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Research Article

Investigation of the Effect of Polycarbonate Rate on Mechanical Properties of Polybutylene Terephthalate/Polycarbonate Blends

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Polybutylene terephthalate (PBT) is a brittle polymer with the disadvantage of low impact toughness, so it is not easy to meet the requirements of both high tensile strength, flexural strength, and high impact strength. In this study, PBT/polycarbonate (PC) blends at different ratios of 95/5, 90/10, 85/15, and 80/20 are investigated. Tensile strength, flexural strength, and unnotched Izod impact strength are studied according to the ASTM D638, ASTM D790, and ASTM D256 standards. The results show that tensile strength, which increased with increasing PC content, is 53.00, 62.34, 60.59, 62.98, and 64.46 MPa for 0, 5, 10, 15, and 20% PC samples. Flexural strength and elastic flexural testing of PBT/PC blends are higher than neat PBT. In addition, the unnotched Izod impact strength of PBT/PC is also higher than PBT. However, when PC content increases, impact strength tends to decrease. Impact strength is 44.82, 80.46, 68.82, 50.45, and 48.05 kJ/m^2 corresponds to 0, 5, 10, 15, and 20% PC, in which 5% PC sample is twice as high as the impact strength of PBT. Microstructure of the blends has shown that PC has become dispersed phase in PBT matrix. The size and quantity of dispersed PC particles increase with increasing PC rate in the blend. Thus, when adding PC, PBT/PC all meet the requirements of high tensile strength, flexural strength, and high impact strength. The PBT/5% PC model gives the highest impact strength while still ensuring durability, which potential application for making car door handles.

1. Introduction

Polybutylene terephthalate (PBT) possesses various good characteristic properties: low moisture absorption, good dimensional stabilities, high strength and modulus, good moldability, and high resistance to fuels, oil, fats, etc. industrial solvents. These advantages make PBT a great choice for application in many technical realms, such as electrical and electronics (connectors, IC socket, switches, relays, and so on), automotive (bumpers, ignition system parts, coupler, and so on), and household appliances (toaster housings, hairdryer parts, and so on) [1–5]. However, PBT has low impact strength, making PBT unsuitable for applications requiring both tensile, flexural strength, and impact strength [6–10]. The impact strength of PBT (27 J/m) is as low as that of PET (25 J/m) [11]. In Liu's study [12], the impact strength of PBT is 64 J/m, which is ten times lower than that of PC (685 J/m). The impact strength of PBT is 2.2 kJ/mm^2, which is also much lower than PA6 5.5 kJ/mm^2 [13]. Other studies found similar results. The impact strength of PBT is 2.2 ~ 2.84 kJ/m^2, while PC is 9.54 kJ/m^2 [14, 15].

To improve the impact strength, PBT is blending with other polymers to create a polymer blend that possesses the advantages of all component materials [16–20]. Among various prospective materials that can integrate with PBT, polycarbonate (PC) has been studied in many pieces of research because its characteristic properties could perform a perfect combination with PBT [21–25]. Research by Sanchez et al. on the properties of the PBT/PC blends with 0, 10, 20, 30, 40, and 50% PC shows that two distinct fracture zones were observed in the blend compositions: a ductile fracture and a brittle zone. The blend exhibited an overall improvement in the mechanical properties compared to neat PBT. Specifically, elastic modulus increases with the increase in the percentage of PC in the combination [26]. Author Wu et al. studied the fracture toughness and fracture mechanism of the PBT/PC with PC percent from 0 to 100%. The test result shows that the impact toughness of samples increases when the PC percentage in the blend increases [27, 28]. A similar result was reported by Tan et al. on PBT/PC blend with ratios of 100/0, 80/20, 70/30, and 60/40, respectively, indicates that the increase of PC percentage in the blend results in a significant increase of impact strength, flexural strength, and flexural modulus [14]. The mixture of PBT/PC with blend ratios of 100/0, 90/10, 80/20, and 70/30 was studied by Rejisha et al. Results point out that the tensile strength, tensile modulus, flexural strength, flexural modulus, and impact strength all increase as the proportion of PC in the blend increases. Above 20% PC, the blends showed a decrease in tensile and flexural strength. However, as the PC concentration increased, the impact strength also increased [29]. Research by Wang et al. also demonstrates a similar result [30]. When expanding the PC content from 0 to 20%, the tensile strength of the blend is increased from 59.6 MPa to 63.3 MPa, the flexural strength from 86.3 MPa to 94.5 MPa. With the addition of PBT, the hardness of the PC/PBT blend increases.

