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Modification of mechanical properties of recycled polypropylene from post-consumer containers

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Abstract

This study is conducted to look at the modification of mechanical properties of recycled polypropylene (PP) from post-consumer containers with the addition of stabilizers, elastomer (ethylene–octene rubber, EOR) and calcium carbonate ($CaCO_3$). The mechanical and thermal properties of the blends were evaluated. The results showed limited changes with the addition of elastomer and calcium carbonate on the mechanical properties of the recycled polypropylene. Some differences were observed, but the trends were not reproducible over the different compositions. DSC analysis confirmed the presence of polyethylene (PE) in the recycled polypropylene. The polyethylene impurity and the presence of many different qualities of polypropylene in the recycled material may have prevented any possible improvement in the mechanical properties by the addition of EOR and $CaCO_3$, improvements seen in previous studies on virgin polypropylene. The compatibility of the different homopolymers and copolymers of PP used in consumer packaging is not known, while polyethylene and polypropylene are known not to be miscible with each other. The mixture of qualities and materials may explain such a poor blending. Reusing and upgrading of recycled PP from post-consumer containers would therefore first require a better sorting of the post-consumer waste. The use of an adequate compatibilizer that would allow a uniform and homogeneous blending of the raw material mixture might enhance the mechanical properties.

1. Introduction

The use and demand of polypropylene is increasing at a very fast pace. In 2000, polypropylene represented 23% of the thermoplastic consumed in Western Europe. Its sales in tonnage is the third most important amongst plastics in the world (Zebarjad et al., 2006). Indeed polypropylene can be produced from low-cost petrochemical raw material, making it an inexpensive thermoplastic, relative to others, while showing good processability and reasonably high mechanical properties. However, due to its chemically stabilized state for long service life and high volume-to-weight ratio, it is one of the most visible forms of waste in landfills. The pressure to recycle has increased significantly for economic, political and environmental reasons in today's society. Waste is perceived as a major problem, especially for high consumption plastics such as polypropylene (Papaspyrides and Poulakis, 1996). The recycling process of post-consumer waste has appeared to be complicated because of the necessity of materials separation, as well as lower material properties (strength, stiffness, stability...) of recycled materials. It is hard to conduct and maintain a constant quality of recycled material coming from household waste because of the many types and grades of polymers used. On the contrary, materials used in car bumpers, drink bottles, and drink caps for instance follow a closed recycling loop which assure their quality. Some studies show that up to 10% of foreign materials can be found in recycled polypropylene despite being sorted centrally by trained personnel (Seiler, 1995).

Techniques, for instance automatic sorting facilities using infra red technology, can be used to reduce the amount of impurities, but their use increases the cost signif-

