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Effect of contaminants and processing regime on the mechanical properties and moldability of postconsumer polyethylene terephthalate bottles

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ABSTRACT

In this research, post-consumer polyethylene terephthalate (PC-PET) bottles were processed and characterized. The aim was to investigate the influence of number and type of melt processing steps and the presence of contaminants on the mechanical properties and moldability of PC-PET. Results and observations of current research showed that direct processing of PC-PET by injection molding (i.e. skipping melt extrusion step) is preferable in order not to deteriorate mechanical properties especially the toughness of PC-PET. Contaminants found in PC-PET waste stream include labels and bottle cap rings made of polyethylene (PE) and paper labels. Unlike PE contaminants, paper contaminants can drastically reduce toughness of PC-PET and severely affect its moldability. Molded samples of PC-PET containing traces of papers appeared incoherent and fragmented pieces due to poor adhesion between PET and papers. The recommendation given by current research is to remove paper contaminants from PC-PET waste stream before melt processing and melt processing steps should be limited.

1. Introduction

Mechanical or material recycling of thermoplastic offers a practical solution for municipal solid waste reduction. Post-consumer plastics such as polyethylene (PE), polyethylene terephthalate (PET), and polystyrene (PS) may be segregated from each other by physical methods such as density difference and hence processed as single plastics (Super et al., 1993; Owen and Bevis, 1975). Advanced separation methods are needed when dealing with plastic recycling in order to extremely minimize cross contaminants between different batches (Wu et al., 2013). Despite the importance of the segregation step in mechanical recycling for producing single-phase plastic material, traces of contaminants in form of comingled materials such as metals and other plastics, may exist with the recycled plastic, which would greatly affect its final properties. For example, acetaldehyde (a constituent produced when PET is degraded) and polyvinylchloride (PVC) can hinder the recyclability of PET (Webb et al., 2013). Contaminants in form of organic residues can deteriorate the quality of extruded and injection molded products of wood plastic composites (WPCs) and hence need to be sorted out carefully from wood waste stream (Sommerhuber et al., 2015). Mechanical properties of recycled *isotactic* polypropylene (iPP) can be inferior to great extent if only up to 5% of PE is present in the recycled PP streamline (Luijsterburg et al., 2016). Other contaminant traces such as PET, which would have negative effect on mechanical properties of PP, may be excluded upon processing recycled PP by using a melt filter (Luijsterburg et al., 2016). Contaminants in form of fragmentations of inorganic matters at a certain concentration in multi-layer recycled polymer can reduce their performance in terms of mechanical properties (Wyser et al., 2000). PP itself along with other contaminants and fillers can deteriorate long-term properties such as molecular weight of post-consumer high-density polyethylene (HDPE) (Alzerreca et al., 2015). The rheological properties of PE film waste contaminated with biopolymers such as polylactic acid (PLA) was found to deteriorate regardless the percentage of PLA in the blend system of PE/PLA (Gere and Czigany, 2018). Food contaminants such as milk residuals were reported to have insignificant effect on the flow and tensile properties of recycled milk jugs (Kuhlman, 1999). Engineering polymers either fiber reinforced or without any reinforcements, despite their superior characteristics, may suffer from the presence of various types of contaminants (Zhang and Mason, 1999; Liang and Gupta, 2001; Schiebisch et al., 1995; Blyler and Bair, 1975). Specimens of epoxy reinforced with carbon fibers were reported to lose about 80% of their shear strength upon immersing in organic solvents, e.g. Acetone (Zhang and Mason, 1999). Liang and Gupta (2001) postulated that recycled

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stream of polycarbonate (PC) and acrylonitrile butadiene styrene (ABS) should at least have less than 1% of contaminants in order to restore much of their original mechanical properties such as impact strength in comparison with those of virgin materials. The presence of ABS and PP as impurities in high impact polystyrene (HIPS) waste stream can produce recycled articles with very low impact strength values (Perrin et al., 2016) Schiebisch et al. (1995) have reported that contaminants in form of various thermoplastics may not hinder the reuse of polyamide 6 (PA6) provided that their concentration does not exceed 5% with well distribution in PA6 matrix. On the other hand, coating layers that are routinely associated with plastic materials may react with PA6 at high temperature and alter the properties of recycled PA6 (Schiebisch et al., 1995). Volatile residuals, impact modifiers, and halides, which act as flame-retardants for ABS, were reported to alter its rheological characteristics such as viscosity and relaxation (Blyler and Bair, 1975). Dirt and packaging tapes can greatly affect some of the properties of PE films (Marsh et al., 2006). Specifically, dirt contaminants were seen to alter elasticity and melt viscosity of PE (Marsh et al., 2006).

Contaminants are not the only cause for the reduction in the properties of recycled plastic product. It is known that reprocessing of plastic waste by various means of melt processing equipment such as extruder and injection molding can lead to product properties deterioration due to molecular weight reduction and degradation.