This work is aimed to study the influence of PC content on tensile strength, flexural strength, and impact toughness of the PBT/PC blend. We tried to find an appropriate PBT/PC ratio with high impact toughness while still providing tensile and flexural strength without adding any compatibilizers.

2. Materials and Methods

PBT (LANXESS Pocan B1505 000000), melting temperature 225°C. PC (SABIC PC Resin PC0703R), melting temperature 270-280°C. PBT resin was dried at 100°C for 2 to 4 hours, and PC resin was dried at 120°C for 2 to 4 hours. The dried resins were mixed manually at different volume percentages. Table 1 shows the compositions of each sample. Finally, these blended materials were molded at an injection molding machine.

Table 1: Compositions of the samples (wt.%).

Sample	PBT (wt.%)	PC (wt.%)
M1	100	0
M2	95	5
M3	90	10
M4	85	15
M5	80	20

Tensile strength test, flexural strength test, and unnotched impact strength test are carried out according to ASTM D638, ASTM D790, and ASTM D256. Tensile strength and flexural strength were investigated using Shimadzu Autograph AG-X Plus 20kN universal testing machine with a speed of 50 mm/min. The same device measures flexural strength at a rate of 16.64 mm/min. Specifications of Shimadzu Autograph AG-X Plus 20 kN: capacity 20 kN, crosshead speed range 0.0005~1000 mm/min, maximum return speed 1200 mm/min, crosshead speed precision ±0,1%, and crosshead-table clearance 655 mm. The Tinius Olsen IT504 Izod impact tester carries out the unnotched impact test. Specifications of Tinius Olsen IT504: essential pendulum capacity 2.82 J, basic pendulum capacity with low blow 2.75 to 2 J, drop height 0.61 m, and impact velocity 3.46 m/s.

The microstructure of the blend at various concentrations is investigated by using a high-resolution FESEM microscope Hitachi S-4800. Parameters: the resolution of secondary electronic image 1.0 nm, 1.4 nm, accelerated voltage reducer); 2.0 nm (1 kV, WD =1.5 nm, conventional model); magnification: LM 20-2000 times; high magnification HM 100-800000 times.

3. Results and Discussion

3.1. Surface Morphology. The screw temperature and nozzle temperature in injection molding is 265°C and 270°C, respectively. Figure 1 shows the actual picture of the test specimen types.

The colors of the samples are identical due to a slight difference in the percentage of PC among each blend ratio. Surface gloss is not high because the mold is only polished enough for the sample to stay inside the cavity after two halves of the mold are separated, making the sample out of the mold easier. The aesthetics of models does not affect the measurement or result of the tests. The microstructure test is also unaffected since SEM micrographs are only taken at fracture surfaces.

The injection molding process is quite favorable at 100/0, 95/5, 90/10, and 85/15 ratios due to low PC concentration. Difficulties appear in the processing of the 80/20 blend. Fast crystallization of the blend leads to quick solidification of the sprue. Solidified sprue gets stuck inside the sprue bushing; thus, the melt is unable to enter the mold anymore. At this point, the sprue must be removed manually using a gas torch and a piece of steel wire.

3.2. Tensile Strength. Figure 2 provides an overview of the influence of PC on the tensile strength of PBT/PC blends.

It can be observed that the tensile strength of the blend is higher than that of neat PBT at all blend ratios. However, the increase is not uniform. Tensile strength increased sharply from 52.99 MPa of neat PBT to 62.34 MPa when the percentage of PC in the blend was below 5%, but decreased slightly to 60.58 MPa when PC rate was between 5 and 10%. The tensile strength then increases again when the PC concentration is 10% higher, up to 64.45 MPa of 80/20 blend ratio. This overall increase has been observed in much previous research. The tensile strength of PBT, PBT/10% PC, PBT/20% PC, and PBT/30% PC is 54, 61, 65, and 63 MPa, respectively [29]. This result shows that with increasing PC content, tensile strength increases. This increase is a result of the toughening effect of PC. However, if the PC content is above 20%, the tensile strength tends to decrease. The reason is due to the higher polarizability of the PC and its semicompatible with PBT.

