Mechanical and structural properties of composites made from recycled and virgin polyethylene terephthalate (PET) and metal chip or mesh wire

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Abstract. Although polyethylene terephthalate (PET) is a champion of recycling, intense research is being done to find new solutions for using recycled plastic. This study aims to characterize the mechanical and structural properties (SEM- scanning electron microscopy) of products made from recycled metal swarf or mesh wire with recycled plastic (PET) in comparison with virgin plastic. Samples manufactured from virgin and recycled PET are made by pressing and high temperature. The loss of mechanical properties of products made from recycled plastic is a major drawback that influences their use. SEM images confirm that the dispersion and distribution of the PET phase is not very uniform. By addition of virgin plastic in various compositions with recycled plastic, processing parameters and mechanical properties can be optimized.

1 Introduction

Polyethylene terephthalate (PET) is a semi-crystalline polymer and its composites are widely used in the packaging, construction, automotive, household, electrical and textile industries. Considerable efforts have been made to improve the various physical, mechanical and barrier properties of PET by mixing with the nanoclass to produce PET composites from stratified clay [1-13] The efficiency of the recovery of polymeric materials is much increased if they are finely ground after grinding. The grinding is done with machines at a more advanced grinding level.

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Many plastic materials, such as those made of poly (ethylene terephthalate) (PET) and used for beverage containers, are formed by blowing, reheating or other operations that require thermal softening of the polymer [15-22].

When preparing the containers provided using operations that require thermal softening of the polymer, reheating time or time required for reforming, to reach the proper temperature for blowing molding (also called heating time), it affects both productivity and the quantity of energy required.

Xiao Wang et al. [24] present a study on modeling and optimizing the adhesion process by laser transmission technique between PET and 316L stainless steel using surface response methodology. The choice of laser parameters plays a very important role in determining the quality of the joint in the technique of laser transmission between PET films and 316L stainless steel plates. The parameters that influence the quality of the laser transmission at the connection between PET and stainless-steel plates were optimized using the response methodology for its realization, high power and a minimum common width. The experimental values are almost the same as the values offered by the mathematical model used and it indicates that the scanning model offers the appropriate answers by optimizing the key parameters through fast processing.

With improved processing equipment, it became possible to produce more units per unit of time. Thus, it is desirable to make polymeric composites that provide improved reheating properties, through faster reheating (increased preheating rate) or with less energy for reheating (increasing the efficiency in reheating), or both in comparison with conventional polymeric compositions.

The composition of polymers suitable for casting and including polyester polymers or copolymers, having incorporated metal particles that improve the heating properties are increasingly being studied in the literature [11]. The processes for obtaining such compositions are also studied. The steel particles can be incorporated into the polyester by melting or they can be added at any stage of polymerization, such as during the polymerization melting phase. A range of particle sizes can be used, as well as a few particle size distributions.

This study purpose is to characterize the mechanical and structural properties (SEM) of composites manufactured from recycled metal swarf or mesh wire with recycled plastic (PET) in comparison with virgin plastic.

2 Materials & Methods

The recycled PET flakes used in this study were purchased from a local company. These were obtained by grinding various packaging materials.

The virgin PET was from BP Aromatics, metal swarf from waste collected after the turning process and the braided metal mesh used in the industry. The recycled PET was crushed, washed and dried in order to obtain composites with the virgin PET, metal swarf and braided metal mesh.

The analyzed samples had the following composition: **C1**: virgin PET 65 wt.%, recycled PET 135 wt.% with wire mesh; **C2**: virgin PET 125 wt.%, recycled PET 125 wt.%, metallic swarf 30 wt.%; **C3**: virgin PET 50 wt.% with recycled PET 200 wt.%. Samples to be tested were processed using a laboratory press at a pressure of 15 bars. The upper and lower plates of the device were maintained at 250°C for 8 minutes. The temperature was monitored with the help of four thermal contact sensors mounted perpendicular to the body of the cylinder to avoid temperature losses. Temperature monitoring was carried out between 20 and 250°C, at a rate of temperature increase of 5°C per minute. From thermal point of view was applied the protocol: heating from 20 to

250°C, heat treatment for 8 minutes at 250°C, and then the crystallization step between 250 and 20°C. Fig. 1 is a schematic diagram of the manufacturing process for the three samples C1, C2, C3.

Fig. 1. Manufacturing process scheme.

Using a scanning electron microscope (SEM, FEI Inspect S, Netherlands), the morphology of the nanocomposite surface was performed. Mechanical properties samples were evaluated using a mechanical testing machine (Lloyd Instruments-LR5k Plus) equipped with Nexygen Software. The tests for the mechanical resistance of bending and traction were performed and the average of ten obtained values was recorded.

