Influence of Different Dry-Mixing Techniques on the Mechanical, Thermal and Electrical Behavior of Ultra High Molecular Weight Polyethylene/Exhausted Tire Carbon Composites

INFLUENCE OF DIFFERENT DRY-MIXING TECHNIQUES ON THE MECHANICAL, THERMAL AND ELECTRICAL BEHAVIOR OF ULTRA HIGH MOLECULAR WEIGHT POLYETHYLENE/EXHAUSTED TIRE CARBON COMPOSITES

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Introduction

Global warming, depletion of fossil fuel and availability of waste materials are key-factors in the development of waste valorization processes. Among others, exhausted tire (ET) disposal represents a serious pollution problem due to the dangerous impact on the environment and human health, so that in all of European area tires landfilling has been forbidden. Nowadays, about 66% of exhausted tires is confined in landfill (outside Europe) or incinerated. A smaller part of the tires is recovered through industrial process for raw materials recycling, for gasification and pyrolysis [1]. These thermochemical routes are cost-effective approaches for end-life tires management and provide an interesting opportunity with a view to a "zero waste" circular economy. In this field, pyrolysis is recognized as efficient method for waste valorization with the simultaneous production of combustible gas, hydrocarbon mixtures and carbon. Numerous reports analyzed the advantages and disadvantages of the ET pyrolysis process with respect to other thermochemical approaches [2]. The main advantages include both the minor environmental impact and the recovery of liquid and solid materials. The solid char (i.e., exhausted tire carbon-ETC) has a very complex composition and mainly contains the original carbon black, inorganic compounding fillers and carbonaceous deposits. Up to now, it has been mostly used for the preparation of activated carbons both by physical and chemical activation for the removal of organic/inorganic pollutants from industrial wastewater and air [3]. Another possible use is for the development of doped carbon-based electrodes. However, only few papers report on the use of ETC as a filler for the preparation of polymer composites. In this context, it has been used for the preparation of rubber composites [1] to be reused in tire formulation and of epoxy nanocomposites for coating applications. Considering that the demand for using polymer composites in various application areas is massive and that the incorporation of ETC in a solid market is challenging, further studies are required to overcome the barriers behind the incorporation of ETC into polymer composites and giving a positive impact to the sustainability. In this light, we have prepared ultra high molecular weight polyethylene (UHMWPE)-based ETC composites, in order to assess the effect of the filler on the mechanical, thermal and electrical properties of the polymer matrix. Two techniques were employed for mechanically mixing the powder components, i.e. a homogenizer (PEx_H samples, where x is the ETC wt.%) and a home-made impact mill (PEx_M samples); the mixing step was followed by compression molding. Characterization was completed by means of rheological study, and scanning electron and optical microscopy. UHMWPE has been selected because it is largely exploited for a huge variety of industrial applications, thanks to its properties, processability and low cost. Besides, the interest in UHMWPE-based composites containing carbonaceous fillers is steadily increasing, particularly referring to the design of new conductive polymer composites.

Results and discussion

Figures 1A and 1B show the cross-section micrographs of PE3_H and PE3_M composites, respectively. In both images, the filler particles are distributed around the perimeter of the original polymer grains. However, in the homogenized composite, ETC is not well packed as it shows the presence of some holes (white arrow in Figure 1A). Conversely, using the impact mill, the ETC particles and polymer tightly combine each other. When the ETC concentration is 10 wt.%, the ETC particles completely cover the surface of the original UHMWPE powders and form a packed network. Nevertheless, the composite obtained by homogenizer presents a less uniform distribution of filler with respect to the composite obtained by impact mill (Figures 1C-D). Figure 2 reports the dimensionless low-frequency complex viscosities (the ratio between the complex viscosity of the composite and that of unfilled UHMWPE, both evaluated at 0.1 rad/s) as a function of the ETC loading for both PEx_H and PEx_M systems.

It is clearly noticeable that higher complex viscosity values are shown for PEx_M composites. The large particle agglomerates formed in PE_H composites limit the establishment of polymer/particle interactions, thus preventing the achievement of the high complex viscosity values attained by the impact milled counterparts.