Table 2 shows the break-strain and elastic of the tensile testing. It can be seen that the elastic of the PBT/PC blend is higher than that of PBT, and the elastic increases as the

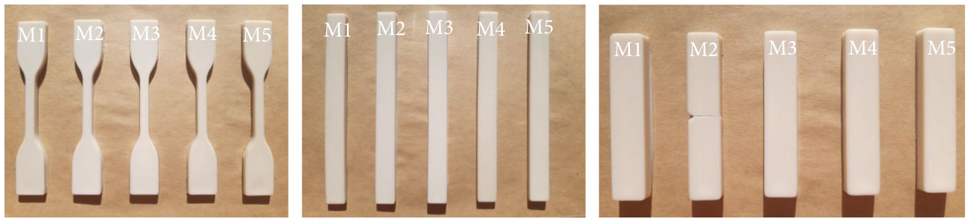


Figure 1: Tensile, flexural, and unnotched impact testing samples.

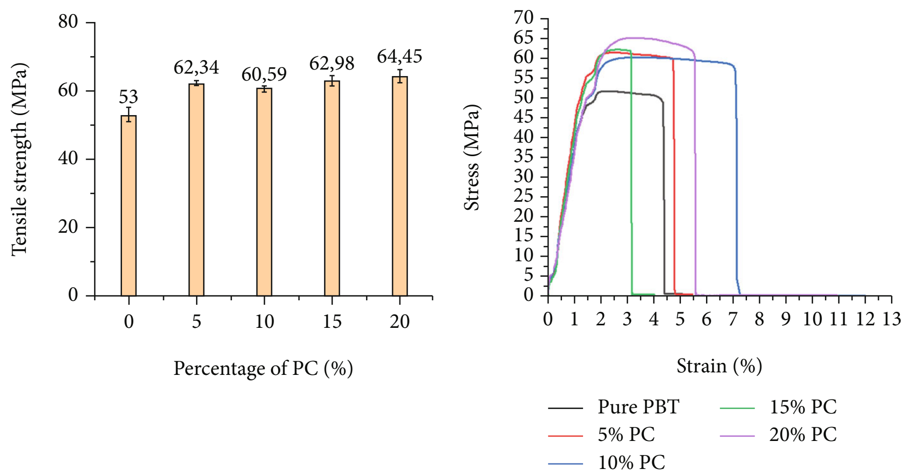


Figure 2: Tensile strength chart and tensile strain-stress diagram.

Table 2: Break-strain and elastic of the tensile testing.

Sample	PBT (wt.%)	PC (wt.%)	Break-strain (%)	Standard deviation of break-strain (%)	Elastic (MPa)	Standard deviation of elastic (MPa)
M1	100	0	10.84	10.12	1356.79	221.60
M2	95	5	12.15	7.20	1736.90	80.72
M3	90	10	7.87	3.32	1909.30	165.54
M4	85	15	9.36	8.30	2105.17	252.76
M5	80	20	8.94	7.46	2081.20	167.47

PC content increases. However, when the content exceeds 15%, elastic tends to decrease. Tensile break-strain shows an oscillating trend, the highest is 12.15%, and the lowest is 7.87%. Except for the PBT/5% PC blend, which has a higher break-strain than neat PBT, the remaining blends are lower than the 100% PBT sample. The behavior is almost the opposite of that observed in cases of other properties. Author Sanchez et al. [26] showed that the effect of free volume or density variation on stress-related properties appears to be the opposite of the impact occurring in strain-related properties such as elasticity.

3.3. Flexural Strength. Figure 3 shows an overview of the influence of PC on the flexural strength of PBT/PC blends.

Flexural strength of PBT/PC blend exhibits behavior quite similar to tensile strength. There is a significant increase in flexural strength from 72.92 MPa to 89.84 MPa when the percentage of PC in the blend is below 5%. A slight decrease was observed when 5% to 10% PC presents in the blend composition. Flexural strength increases again when the PC rate exceeds 10%, to the maximum value of 98.48 MPa at the 80/20 ratio. Overall, the flexural strength has improved much more than neat PBT. This tendency of increase is showed in the research of Tan et al. Flexural strength of neat PBT increased from 76 MPa to 77.8 MPa of PBT/30% PC blend [14]. The flexural strength increases with increasing PC content; specifically, the flexural strength of neat PBT, PBT/10% PC, and PBT/20% PC is 72, 79, and 87 MPa, respectively, as indicated in the study of Rejisha et al. [29].

The elastic of the flexural testing was demonstrated in Table 3. When PC content is 5%, elastic increases compared to PBT. Increasing the PC content to 15%, the elastic tends to decrease gradually. However, elastic increases when the content is 20% PC. Elastic of PBT/PC blends are all higher than neat PBT. In the study of Rejisha et al., when PC contents are 10% and 20%, elastic modulus increases to 2.91 and 3.45 GPa, which are much higher than 2.27 GPa of neat PBT [29]. The study of Tan et al. [14] found similar results. Elastic modulus of PBT/20% PC, PBT/30% PC, and PBT/40% PC are 2088.4, 2158.0, and 2494.7 MPa, which are higher than that of PBT (2050.5 MPa).

