Study on recycling of Poly(butylene Terephthalate) and Polypropylene blend

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Abstract. Poly (butylene terephthalate) (PBT) is a breakable plastic because its high modulus value makes it unsuitable for specific applications. Recycling PBT is even more complicated when the color is no longer the original milky white. This study takes R-PBT from the brush hair scraps and blends with 10% Polypropylene (PP). The results show that the mold continually adhered to is challenging to inject the sample 100% R-PBT. The surface of sample R-PBT /10% PP has a good gloss and smooth texture, while there is a high shrinkage rate in sample 100% PP. The hardness of sample R-PBT /10% PP is increased when adding PP. In addition, sample 100% R-PBT has a distinctive shape with tiny fibers, while model 100% PP has a flat surface. For the R-PBT /10% PP sample, the microstructure has two distinct regions: PBT matrix and PP dispersed-droplets.

1. Introduction
Poly (butylene terephthalate) (PBT) is an inelastic plastic, so it is commonly unsuitable for specific utilization, particularly those needing outstanding impact toughness. Blending PBT with incompatible polymers can appreciate these limited properties of PBT. Neat PBTs are often mixed with polyolefins consisting of a range of polyethylene (PE) and polypropylene (PP) [1,2]. Research of PBT/polyolefin-based blends show remarkable changes in their mechanical properties, with further improvement to the PBT/polyolefin blend at low concentrations (about 2–5% polyolefin). However, studies mainly focus on PBT/HDPE mixtures [3]. Wang et al. [4] studied HDPE with core-shell polyamide-6/PBT. It was found that the toughness of sample 80HDPE/10PA6/10PBT blend is 2–3 times higher than pure HDPE due to the addition of PBT and PA6. Morphological observations revealed that the addition of PBT and PA6 leads to the apparition of core–shell-dispersed particles in the HDPE matrix. A study by Yang and Smith [5] demonstrated that the melting behavior with the different processing of reprocessed PBT/HDPE blend is dissimilar from the crystallization behavior of neat PBT samples. A similar result has been reported by Monticciolo et al. [6], suggesting that the solvent barrier properties of the PE and PBT blends may be highly related to the expansion of the physical lattice structure of PBT particles. Qi et al. [7] also studied PBT/HDPE blends. The results determined that when adding HDPE, the strength of the PBT/HDPE blend tended to decline. To improve the cohesion of PBT and HDPE, a lot of studies have added a compatibilizer to PBT/HDPE blends. In the work of Joshi et al. [8], an 80PBT/20HDPE blend was developed with a PE-based ionomer. Ultimate mechanical properties showed a significant


improvement when adding ionomer. Ozden et al. [9] blended PBT/HDPE with four various stabilizers collected from the natural derivatives of five-valent phosphorus. All stabilizers developed the melt balance of the blends when applied at low rates (<0.2% in quantity). According to Pesneau et al. [10], the PBT/PE blends are in-situ compatible by adding a hydroxylated ethylene-vinyl acetate copolymer. This copolymer is compatibilized with PE like EVA. In addition, Hong et al. [11,12] analyzed the influence of organically modified nano-clay on PBT/PE compounds morphology. Adding 1 to 3 phr organic modified nano-clay reduces the practical size for PBT/PE blends. In terms of LDPE, blends of PBT with very low-density polyethylene (VLDPE) have been studied in Nabi’s [13] research. The result shows that the tensile and modulus decreased gradually as the VLDPE percent increased. However, the impact strength increased slightly with an expansion in VLDPE percent. The microstructure shows spherical domains of VLDPE distributed in the PBT matrix. Gribben [14] proved that the maleic anhydride-grafted-LLDPE is miscible with PE and has a chemical function with the polyamide and hydroxyl phases of PBT. Modulus and elongation are also significantly improved.

