RECYCLING OF PP-BASED SANDWICH PANELS WITH CONTINUOUS FIBERS COMPOSITE SKINS

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ABSTRACT

The growing use of composite materials in various industrial sectors is now frequently accompanied by the concern for recycling scrap materials and composite waste parts. Government and customers are becoming aware of environmental pollution created by these materials and strict regulations for recycling of composite products waste are expected. New recycling methods are required to overcome the technical hurdles associated with recycling of such materials.

In this paper the set-up of a procedure for recycling of polypropylene (PP) based thermoplastic sandwich panels is presented. Continuous glass fibers/PP matrix laminates (60% by weigh) as skin and a PP foam with density of 90 kg/m^3 as core material have been used.

The proposed recycling procedure can be considered a secondary recycling process in which the waste sandwich panel with long fibers composite skins is converted into a short glass fibers composite material. The panel reduced in small parts has been first grinded by a mill and then homogenized using a mixer or a single screw extruder. Finally the mixed or extruded compound has been re-grinded and injection molded for mechanical testing and morphological characterization. The influence of mixing time, mixing temperature and mixer rotor speed on the mechanical properties of the recycled material has been experimentally investigated, leading to the definition of the best processing conditions. The influence of fiber content on tensile, impact and rheological properties of recycled material has been evaluated by testing samples obtained by injection molding pellets obtained from panels with different skins-core thickness ratio. The statistical distribution of orientation and length of the glass fibers has been characterized using an optical microscope, while the homogeneity of fibers distribution and the presence of voids is evaluated by SEM analysis.

1. INTRODUCTION

The growing use of composite materials in various industrial sectors is now frequently accompanied by the concern for recycling scrap materials and composite waste parts. Government and customers are becoming aware of environmental pollution created by these materials and strict regulations for recycling of composite products waste are expected [1]. New recyclable composites and recycling methods are required to comply with these regulations.

In this study a recycling procedure of PP based sandwich panels is proposed and studied. It can be considered as a secondary recycling process, in which the waste sandwich panel with long fibers composite skins is converted into a short glass fibers composite material.

The influence of mixing on the mechanical properties of the recycled material is studied, leading to the definition of the best processing conditions. The effects of fibers content on both static and impact mechanical performances of the recycled material, as well as on the rheological behaviour of the injected mixture, is also evaluated and explained by means of morphological characterization.

2. EXPERIMENTAL DETAILS

Materials

The sandwich panels, object of this study, were realised by compression moulding process, which had been optimised in a former study about processing of PP-based sandwich panels [2]. A closed cells PP foam with a density of 90 kg/m^3 supplied by Kaneka, Belgium, was used as the core. The skins were obtained by stacking balanced weave fabric plies (surface density 745 g/m^2), consisting of commingled E-glass/PP yarns (60% by weight of glass), supplied by Vetrotex under the trade name Twintex®. Several core/skin thickness ratios were used in order to change the relative amount of matrix and glass fibers in the recycled material.

Equipments

The sandwich panels were grinded in a laboratory mill; then the material was homogenized either by a single screw extruder (screw diameter of 19.05 mm, length to diameter ratio of 25) or in a batch mixer (HAAKE rheomix252P and rheomix600P respectively). The extruder working parameters were fixed by preliminary tests, leading to a screw rotation speed of 40 rpm and a maximum temperature of 200 °C in the final portion of the screw and in the die. The torque, the chamber temperature, the mixing speed (lobe speed), the chamber residence time are the mixer working parameters [3].

A laboratory injection moulding facility (RAY RAN PR3400) was used to produce the specimens for mechanical testing. Preliminary tests led to the following values for the injection moulding process parameters: 185 °C for the cylinder temperature, 35 °C for the mould temperature.

Mechanical characterisation of the moulded specimens was performed using a LLOYD INSTRUMENTS LR5K dynamometer. Tensile tests were carried out at a crosshead speed of 5 mm/min according to ASTM C638; specimen length was set to 25 mm, thickness to 3 mm and width to 6 mm.

Charpy Impact tests were performed by ATS FAAR IMPACTS 15 pendulum. The hammer is equipped with a force transducer, by which the sample breaking energy and the absorbed energy versus time during the impact can be measured and displayed. The ASTM D256 standard was followed for such tests, in which an unnotched horizontal sample with 12.5 x 3 mm cross section was held on 95.3 mm spaced supports.

