Valorisation of poly(lactic acid) wastes by mechanical recycling: improvement of the properties of the recycled polymer

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The use of bioplastics is attracting increasing attention during the past years, reaching a global production capacity of 4.16 million tonnes in 2016, of which nearly 40% were destined to packaging applications (European Bioplastics, 2016). Poly(lactic acid) (PLA) is currently one of the most widely used bioplastics, mainly in food packaging applications, due to the easy processing and good properties. Therefore, the PLA market is expected to experiment an annual growth rate of 10% until 2021 (Aeschelmann and Carus, 2016).

This growing trend in the consumption of PLA could generate some environmental issues, since most of the commercial grades used in packaging applications do not easily biodegrade in ordinary conditions. In fact, many composters consider PLA as a "contaminant". Moreover, PLA wastes can also contaminate the polyethylene terephthalate (PET) waste streams, because colour and density of PLA and PET are similar. Hence, most of the PLA containers are improperly discarded after their first use, thus generating an important environmental problem. In order to address this issue, several alternatives have been proposed and evaluated for the valorisation of plastic waste, such as incineration, chemical and mechanical recycling. Several studies based on Life Cycle Analysis (LCA) have concluded that mechanical recycling is, from an environmental point of view, the most interesting alternative for the valorisation of PLA wastes coming from packaging applications (Piemonte, 2011, Rossi et al., 2015).

Although mechanical recycling presents some interesting advantages, as it reduces the consumption of renewable resources and energy (Niaounakis, 2013), some challenges arise in its application to PLA wastes. Firstly, the introduction of a new plastic in the mechanical recycling processes leads to the necessity of developing more adequate and cheap recovery methods. Secondly, it is necessary to evaluate the performance of the recycled materials, since if there is an important decrease on the properties during the recycling, it would not be possible to develop markets for goods made with the recycled plastic, making the mechanical recycling an unfeasible process.

Previous studies have shown that the optical, mechanical, thermal and barrier properties of the recycled PLA vary with the mechanical recycling process applied, although the differences were small in all the cases, and the properties of the recycled plastics were similar to those of virgin plastic (Beltrán et al., 2016a, Beltrán et al., 2016b). However, it is necessary to foresee the appearance of fractions of highly degraded waste, which may compromise the properties of the recycled plastic and, thus, the feasibility of the recycling process. Therefore, it is necessary to develop strategies for improving the properties of recycled PLA. Among these strategies we can consider thermal treatments, mixing of recycled and virgin resins, utilization of nano-reinforcements (such as nanoclays, graphene, carbon nanotubes and nanofibers) and chemical treatments (utilization of chain extenders, stabilizers and peroxides). The main aim of this work is to evaluate different strategies for upgrading recycled PLA, specifically the mixture of virgin and recycled resins and the utilization of chain extenders and peroxides.

A commercial grade of PLA, especially designed for packaging applications, was subjected to different mechanical recycling processes, including demanding washing stages. The recycled PLA was then divided in three fractions, which were subjected to different treatments: One was mixed in 50/50 proportion with virgin PLA, another was extruded with a chain extender and the other was extruded with commercial peroxide. The resulting materials were compression molded into films, and then characterized by means of intrinsic viscosity measurements (IV), differential scanning calorimetry (DSC) and infrared spectroscopy (FTIR-ATR). The thermal stability was measured using thermogravimetry (TGA), the mechanical properties were compared by using microhardness measurements and the optical properties were analyzed using UV-Vis spectroscopy (UV-Vis) and standard colorimetry.

It is known that PLA could suffer thermomechanical, photochemical and hydrolytic degradation during its service life and in the mechanical recycling process, which could affect the final properties of the recycled materials. Fig. 1 shows the viscosimetric molecular weight of the virgin PLA and two recycled materials (PLAR and PLARW) which have been subjected to different accelerated degradation-recycling processes. It can be seen that the mechanical recycling caused a decrease on the molecular weight of PLA, especially in samples subjected to demanding washing steps, such as PLARW, and thus may cause a decrease on the properties of recycled PLA.

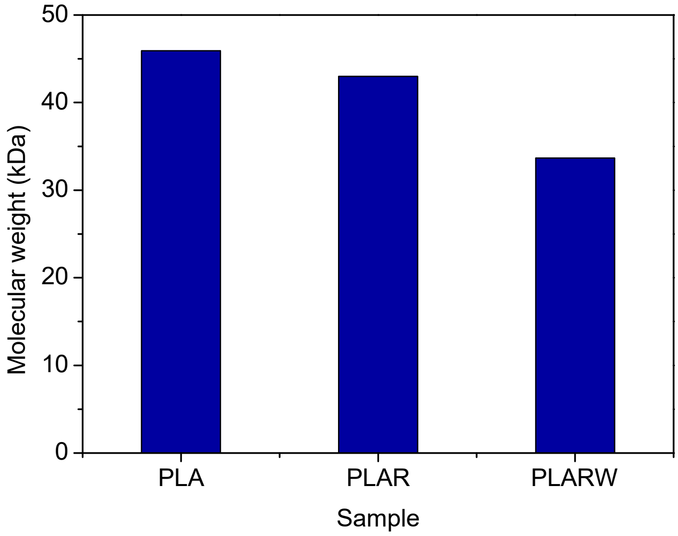

Fig. 1. Viscosimetric molecular weight of the virgin and recycled samples

The results indicate that the 50/50 blend of virgin and recycled PLA has acceptable properties. In addition, the strategies studied in this work based on the use of peroxides and chain extenders allow to increase the molecular weight and properties of the recycled plastics. Considering also that the treatments studied have a moderate cost, the results suggest that the evaluated strategies are useful to increase the viability of the mechanical recycling of PLA.

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