3.4. Izod Impact Testing. Figure 4 shows the average unnotched Izod impact strength of the PBT/PC blend. A significant increase is observed at 5% PC in the blend. The value of 80.46 kJ/m^2 is almost double to 44.82 kJ/m^2 of neat PBT. But then, the result showed a tendency of decrease.

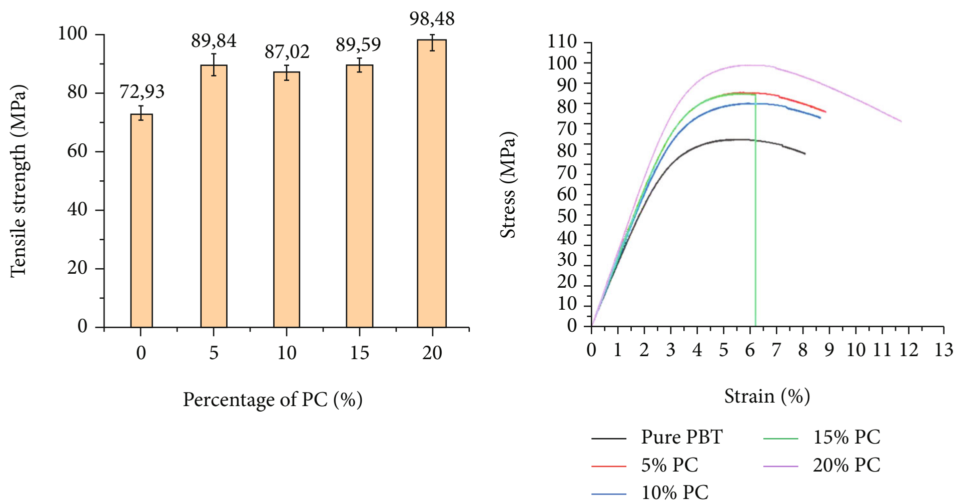


Figure 3: Flexural strength chart and flexural strain-stress diagram.

Table 3: Elastic of the flexural testing.

Sample	PBT (wt.%)	PC (wt.%)	Elastic (MPa)	Standard deviation of elastic (MPa)
M1	100	0	2049.61	96.18
M2	95	5	2440.44	136.09
M3	90	10	2383.24	92.96
M4	85	15	2299.78	77.95
M5	80	20	2568.07	209.41

Table 4: The average hardness of test samples.

Sample	PBT (wt.%)	PC (wt.%)	Hardness (Shore D)					Average of hardness (Shore D)
M1	100	0	72	73	72	73	73	72.6
M2	95	5	73	73	73	72	73	72.8
M3	90	10	73	74	74	74	74	73.8
M4	85	15	74	74	74	74	74	74
M5	80	20	75	75	75	75	74	74.8

