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Recycling polymeric multi-material products through micronization

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ABSTRACT

The increasing usage of polymeric materials and the greater range of requirements in product design lead to the combined use of more than one material in the same product, component, the so-called multi-material products. These products represent a risk for the environment, as they make the conventional recycling process more complicated. The main problem in recycling polymeric multi-material products is related to the difficulty in separating their components. Thus, it is necessary to find solutions to allow multi-material recycling without the need to separate these materials. In this context, this study aimed to analyze the technical feasibility for the application of micronization in recycling polymeric multi-material products and to evaluate the potential of the resulting materials for use in new products. Therefore, a theoretical part, focusing on polymeric multi-material products and micronization, and a practical study, consisting of multi-material toothbrushes recycled via micronization, were presented. The experimental investigation involved the micronization of multi-material toothbrushes, followed by extrusion and injection molding. Subsequently, the resulting material was evaluated using scanning electron microscopy (SEM), tensile strength test and dynamic mechanical thermal analysis (DMTA). The results showed that micronization is a potential process to promote the recycling of multi-material products, and there was no degradation during the process. The recycled micronized material had a low level of interaction with the LLDPE matrix, which affected the elongation at break, causing loss of ductility and tenacity compared to virgin LLDPE. However, it did not affect the tensile strength, which presented an increase of 18.43% compared to the reference. Despite better performance in tensile strength, the recycled sample showed an intense decrease in the storage modulus in temperatures above 30 °C. This may limit the use of these materials in certain products. Based on the results obtained, it can be concluded that the resulting material has potential applications in new products.

1. Introduction

The use of polymers in diverse products has gained more importance in recent years (Allwood and Cullen, 2012; Gabrys et al., 2013; Julier, 2013). The evolution of polymeric materials and the increase in product requirements culminated in the combined use of more than one polymer in the same product component (Thomas and Yang, 2009; Wargnier et al., 2014), giving rise to so called multi-material products (Kromm et al., 2007).

Polymeric multi-material products are usually produced by co-injection molding (Kim and Isayev, 2015) and present several advantages related to Design for Manufacture and Assembly (DfMA), such as reduced manufacturing time and costs, final product quality, less need for manpower etc. (Advani and Hsiao, 2012; Wargnier et al., 2014). Despite the technical advantages, there are some disadvantages to the environment, due to problems with reprocessing, recycling and separation (Allwood and Cullen, 2012; Worrell and Reuter, 2014).

Difficulties in recycling polymeric multi-materials have a major impact on the environment, especially in the end of life, once it generates waste. Solid waste generation rates have increased and

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are responsible for stocking landfills, which opposes the idea of a fully closed material cycle (Bosmans et al., 2013). Furthermore, the difficulties in recycling these products impact on the extraction of raw materials for new products, since waste could be used to replace virgin raw materials, reducing the demand for primary production (Ichinose and Yamamoto, 2011; Kollikkathara et al., 2010; Koushal et al., 2014). In addition to the impact on environment, the recycling issues are also related to economic (Murakami et al., 2014; Ohnishi et al., 2016), social (Wilson et al., 2006) and regulatory (Campos, 2014) factors.

Therefore, it is necessary to find solutions to enable the recycling of multi-material products. Several studies have been conducted with the purpose of reprocessing difficult recycling materials using micronization (Casa and Castro, 2014; Hong et al., 2015; Prameetthaa and Bharatkumar, 2014; Stark et al., 2014). This research aimed to analyze the technical feasibility of applying micronization in the recycling of polymeric multi-material products and to investigate the potential of the resulting material for their application in new products. This was an interdisciplinary study, involving Product Design, Materials Sciences and Environmental Quality. It also aimed to achieve sustainable development.

2. Context overview and earlier studies

2.1. Polymeric multi-material products

Polymers have revolutionized the way that designers and consumers perceive the products (Julier, 2013). The demand for polymeric materials intensified after World War II and continued to grow rapidly (Allwood and Cullen, 2012).