Rheological characterisation of the recycled material was performed by cone and plate ARES rheometer.

3. RESULTS AND DISCUSSION

Recycling

During homogenisation in the extruder or in the mixer, the high temperature and the mechanical stresses can cause a degradation of the polymeric matrix, leading to a reduction of the molecular weight and consequently to a reduction of the modulus [4]. The higher the time at temperature above the melting point under mechanical stresses, the higher is the risk of degradation. In the extruder such time depends on the screw rotational speed, while in the mixer it is fixed by the operator. This explains why a lower degradation of the matrix was obtained with the mixer, as revealed by mechanical characterisation of specimens obtained by means of the two facilities. As a consequence, the mixer was preferred to the extruder for a deeper investigation.

The last stage of the recycling process consisted in the pelletization in the mill, where a proper sieve fixed the pellets maximum dimension to 5 mm. A block diagram of the recycling procedure is reported in Fig.1.

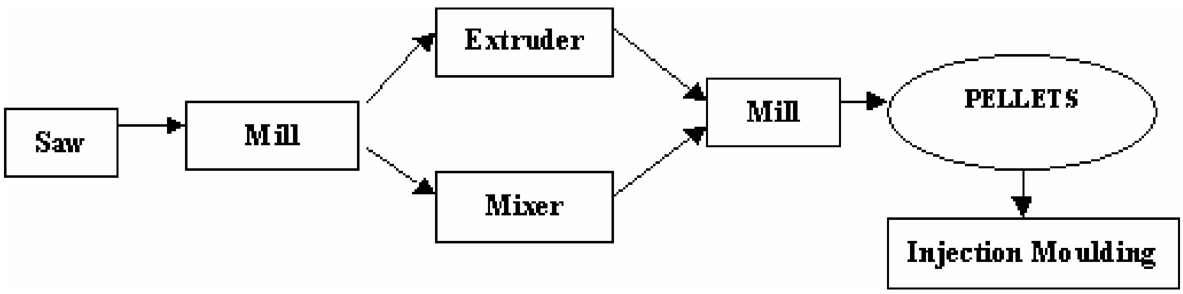


Fig. 1. Recycling procedure scheme.

<u>Optimisation of the mixer parameters</u>

Sandwich panels with skin thickness of 1 mm and core thickness of 20 mm led to a 40% of fibers by weight in the recycled samples. The mixing time, the rotor speed and the mixer chamber temperature were varied in turn keeping constant the other two variables. The explored ranges are listed in **Table 1**.

Table 1. Values attributed to the mixer process parameters.

mixing time	
10 min	T=200 °C n=40 rpm
15 min	
20 min	

chamber temperature	
170 °C	t=15 min n=40 rpm
185 °C	
200 °C	
220 °C	

rotor speed	
30 rpm	T=200 °C t=15 min
40 rpm	
50 rpm	
60 rpm	

The higher values of tensile modulus and strength were obtained for a mixing time of 15 min (Fig. 2). Lower mixing times led to poor fibers dispersion and wetting. On the other hand, a mixing time higher than 15 min caused excessive fibers fragmentation and matrix degradation leading to a reduction of the tensile properties.