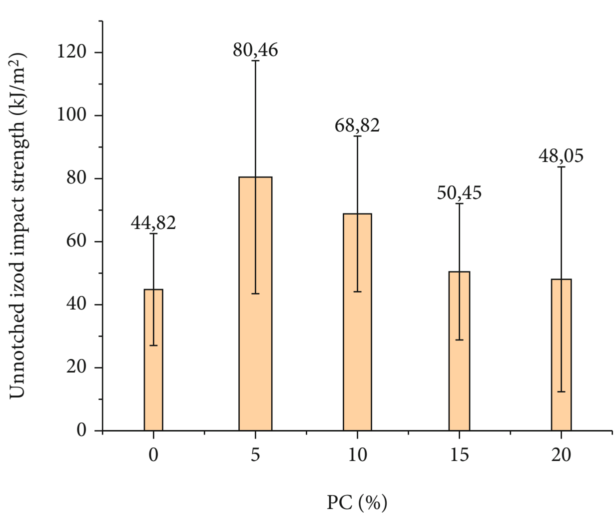
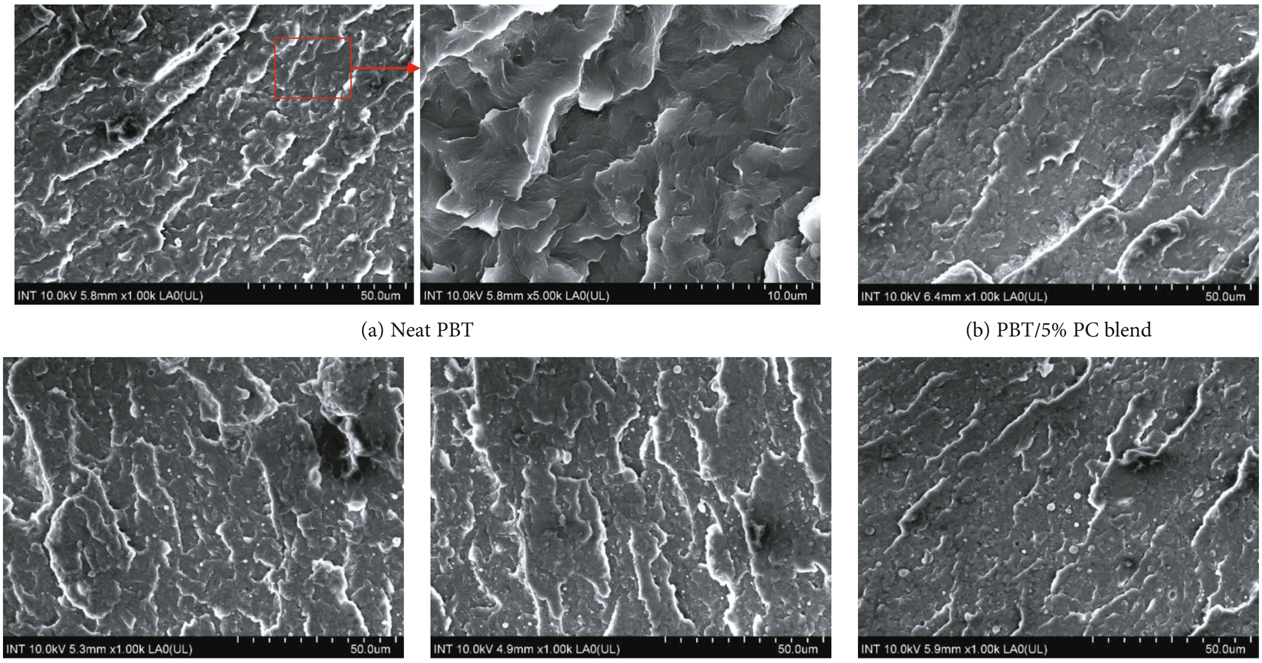


Figure 4: The average unnotched impact strength of test samples.

Unnotched impact strength decreases rapidly from the highest value to 68.82 kJ/m^2 of 90/10 blend, 50.45 kJ/m^2 of 85/15 mix, and 48.05 kJ/m^2 of 80/20 blend. It can be clearly seen that unnotched impact strength decreases with increasing PC percentage in the blend. However, unnotched impact strength at all blend ratios is still higher than that of neat PBT. This result is presumed to be an effect of transesterification between PBT and PC during melt blending [27]. Wu et al. explained in their further research that the PBT-PC copolymers formed by transesterification act as a compatibilizer to enhance the PBT-rich blend's interfacial adhesion, resulting in heightened impact strength [28]. Author Rejisha et al. have proven that as the concentration of PC increases, the impact strength also increases because the PC has an excellent impact strength compared to that of PBT [29]. In the study of Tan et al. [14], the notched Izod impact strength of PBT/20%PC blend is 7.25 kJ/m^2, which is higher than 2.84 kJ/m^2 of the 100% PBT sample.

3.5. Hardness. Table 4 indicates the average hardness of PBT/PC blends. It can be seen that the hardness values fluctuate around 72.6 to 74.8 Shore D. According to Sanchez et al. [26], mechanical properties are often related to density. Due to densification, free volume is lost, which in turn makes motion difficult at a segmental. The result leads to increase stiffness. Author Tan et al. [14] also demonstrated similar results. The higher the relative percentage of PC within the blends, the better the stiffness.

3.6. Microstructure Results. Figure 5 demonstrates the SEM micrographs taken on the fracture surface of the neat PBT sample and 95/5, 90/10, 85/15, and 80/20 blend samples, respectively. The smooth fracture surface points out that there are no bridging domains between PBT and PC phases.