Most of the previous studies dealt with comingled plastics, i.e. two or more plastic articles of different types were mixed together. However, one should be cautious about some contaminants presence in same plastic articles such as product labels and bottle cap ring, glue, and others. These contaminants, although exist in trace amount, may drastically deteriorate properties of the recycled plastics especially the mechanical properties. To the best of our knowledge no single paper in the open literature tackled the influence of traces contaminants in form of papers on the mechanical proprieties and processability of PC-PET. Therefore, the aim of this work is to investigate the influence of paper contaminants on the mechanical properties and processability of PC-PET.

2. Experimental

2.1. Materials

PC-PET articles mainly consisting of water and soft drink bottles were used as recycled materials. Virgin PETs used were BC111 and BC112, polyesters blow-molding grade for water and soft drink bottles respectively. BC112 has a pigment with higher value of intrinsic viscosity compared with that of BC111. The manufacturer of these two virgin PET is Saudi basic industry corporation (SABIC) in Riyadh, Saudi Arabia.

2.2. Procedure

First, lids (caps) of the as received PC-PET bottles include both transparent and colored were removed manually. Then, PET water bottles (transparent) were separated manually from PET soft drink bottles (colored). After that, a plastic crusher (type S-460 Pauline) was used to crush bottles into flakes using a 6 mm sieve. Even though, a crushed bottle was solely made of PET there will be some other materials associated with it that are hard to remove manually such as the plastic ring used to seal the cap for the new bottle and the bottle label (Fig. 1). Note here that bottle label may be made of PE or papers. Hence, the raw crushed PET will not be 100% PET. The percentage of PE, papers, and PET were 3.09 wt%, 2.11 wt% and 94.8 wt% respectively. Both batches, i.e. transparent PET and colored PET, were subjected to sink and float process to separate materials with specific gravity less than one, i.e. lid ring which is made of HDPE.

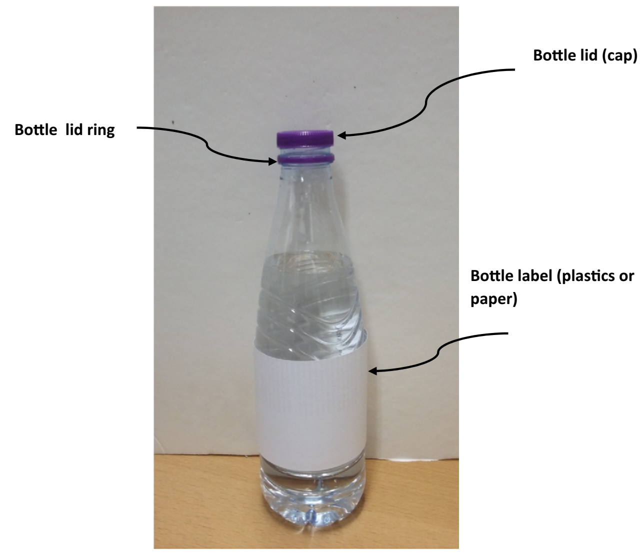

Fig. 1. PET water bottle showing the label and lid ring.

Sunk material, PET, was not solely PET but it had some traces of papers that absorbed much water during the sink-float process and tended to sink with PET flakes. The percentage of paper with PET flakes was determined to be ~1 wt%. Finally, equal weights of transparent and colored PET with and without traces papers were mixed together to be processed with other PET materials with different processing methods as indicated in Fig. 2. Fig. 2 shows the flow chart of the sorting and processing of the different batches of PC-PET used in this study. Some PC-PET were prepared by extrusion while others were only prepared by mini molding process were the extrusion step was skipped. In all processing methods, PET materials were dried overnight in a vacuum oven at 90 °C. In the extrusion process, PC-PET flakes were fed to a 26 mm co-rotating twin screw extruder (Scientific LTE26-32 by Lab. Tech., Ltd). Screws were operated at a speed of 30 rpm, while the temperature of main zones of the extruder was set at 260 °C except for the first zone near the hopper where a temperature of 250 °C was used. The extrudates were drawn into a water bath pelletized, and stored in plastic bags. All prepared samples of PC-PET were mechanically tested while some selected samples mainly with paper contents were prepared by compression molding as sheets to test their ability to form good molded parts.

2.3. Mechanical properties

A dynisco mini molder (LMM) was used to mold samples for the Izod Impact strength and tensile strength tests as per ASTM D 256 and ASTM D1708 respectively. LMM was operated at a temperature of 270 °C with a rotating speed of 30 rpm. A Tinius Olsen pendulum impact tester (IT 504) was used to measure notched Izod impact strength of the samples. Tensile strength of the samples was measured by a Hounsfield universal testing machine, model H5KS, using a 5 KN load cell. For both tests, i.e. impact and tensile, five specimens were tested and the average and standard deviation were recorded.

2.4. Compression molding

Flakes and pellets of PC-PET and others were compress molded by a hot press (model 4533.4NE1001 manufactured by carver,