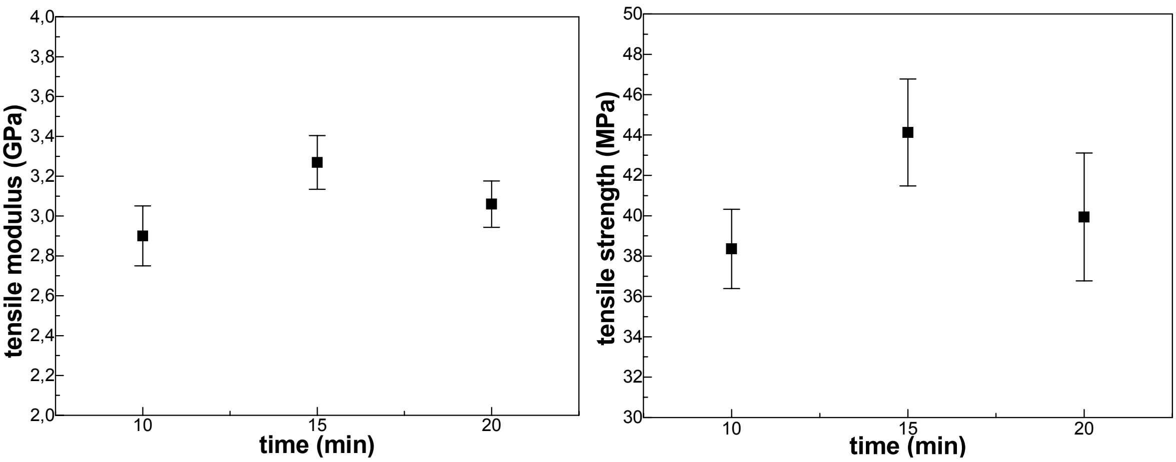


Fig. 2. Effects of mixing time on tensile properties.

The effect of mixing temperature is visible in Fig. 3. Temperature values lower than 200 °C are associated with high matrix viscosity and high shear stress leading to a more pronounced fibers fragmentation and then to reduced mechanical properties.

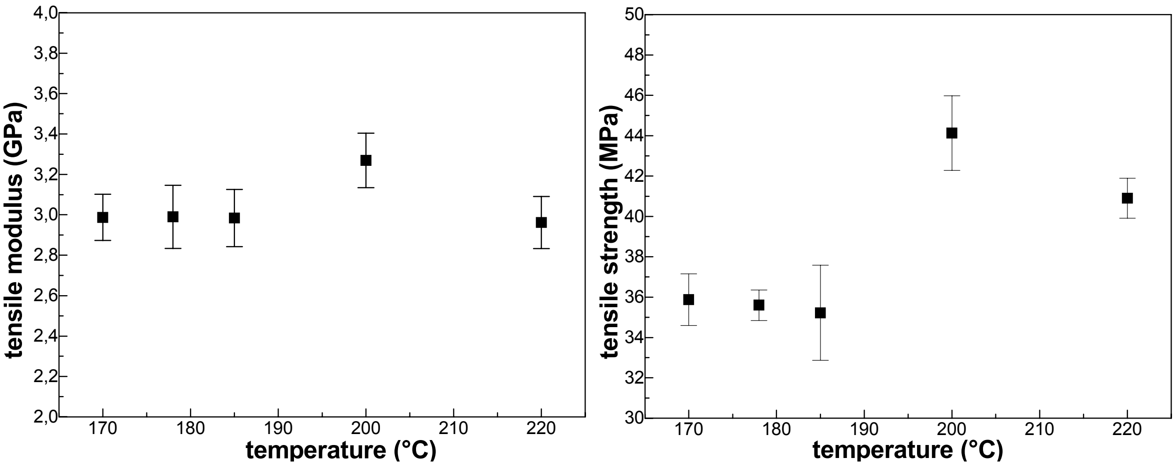


Fig. 3. Effects of chamber temperature on tensile properties.

This fact was confirmed by optical microscopy analysis performed on samples obtained after matrix burning. The cumulative distribution curves of the fibers length showed that a higher fraction of shorter fibers was obtained at lower chamber temperature (Fig.4). On the other hand, above 200 °C, matrix degradation was responsible for the observed reduction of the tensile properties.

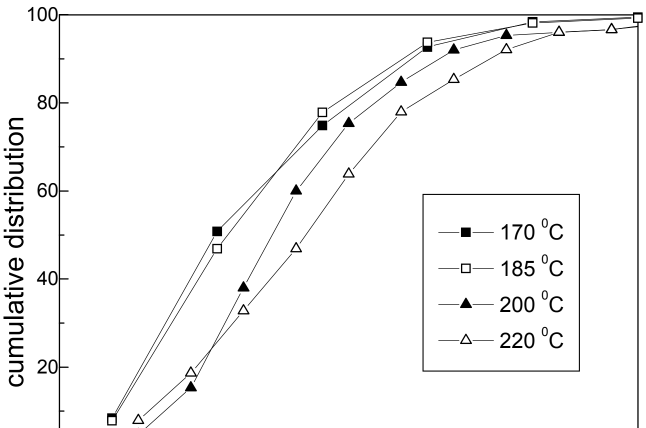


Fig. 4. Cumulative distribution of fibers length versus chamber temperature.