(a) Neat PBT

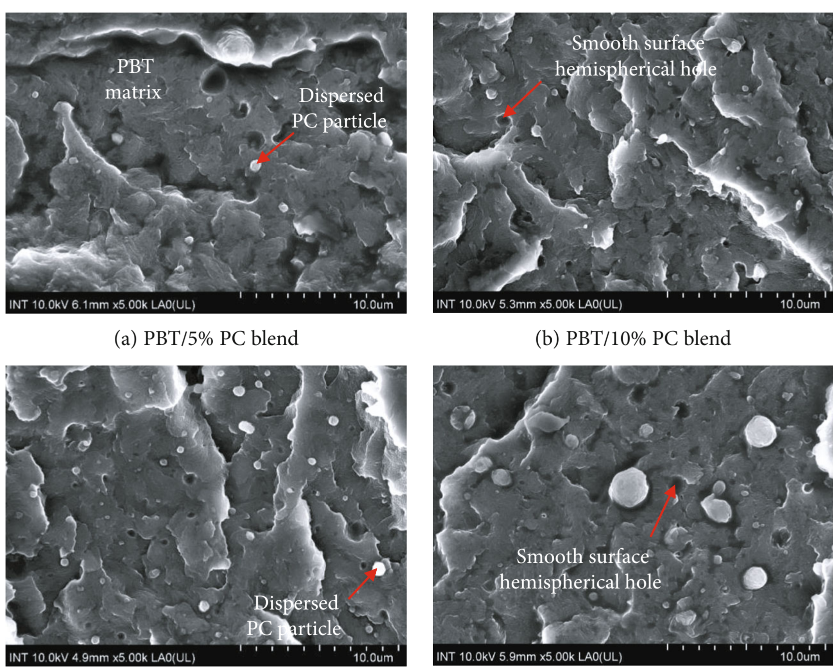
(b) PBT/5% PC blend

(c) PBT/10% PC blend

(d) PBT/15% PC blend

(e) PBT/20% PC blend

Figure 5: FESEM of fracture surface of PBT/PC blends.



(a) PBT/5% PC blend

(b) PBT/10% PC blend

(c) PBT/15% PC blend

(d) PBT/20% PC blend

Figure 6: FESEM of fracture surface of PBT/PC blends sample at high magnification.

Debonded PC particle in PBT matrix has no load-bearing ability and provides an easy path for crazes to develop into cracks, which result in fast and unstable fracture, hence, brittle fracture behavior. According to Wang, PC/PBT are usually noncrystalline/crystalline polymer blends since PBT are crystalline polymers and PC are noncrystalline polymers. The phased crystallization of PBT restricts the movement of the macromolecular chain of PC. Interfacial bonding between the crystallization of PC of PBT and the amorphous phase is undesirable [30].

Figure 6 demonstrates the SEM micrographs taken on the fracture surface of 95/5, 90/10, 85/15, and 80/20 blend samples at high magnification. Numerous debonded PC particles can be observed clearly, indicates the phase separation between PBT and PC. PC becomes the dispersed phase, and the hemispherical, smooth-surfaced indentations were left after PC domains had been pulled off from the counterpart fracture surface during fracture. The size and quality of dispersed PC particles also increase proportionally with PC percentage. According to Wu et al., the smooth surface of the hemispherical holes, as seen in Figure 6, indicates the inferior interfacial adhesion between the PBT and PC phases. The propagating crack is provided with an easy path by the poor interface of PBT/PC. The effective fracture surface is reduced as well [10, 27]. Researcher Lin et al. [24] believe that in PBT/PC blends, transesterification reactions can occur between PBT and PC in the melted mixture. This reaction is the primary exchange reaction between them. Progressive transesterification reactions cause the change of the initial homopolymers to copolymers which can act as a compatibilizer for the PBT/PC blend. However, copolymers are often limited since they are formed through transesterification. Thus, it results in poor interphase adhesion of PBT and PC.

4. Conclusions

Tensile strength, flexural strength, and elastic of PBT/PC blends are all higher than neat PBT. Tensile strength is 53.00, 62.34, 60.59, 62.98, and 64.46 MPa for samples 0, 5, 10, 15, and 20% PC, respectively. Unnotched Izod impact strength of PBT/PC is also higher than PBT, but as PC content increases, impact strength decreases. Specifically, 80.46, 68.82, 50.45, and 48.05 kJ/m^2 correspond to 5, 10, 15, and 20% PC. PBT/5% PC sample has double the impact strength of neat PBT (only 44.82 kJ/m^2). Microstructure of the blends shown that PC has become dispersed phase in PBT matrix.

Thus, when adding PC, all PBT/PC blends meet the requirements of high tensile strength, flexural strength, and high impact strength, in which PBT/5% PC blend gives the highest impact strength while still maintaining tensile and flexural strength.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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