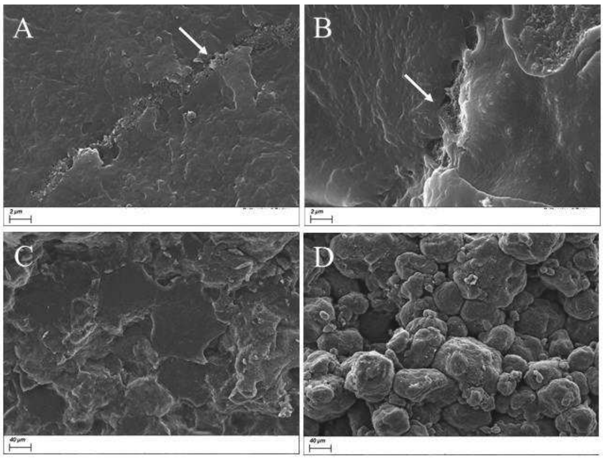

Figure 1: Cross section images of UHMWPE composites containing 3 (A and B) and 10 wt.% of ETC (C and D) obtained by homogenizer (A and C) and by impact mill (B, D).

Furthermore, the difference between the complex viscosity values of the two series of composites is more pronounced at high ETC contents. These findings can be associated with the higher effectiveness of the ball impact method in achieving a better distribution of the particles around UHMWPE grains in the initial powder mixtures, resulting in the formation of a more regular microstructure, especially in the composites containing higher ETC amounts.

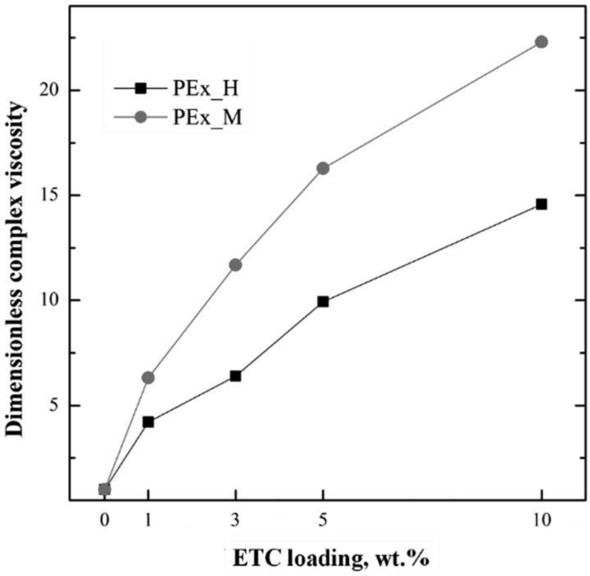

Figure 2: Dimensionless complex viscosity values (measured at 0.1 rad/s).

In the impact milled composites, the good dispersion and formation of close packed structure are responsible for the higher values of the thermal conductivity, electrical resistivity and mechanical properties with respect to those measured for homogenized counterparts.

Concerning the electrical measurements, shown in Figure 3, all the composites, irrespective of the preparation method, follow a classical electrical percolation behaviour. Moreover, the electrical resistivity of milled composites is always lower respect to that of PEx_H; however, at high loadings (i.e., 10 and 20 wt.%), it approaches that of the homogenized composites.

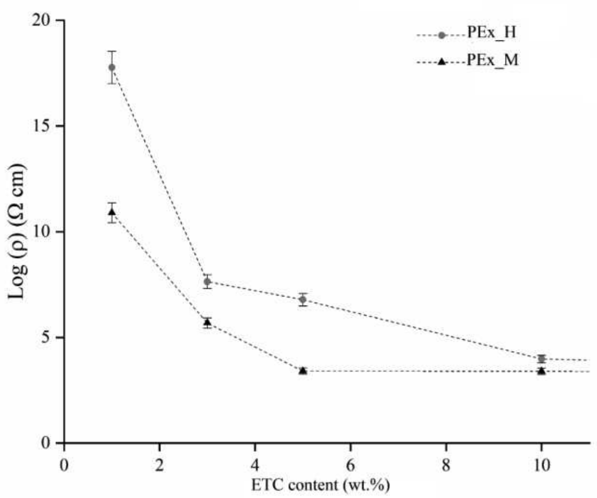

Figure 3. Electrical resistivity vs. ETC content for composites obtained by homogenizer (PEx_H) and impact mill (PEx_M).

Conclusions

In this work, the mixing methods used for preparing UHMWPE-based composites containing exhausted tire carbon affected the rheological and morphological features of the composites that, in turn, influenced their mechanical, thermal and electrical behavior. Better performances were achieved for the composites obtained with the impact mill, which showed improved Young modulus, reduced electrical and thermal resistance with respect to homogenized counterparts. The results were ascribed to the better distribution of filler and close packed filler around the polymer grains. From a general point of view, it was demonstrated that ETC has great potential as a filler for polymers in a variety of electrical and engineering applications.

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