Increasing the rotor speed, an improvement of the mechanical properties was observed up to 40 rpm (Fig.5); for higher values, shear stress on the matrix and fiber fragmentation become predominant on the positive effect of homogenisation [5]. Tensile strength appears more sensitive than tensile modulus to the fibers length reduction.

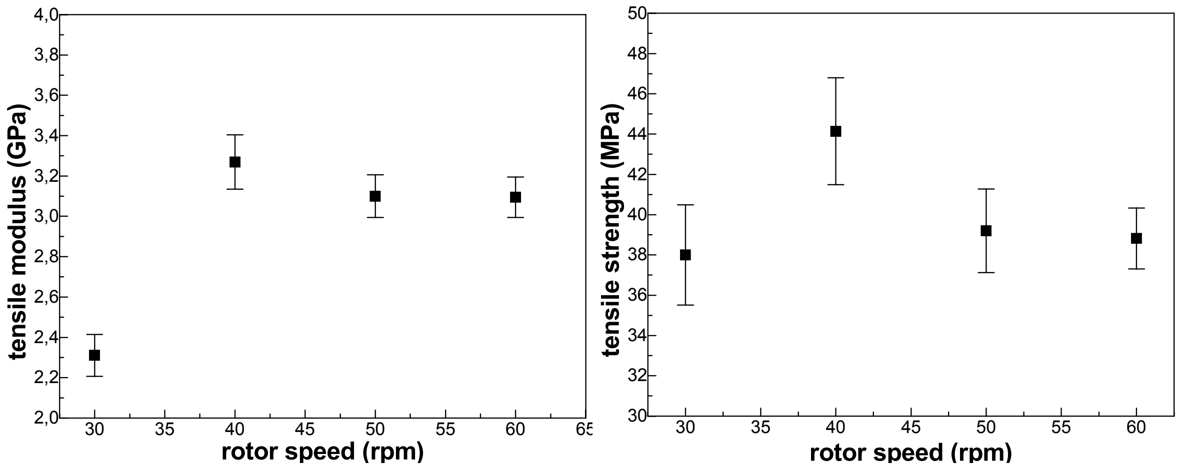


Fig. 5. Effects of rotor speed on tensile properties.

Effect of fibers content

The optimal values of the process parameters drawn by the described maximisation of the tensile properties were used to prepare the samples for the evaluation of the effects of fibers content on the mechanical properties of the recycled material.

Recycled material samples with different fibers content were obtained changing the skin-core thickness ratio. A sample of neat PP obtained from the foam only was also analysed for comparison purposes. As expected, the tensile modulus increased with the fibers content, while the tensile strength was characterized by a maximum at a fibers content of 40% (Fig. 6). This because tensile strength is more sensitive to a reduced homogenisation and to an increase of void content that is likely to occur at high fibers weight fraction.

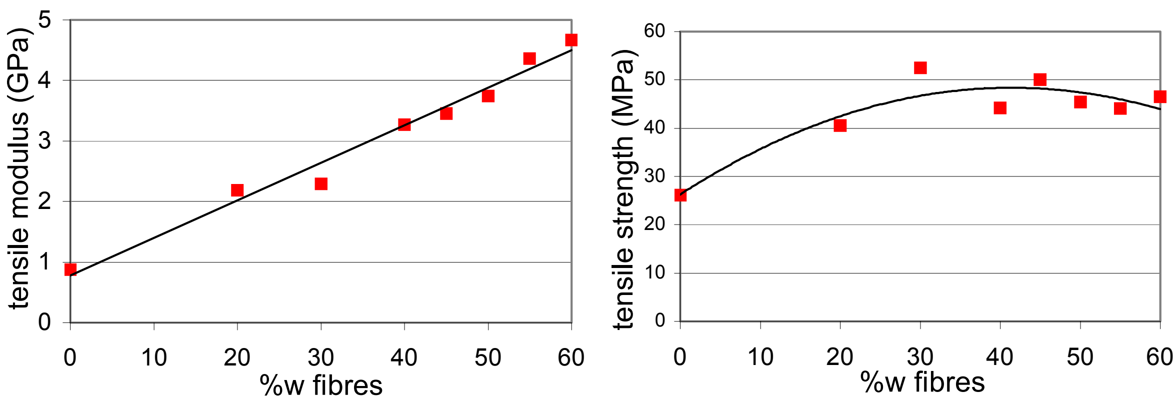
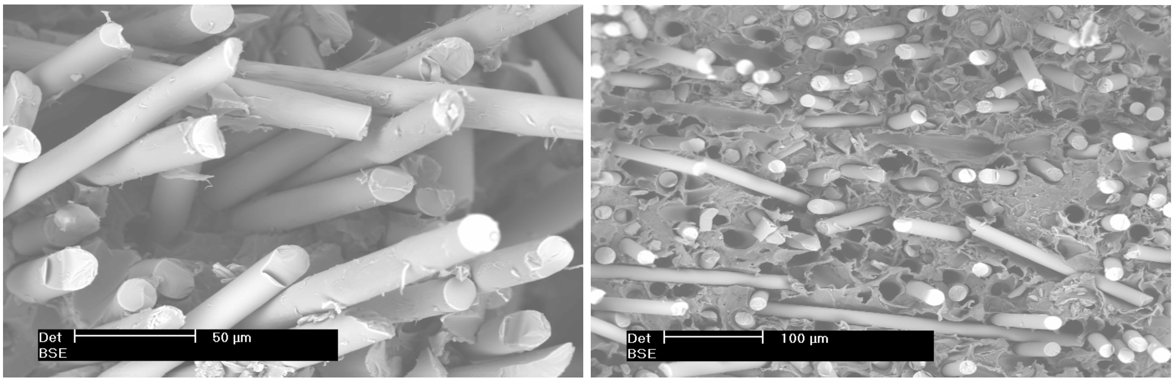