3 Results & discussions

The analysis of surfaces, sections and fractures was done by SEM, and was followed at several magnitudes between 100x and 5000x (Fig. 2-4). In fig. 2.a, b, c it is possible to observe the existing homogeneity on the surface of the sample, the lack of any cracks or voids of air as well as the smoothness of the sections that exist between the deformed areas. Was found that the PET flakes adhered to each other without splitting material at removing the sample from the press. It can be observed that, with the increase of the temperature for obtaining the composites, the degree of mechanical and / or chemical adhesion between the composite components increases. When analyzing the microstructure given in section of fig.3b it can be observed the complex structure of the composite and the existence of a predominant orientation of the PET fibers, in the up and down direction of the graph. The connections between virgin PET and recycled PET can be observed only randomly in areas where fibers are overlapping has not been realized in full-circle detail shown in fig.3b. The causes of these imperfections can be multiple air voids, remaining impurities in the recycled PET or particles with a tendency to agglomerate. The PET mixture adhered completely to the wire mesh shown in fig. 3.c, d, which confirms the compatibility and affinity of the matrix to the filling material.

Although the flakes adhered to each other in the mass of the sample, on the outer faces there was observed the existence of areas where the flakes were not completely melted (fig 2. b), their initial shape and dimensions being observed.

Fig. 2. SEM images for sample C 3 : virgin PET and recycled PET a) Surface(Magnitude 5000 X); b) section(Magnitude 5000 X); c) rupture (Magnitude 5000 X).

Fig. 3. SEM images for sample C1: virgin PET, recycled PET and wire mesh: a) Surface (Magnitude 1000 X); b) Section (Magnitude 1000 X); c) Section through wire mesh (Magnitude 500 X); d) Longitudinal section over the wire mesh (Magnitude 100 X).

Fig. 4. SEM images for sample C2: virgin PET, recycled PET, metallic span: a) surface (Magnitude 500 X); b) Section through rupture (Magnitude 1000 X); c) Rupture (Magnitude 1000 X); d) Surface (Magnitude 500 X).

In fig. 4 is presented the mixture between PET, recycled PET, and metallic swarf. On the outer facets, the metallic swarf is shown in a uniform dispersion(Fig. 4.a).Due to the chosen process parameters the sedimentation phenomenon was avoided(Fig. 4.d).The melting process was uniformly performed, resulting in a composite without air or gas in the sample mass(Fig. 4.b,c).

Changing in the materials used to manufacture parts are made for a variety of reasons, including cost, absolute performance, brightness and longevity. Although improved design engineering can achieve weight reductions, a point is reached where further improvements can only be made by using lighter materials. Therefore, considerable efforts have been made to replace steel and castings with lighter materials, such as aluminum and polymers.

Polymers are used in manufacturing for financial and technical reasons. The result pursued in this study, by applying such technologies, is the realization in short term and with neglectable additional investment of a limited number of copies from: the product itself; replica (on a scale or other material) of the product at various stages of development;

tools and devices necessary to manufacture the product, to validate the creative concepts up to the current phase, various tests and further orientation of the product development approach. In fig. 5 are the presented the mean values for the traction and bending resistance for the C1 C2, C3 analyzed samples.

Fig. 5. Mean values for the traction and bending resistance for the C1, C2, C3 analyzed samples

Experimental analysis and results obtained in this study, show that any change in composition, can lead to some improvement of the mechanical properties of the parts manufactured from virgin and recycled PET. The sample parameters C1 result in the higher values of bending and traction strength (fig. 5).

The mechanical properties of reinforced polymeric composite materials must be appropriate to the type of composite analyzed, considering the structure of the product to be made from such materials. For any polymer composite material, it is considered necessary to have a minimum of tests based on which the respective material can be satisfactorily characterized. For these researches, we will focus on testing the composite materials obtained at: the resistance to monoaxial traction, the resistance to bending, and the resistance to compression.

The bending modulus in composites is mainly a function of the modulus of individual components [24]. An increased bending property is attributed to the high stiffness of the components added to the system in a higher percentage than virgin or recycled polymer.

The results of the different mechanical and rheological properties are compared and correlated to demonstrate the coherence between the obtained results and the composition of the tested materials. The polydispersion index is also very important, because the probability of chain breaking is higher for polymers with high molecular weight. By analyzing the obtained results in this study, it is obvious that recycled PET has a lower impact and a reduced fracture resistance as compared to the one of the virgin PET. This is not unusual because the thermal processing of thermoplastic materials, especially condensation polymers can suffer greatly regarding the reduction of mechanical properties when processed at high temperatures.

Analyzing the obtained results, we can say that virgin PET can be incorporated in different percentages, metals in powder form, and the final application (which requires improved mechanical properties) will indicate the type of agent of functionality to be selected. The results also show that the sample with the highest virgin PET content in the composite series has the highest mechanical strength / traction.

4. Conclusions

Experimental analysis and results obtained in this study, show that any changes in samples composition, can lead to insignificant improvement of the mechanical properties of the parts made from virgin and recycled plastic. The addition of the metal mesh between 2

layers of mix between virgin and recycled pet and the metal swarf improved the mechanical characteristics of the composite, as compared to the unarmed one. The results also show that the sample with the highest virgin PET content in the composite series has the highest mechanical strength / traction. SEM images confirm that the dispersion and distribution of the PET phase is not very uniform. By addition of virgin plastic in various compositions with recycled plastic, processing parameters and mechanical properties can be optimized. In the future the focus on research will be oriented on finding the right methods to achieve a greater integration of the recycled pet into new products, made by innovative technologies that will consider the circular economy goals-respect for the environment and economic efficiency.

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