The use of polymers is of increasing importance and has stimulated research on new types of polymers, new ways of processing and applications. These efforts resulted in a significant diversity of polymers available, being one of the factors leading to the use of more than one type of material in the same product component, the so-called multi-materials (Thomas and Yang, 2009). Other factors have also influenced the emergence of multi-materials. The need to reduce costs and to improve the performance of technical products has led designers and engineers to incorporate more functions in just one component (Wargnier et al., 2014). These requirements cannot be achieved when a product is composed of a single material. Therefore, the current trend is to develop multi-material products. The case of toothbrushes is an example. A few years ago, the material selection for hygiene products was restricted to health issues. Nowadays, however, ergonomics and aesthetics are also being considered (Yang et al., 2005). To fulfill these requirements, the use of different materials is necessary. The main advantages of multi-materials consist of improving component performance, integrating more functions to material, reducing costs, facilitating production and avoiding voluminous parts (Wargnier et al., 2014). The applications of multi-material products extend far beyond daily products. They range from personal care items, such as toothbrushes and razors, to vehicle panels, foods and beverage packages, tool handles, among others.

In industries, the most used process to manufacture these products since the early 70s is the co-injection molding (CIM), also known as sandwich injection molding. The possibility of combining two different polymers provides unique properties that could not be achieved through the traditional injection molding process, with one single injection (Kim and Isayev, 2015). CIM is a process in which two polymers are simultaneously or sequentially injected in the same mold cavity. The final result is a heterogeneous product, comprising the “core material” (the main material) and the “skin material” (the surface material applied in smaller quantities) that fuse (Zaverl et al., 2013). In the field of engineering (Advani and Hsiao, 2012; Boothroyd et al., 2011), this process presents several technical advantages, such as better quality, reduced manufacturing costs and shorter time, and consequently, the assembly work becomes unnecessary (Advani and Hsiao, 2012). Thus, the product parts can be produced economically, in a single step, by operating one machine and one mold, following the DFMA guidelines (Boothroyd et al., 2011). In addition, CIM is also one of the most promising methods from both the economic and ecological points of view (Kim and Isayev, 2015). However, the environmental quality issues are controversial. According to the ecodesign approach, co-injection molding of multi-materials could represent environmental risks. The melting of two different materials precludes their separation and recycling through the traditional process (Allwood and Cullen, 2012; Worrell and Reuter, 2014). Therefore, the main disadvantage of multi-material products, especially the difficulty in their reprocessing and recycling, is related to negative impacts on the environment.

Some authors (Cândido et al., 2011; Hopewell et al., 2009; Kreiger et al., 2014; Koushal et al., 2014; Nkwachukwu et al., 2013; Rajendran et al., 2012) consider recycling as the best choice in polymeric residue management. However, the amount of polymeric material destined to recycling is still small. From the 280 million tons of polymer produced globally in 2012, less than half was destined to recycling, landfilling or energy recovery through incineration. The remaining residues may be still in use or are being inappropriately discarded. In this sense, if the high demand for polymeric products continues, and the recycling rates remains the same, there will be an amount of 33 billion tons of plastics in the planet by 2050 (Rochman et al., 2013). In this context, the difficulty in recycling presented by polymeric multi-material products leads to many serious environmental damages, including high rates of solid waste generation that can result in an overload of landfill capacity (Kollikkathara et al., 2010), or waste in inappropriate places, presenting risks to the population (Ichinose and Yamamoto, 2011).

2.1.1. Polymeric multi-material recycling and characterization

Considering the need for expanding the practice of recycling, this research proposed the recycling of mixed polymers without the need of separating materials. This way, economical costs linked to the separation process could be reduced when providing recycling of mixed plastic wastes, making it more profitable (Bertin and Robin, 2002; Najafi et al., 2006). Many authors have discussed ways of reprocessing polymer-based composites by several methods (Perry et al., 2012; Palmer et al., 2009; Pickering, 2006; Yip et al., 2002). However, there are only a few specific studies regarding mixed polymers or polymeric multi-material recycling and end-of-life solutions. Among them, we may cite the study that applied a polymer milling process with liquid CO_2 to polymeric mixed waste, obtaining a powder material that was successfully utilized for a new composite material as a matrix (Cavalieri and Padella, 2002). The use of pyrolysis to recycle mixed plastics was also studied (Kaminsky, 1995; Kamisnky and Kim, 1999). Another study (Hopewell et al., 2009) showed that incineration with energy-recovery was indicated as the most suitable way for dealing with highly mixed plastics. Although, according to the UK Waste Resource Action Programme (WRAP, 2008), incineration has the second least favorable environmental performance, been only better than landfill. Despite that, landfill is still the most common destination for polymeric multi-material products and components. The research that analyzed the life cycle of multi-material car components reported that only steel is recycled in final disposal phase. Mixed polymers like polyamide and elastomers are destined to landfill (Ribeiro et al., 2007).