Fig. 6. Effects of fibers content on tensile properties.

SEM analysis revealed a better fibers dispersion at lower fibers content. SEM images of the fracture surface of tensile tests samples are shown in Fig. 7. In samples with higher fibers content non-impregnated packed fibers bundles can be observed (Fig.7a), whereas for lower fibers content the fibers appear always surrounded by the matrix (Fig.7b).



a) b)

Fig. 7. SEM images: a) 55%w of fibers; b) 45%w of fibers.

The influence of fibers content on the impact properties of the recycled material is reported in Fig. 8. The fibers act as anchorage points for the polymer chains, reducing their mobility. As a consequence a great resilience decrease was observed between 0% and 30% of fibers content by weight. Further fibers content increase implied small resilience decrease as a consequence of the higher material stiffness and brittleness.

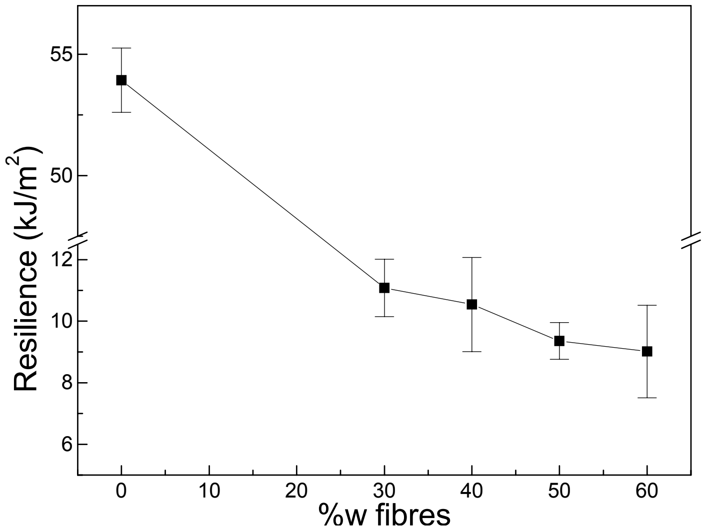


Fig. 8. Influence of fibers content on resilience.

Orientation and length of glass fibers

The fibers orientation was analysed in the central portion of the injection moulded samples used for tensile testing (55% by weight of fibers). The analysis was performed by optical microscopy after having burned out the matrix in an oven at 550 °C [6]. It was assumed that the glass fibers maintain the same position after matrix burning. Evaluation of fibers orientation was carried out by an image analysis software. The probability density curve (Fig.9) revealed a peak in the flow direction of injection (0° orientation), as a consequence of the tendency of the fibers to orientate in the same direction of the flow [7].