About PBT/PP blend, it can be seen that studies on this blend almost add compatibilizer to PBT blends. Borve et al. [15] studied isotactic PBT/PP blends and poly (phenylene ether)/PP blends with 10-30% PBT or poly (phenylene ether). The results exhibit that the viscosity rate among the mixed composition, the compatibilizer content, and the poly (phenylene ether) or PBT content were necessary for the ultimate mixture properties. Moreover, impact strength was the most sensible rejoinder to blend compatibilization. Ignaczak et al. [16,17] used synthesized random copolyester, PBT-r-butylene dilinoleate, and SEBS as compatibilizer PP/PBT blends with 5 wt% of each compatibilizer. The static tensile test showed a signed advance in elongation at break, about 20% for PBT-r-butylene dilinoleate and SEBS, respectively. Morphology of the PBT/PP blend compatible with PBT-DLA copolymer was also studied to represent an interphase alterant, preferentially positioned at the interface. A related effect was informed by Ignaczak et al. [18], a linear triblock copolymer, SEBS, 5% TPE-g-MA was used to be compatible with PBT/PP blends. The work showed that PP/PBT toughness and impact properties improved with the highest SEBS copolymer.

Besides elastomer, several authors focus on copolymers, ionomer, organoclay, volatile oxazoline [19, 20]. Zhang et al. [21] studied PBT/PP blend with an additional 1% liquid crystal ionomer containing the sulfonate group on the terminal as a compatible agent. The results showed that the liquid crystal ionomer composition greatly influenced the mechanical properties, miscibility, and crystallization process of the PBT/PP blend. Increasing the LCI improved the miscibility of the PBT/PP blend, tensile strength, and elongation. PBT/PP immiscible polymer blend in Hajibaba’s research [22] was added with PP-grafted maleic anhydride and organoclay of hydrophilic modifier. According to the non-linear viscosity properties, the PBT/PP/organoclay specimen showed more vital stress superiority than itself with the PP-g-MA sample in the start-up of shear flow. The PBT/PP/Organoclay nanocomposites showed more significant yield stress than PBT/PP blends filled with PP-g-MA/organoclay systems. Similar to the above studies, Vainio’s article [23] used oxazoline by melting free radical graft with a low degradation level of PP. PP-g-OXA decreases the particle dimension of the PBT dispersion phase, enhanced cohesion between the PBT and PP phases. In addition, the research shows that the response between the functions of carboxylic and oxazoline takes place extremely rapidly.

Apart from these, epoxy resin has also received much attention from researchers. In Shieh’s work [24], the maleic anhydride-grafted PP and the multifunctional epoxy resin have been shown to combine effectively in PBT/PP blend due to their anchor along with the interface capabilities. The compatibility may be higher viscosity, and the mechanical properties improved. Holsti-Miettinen et al. [25] studied a reactive liquid crystalline polyester and ethylene-based terpolymer at 80PP/20PBT and 20PP/80PBT ratios. Adding compatibilizer enhanced impact strength of PP/PBT mixtures and PP/20 wt% liquid crystalline polyester blends. In addition to adding a compatibilizer, there are many methods of creating links for PBT and PP [26-28]. Tartaglione et al. [27] studied sepiolite-based composites prepared in a Brabender internal mixer with 3% sepiolites in PBT and PP. The consequences proved that the appearance of sepiolite did not relate to the thermal properties of PBT.
This paper researched blends of recycling PBT (R-PBT), which originates from toothbrush hairs, and LDPE with 10 wt.%. The hardness and microstructure of the R-PBT/PP blend have been investigated.

2. Materials and Methods
The practice adopted to use R-PBT, which is taken from the toothbrush hairs. PP resins from Saudi Arabia. R-PBT resins were blended with 10 wt.% PP (Table 1). After that, the plastic was dried 10 h at 80 °C before testing. The researcher used TKC plastic injection molding devices to create test samples.

| Sample  | Component (wt.%) |
|---------|------------------|
| P10     | PP 10 PBT 90     |
| R-PBT   | 0 100            |
| PP      | 100 0            |

The hardness of the specimen was graded through SHORE hardness analysis systems according to the ASTM D2240 process, utilizing the tester SHORE D Durometer DESIK (Figure 1). Each hardness sample was measured five times and then averaged.