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icantly. Furthermore recycled polypropylene undergoes thermo-mechanical degradation events due to high temperature and shearing during processing (Goldberg and Zaikov, 1987; Gonzalez et al., 1998; Tiganis et al., 1996). Similarly, recycled polypropylene has lower fracture properties (Aurrekoetxea et al., 2001a,b) and heat ageing (Gahleitner, 2002) compared to virgin material. Virgin polypropylene homopolymer has a rather low modulus, a limited impact resistance and high notch sensitivity (Yang et al., 2006). To improve the mechanical and thermal properties, additives, such as mineral fillers and rubbers or elastomers, are blended with polypropylene (Yang et al., 2006; Chan and Wu, 2002; Wang et al., 2002; Levita et al., 1989; Ma et al., 2005; Chen et al., 2004). Elastomer such as ethylene–propylene rubber (EPR) is used to enhance toughness and impact resistance, but has the side effect of also reducing the yield strength and Young's modulus. To complement as well as amplify the effect of the elastomer content, inorganic fillers are added. Calcium carbonate, $CaCO_3$, provides increased impact energy, improved hardness, and higher modulus and tensile strength, while lowering the cost (Jang, 1992; Nam et al., 2001; Premphet and Horanont, 2001). Consequently, the addition of both elastomer and filler in the polypropylene affects the mechanical properties of the hybrid material depending on their composition, but also on their phase morphology (Zebarjad et al., 2006). Literature refers to two separate possibilities for where the inorganic fillers end up, the elastomer particles and rigid particles are scattered in the polypropylene matrix independently, or the elastomer particles attract and absorb the rigid particles (Jancar et al., 1993; Premphet and Horanont, 2000; Barbosa et al., 2000). While using additives on virgin polypropylene improves the mechanical and thermal properties of the material, the phase morphologies would appear to be critical for recycled polypropylene, where impurities such as other polymers and paper are likely to be an important factor to take into account during the blending with additives. The objective of this study is to look at the mechanical properties obtained with the blending of a stabilized recycled polypropylene from post-consumer waste with different compositions of ethylene–octene rubber, EOR, and calcium carbonate, $CaCO_3$. The idea is to enhance the properties of the recycled polypropylene sufficiently for an intended technical application, without losing the ecological and economic advantages of the recycled material. The application in mind during this study is the buckets used in the Tomra Recycling Centre (TRC). Tomra produces reverse vending machines for empty drink bottles and containers. The Tomra Recycling Centre is developed to help consumers recycle and to facilitate the return of several types of used, rigid packaging, including PET, PP and PE. Tomra wants to close material loops by using recycled packaging materials in applications in the Recycling Centre. The buckets in the TRC require most of all high impact resistance due to the high number of products (plastic bottles, glass bottles, tins, cans, and rigid packaging) falling into the buckets. The buckets also require high stiffness due to the high temperature within the Centres in the summer, high wear resistance and resistance to fatigue. This study investigates the possible upgrading of material properties of the recycled PP in order to fulfil the requirements for the buckets. This study investigates also the morphology, thermal properties, and fracture surface properties of recycled polypropylene, by means of calorimetry and microscopy analysis, in order to collect valuable information about the characterization of recycled polypropylene blends.

2. Experimental procedures

2.1. Materials

Different blends were prepared using recycled polypropylene from post-consumer waste. The recycled polypropylene was delivered from Expladan in Denmark. A combination of two kinds of stabilizers was used: Irganox B215 FF, a processing stabilizer and Chimassorb 944 FD, a hindered amine stabilizer (HAS), used for long term thermal properties. The rubber used during these tests is Engage 8401 from Dow Chemical Company, a polyolefin elastomer produced by metallocene technology which is a copolymer of the α-olefin octene and ethylene. Engage 8401 has a melt flow rate, MFR, of 30 g/min (190 °C, 2.16 kg) and a density of 885 kg/m^3. The calcium carbonate used is Danchalk PC $CaCO_3$. The particles have a mean diameter of 3 μm and are surface coated with 2% stearic acid, a low molecular weight organic compound. The stearic acid on the filler particles reduces the particle:particle interaction, leading to a better dispersion of the particles in the PP matrix (Suetsugu and White, 1987; Jancar and Kucera, 1990).

2.2. Blending preparation

Compounding of the materials was performed on a Clextral co rotating twin screw lab extruder with a set of standard polyolefin screws. Each screw has two reversed elements (back flow) and two kneading blocks for a better blending of the materials. The length of the screws was 800 mm with a diameter of 25 mm. In the extrusion set, the barrel temperatures varied from 180 to 215 °C, and the production speed was 100 g/min. A masterbatch of polypropylene and stabilizers was produced prior to the blends in order to facilitate and compose an even dispersion of stabilizers in the polypropylene matrix. Eight different blends with different compositions were made (Table 1). Consequently, the recycled polypropylene was blended twice for the blends containing EOR and $CaCO_3$.

2.3. Specimen preparation

Test specimens were injection moulded on a Battenfeld BSKM 45/20 HY (2 mm thick specimens) or a DSM mini extruder/injection moulder (4 mm thick specimens) at