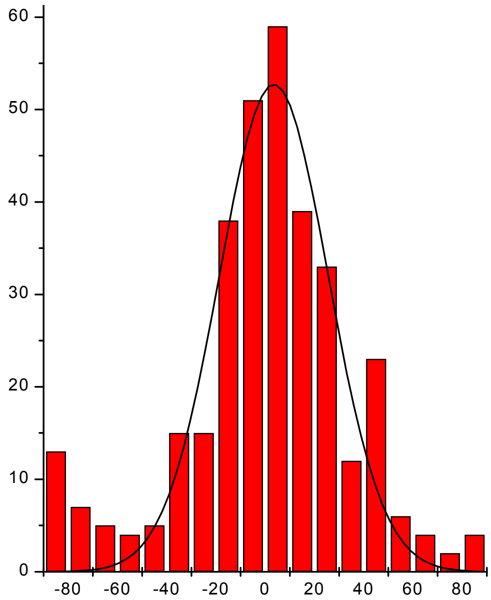


Fig. 9. Probability density for fibers orientations.

The distribution of the fibers length for different fibers content was also evaluated. Lower fibers lengths were observed at higher fibers content, as a consequence of the increased viscosity and fibers breakage in the mixing stage.

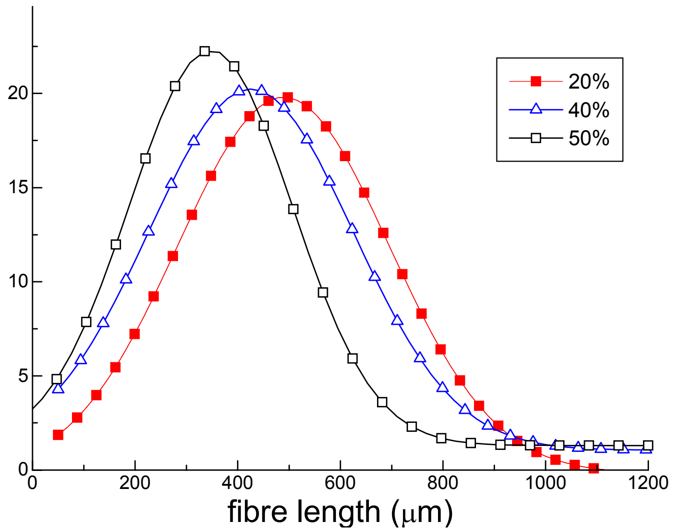


Fig. 10. Fibers length distribution for different fibers content values.

The rheological curves for different fibers contents are shown in Fig. 11. At low strain rate the fibers content has a stronger effect on viscosity values, whereas comparable values resulted for shear rate approaching 10 s^{-1}, when the material has a pronounced non-Newtonian behaviour. This means that, at such higher shear rate values, comparable mould filling times are expected increasing the fibers weight fraction from 20% to 40%.

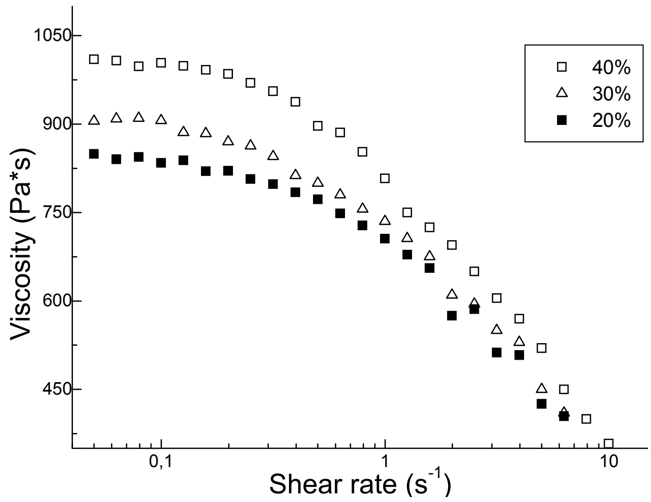


Fig. 11. Viscosity curves for different fibers content values.

4. CONCLUSIONS

In this study the processing and properties of a moulding compound obtained from recycling of continuous fibers PP based sandwich panels was presented. The recycling procedure led to a short glass fibers PP compound suitable for lower performance applications.

The influence of mixing on the mechanical properties of the recycled material was experimentally studied, leading to the definition of the best processing conditions. The effects of fibers content on both static and impact mechanical performances of the recycled material, as well as on the rheological behaviour of the injected mixture was also evaluated.

An analysis of the material morphology was used to better explain the results of mechanical characterization.

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