition occurred at a lower content of PTW/POE in the PBT/PC/PTW/POE blend, and the critical value (τ_c) was 0.52 μm . When τ was less than τ_c , the impact strength should high. When τ was greater than τ_c , the impact strength should low, which was in agreement with Wu's theory.

References

- Okamoto, M.; Shinoda, Y.; Kojima, T.; Inoue, T. *Polymer* 1993, 34, 4868.
- Wu, J.; Mai, Y. W.; Cotterell, B. *J Mater Sci* 1993, 28, 3373.
- Wu, J.; Mai, Y. W. *J Mater Sci* 1993, 28, 6167.
- Wu, J.; Mai, Y. W. *J Mater Sci* 1994, 29, 4510.
- Wu, J.; Yu, D. M. *J Mater Sci* 2000, 35, 307.
- Wu, J.; Yu, D. M. *J Mater Sci* 2003, 38, 183.
- Wang, K.; Wu, J. S.; *Key Eng Mater* 2000, (177–178), 363.
- Hobbs, S. Y.; Groshans, V. L.; Dekker, M. E. J.; Shuktz, A. R. *Polym Bull* 1987, 17, 335.
- Pompe, A. R.; Haubler, L. *J Polym Sci Part B: Polym Phys* 1997, 35, 2161.
- Robert, R. G. *J Appl Polym Sci* 1993, 48, 2249.
- Saitoand, A.; Itoi, H. U.S. Pat. 5,455,302 (1995).
- Wittman, D.; Schoeps, J.; Piejko, K. E.; Weirauch, K. U.S. Pat. 5,484,846 (1996).
- Hoshino, M.; Ogihara, T.; Kadoto, Y.; Maruyama, K. U.S. Pat. 5,516,842 (1996).
- Chacko, V. P.; Desito, P.; Baum, G. A. U.S. Pat. 5,677,150 (1987).
- William, T. W. T.; Lee, J. S. *J Appl Polym Sci* 2000, 76, 1280.
- Chapleau, N.; Huneault, M. A. *J Appl Polym Sci* 2003, 90, 2919.
- ArÓstegui, A.; Nazábal, J. *J Polym Sci Part B: Polym Phys* 2003, 41, 2236.
- Tsai, C. H.; Chang, F. C. *J Appl Polym Sci* 1996, 61, 321.
- ArÓstegui, A.; Nazábal, J. *Polymer J* 2003, 35, 56.
- ArÓstegui, A.; Gaztelumendi, M.; Nazábal, J. *Polymer* 2001, 42, 9565.
- Yang, J. H.; Zhang, Y.; Zhang, Y. X. *Polymer* 2003, 44, 5047.
- Wu, S. *Polymer* 1985, 26, 1855.
- ArÓstegui, A.; Nazábal, J. *Polymer* 2003, 44, 5227.
- Tanrattanakul, V.; Hitmert, A.; Baer, E. *Polymer* 1997, 38, 4117.
- Tanrattanakul, V.; Hitmert, A.; Baer, E.; Perkins, W. G.; Massey, F. L.; Moet, A. *Polymer* 1997, 38, 2191.
- Okamoto, M.; Inoue, T. *Polymer* 1994, 35, 257.
- Wilkinson, A. N.; Tattum, S. B.; Ryan, A. J. *Polymer* 1997, 38, 1923.
- Cheng, S. Z. D.; Pan, R.; Wunderlich, B.; *Makromol Chem* 1988, 189, 2443.
- Yeh, J. T.; Runt, J. *J Polym Sci Part B: Polym Phys* 1989, 27, 1543.
- Nichol, M. E.; Robertson, R. E. *J Polym Sci Part B: Polym Phys* 1992, 30, 755.
- Kim, J.; Nichol, M. E.; Robertson, R. E. *J Polym Sci Part B: Polym Phys* 1994, 32, 887.
- Huang, C. C.; Chang, F. C. *Polymer* 1997, 38, 2135.
- Runt, J.; Miley, D. M.; Zhang, X.; Gallagher, K. P.; Mcfeaters, K.; Fishburn, J. *Macromolecules* 1992, 25, 1929.
- Tattum, S. B.; Cole, D.; Wilkinson, A. N. *J Macromol Sci Phys* 2000, B39, 459.
- Saujanya, C.; Radhakrishnan, S. *Polymer* 2001, 42, 6723.
- Wu, S. *J Appl Polym Sci* 1988, 35, 549.