The microstructure is observed by using a high-resolution SEM microscope HITACHI S-4800 (Figure 2). The primary parameters are the resolution of secondary electronic image 1.0nm - 1.4 nm, accelerated voltage reducer 2.0 nm, high magnification HM 100-800000 times.
3. Result and Discussion

3.1. Surface morphology
Figure 3 shows the specimen after injection molding. The 100% R-PBT sample is complicated to inject; the mold is invariably stuck. The surface of the P10 sample has a good gloss and smooth surface. 100% PP sample has a high shrinkage rate. Sun et al.'s study [1] has shown that, for the PBT/PP blend, the two separate absorption peaks correspond to the two melting temperatures of the individual component polymers. A peak similar to the PP phase could be seen at 166 °C, while another peak corresponding to the PBT phase was about 225 °C. The blend's PBT/PP blends are unmixable because PP is nonpolar while PBT is polar. The morphology of an immiscible polymer mixture depends on the surface stress, viscosity rate, shear force, and the tensile stress encountered during the treatment. An immiscible polymer mixture usually has a high surface tension, so it has a harsh morphology and a comparably great domain size for the sub-component.

![Figure 3. Surface morphology.](image1)

3.2. Hardness
The hardness of test samples was exposed in Figure 4. The values for PP were used as a reference. From the figure, the hardness of sample P10 is increased when adding R-PBT. This result is because PBT has a high hardness. When adding PP, the hardness of samples is significantly improved. Ignaczak et al. [16,17] found a notable improvement in mechanical properties with a growing number of PBT in the polymer blend. Tsal's research [29] showed that the lower added PP content in the mixture, the higher the tensile strength. For example, the tensile strength of PBT/30%PP is 32.1 MPa, which is higher than that of PBT/50%PP and PBT/70%PP (31.3 MPa and 29.3 MPa, respectively).

![Figure 4. The average hardness of test samples.](image2)
3.3. Microstructure results

![SEM micrographs of 100% PBT, PBT/10% PP, 100% PP](image_url)

Figure 5. SEM micrographs of 100% PBT, PBT/10% PP, 100% PP.

Figure 5 manifests the SEM image of the 100% R-PBT, 10% PP, and 100% PP specimens. From figure 5 a), it can be noticed that the 100% R-PBT has a distinctive shape with tiny fibers, while in figure 5 b) 100% PP has a flat surface. For the 10% PP sample, the microstructure has two distinct regions: PBT matrix and PP dispersed-droplets [1, 20]. PP droplets showed a clear spherical crystal structure dispersed in the PBT matrix. P10 had rugged morphology with a big particle, which admits the PBT/PP blend [17]. The distribution of PP particles is rough, and the plurality of PP is dispersed in the PBT matrix. There is no evidence of interfacial adhesion between the PP dispersed phase and the PBT matrix since the surface of the PP particles is plain. Large holes can be observed due to the PP being dropped. PP does not mix and is incompatible with PBT due to the hydrophobic nature of PP and the significant difference in polarity. Besides, PP lacks the essential functional groups to react with PBT [22]. Thus, the PBT/PP blend showed poor dispersion of the PP dispersed-droplets in the PBT matrix, and the mechanical properties of the PBT/PP blend are relatively poor.

4. Conclusion

It is complicated to inject the specimen 100% R-PBT. The mold is regularly stuck. The surface of sample PBT/10% PP has a good gloss and smooth surface, while there is a high shrinkage rate in the sample 100% PP.

The hardness of sample PBT/10% PP is increased when adding R-PBT. Sample 100% R-PBT has a distinctive shape with tiny fibers, while model 100% PP has a flat surface. For the PBT/10% PP sample, the microstructure has two distinct regions: PBT matrix and PP dispersed-droplets.
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