Characterization of recycled carbon fibers reinforcing thermoplastic polymers

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Abstract In recent years, the metallic materials used in the automotive sector have been replaced by plastic materials. Also associated with this, the recycling or reuse of plastics parts is increasingly important. This work appears framed within a project that intends to substitute thermosetting materials for thermoplastics materials, that will be apply in the automotive sector. So, this article compares two thermoplastics materials reinforced by recycled carbon fibers. In the first case, the used materials were layers of recycled carbon fiber prepreg with polypropylene (PP) and in the second case it were used layers of recycling carbon fiber and layers of PP nonwovens. Both materials were processed by compression moulding process, at the same temperature. After processing, the composite materials obtained were evaluated mechanically, physically and thermally. A flammability test was also carried out to verify if it could be used in the automotive sector. After the characterization tests, as a conclusion, the material that offers the better properties is the recycled carbon fiber prepreg with polypropylene, with both materials fulfilling the requirements of the flammability standard.

***Keywords* — Composite Materials, Recycled, Carbon fiber, Automotive Sector**

I. Introduction

In just fifty years, plastics double their presence in total weight of a vehicles materials. Even though the rapid growth and importance of plastic, the automotive industry grows at a high rate and becoming more demanded in terms of performance and weight reduction. So, in order to achieve these requirements, the polymeric materials can be reinforced by fibrous materials, and, typically, in conception of vehicles can be used the glass or carbon fibers as the reinforcement materials of polymers. So, composite materials have been used in development and innovation instead of conventional materials such as steel or aluminum as a consequence of emerging needs related with weight reduction or mechanical properties improvement.

On the other hand, in addition to the previously mentioned needs, the concerns about the sustainability associated with the greenhouse gases emission, which contributes to global warming, are assuming a particular focus too. This reduction in emissions is also related to the reduction of vehicle weight. For example, each kg reduction in vehicle weight allows the reduction of about 20 kg of carbon emissions to the atmosphere [1]. On the other hand, nowadays, thermosetting matrix composites are already being replaced by thermoplastics ones, thus allowing the materials recycling at the end of life cycle. Moreover, due to the increasing mechanical requirements of the automotive sector, carbon fiber has been used for specific applications. However, there are already players who recycle the carbon fiber for reuse.

So, in this work, the main objective is to compare the mechanical, thermal and physical properties of thermoplastics composites reinforced with recycled carbon fiber. Two types of materials were used, namely: in the first case, layers of recycled carbon fiber prepreg with polypropylene (PP); and in the second case, layers of recycling carbon fiber and layers of PP nonwovens.

II. MATERIALS AND METHODS

A. Materials

The raw materials to produce composite materials have been purchased from ELG company ELG. The recycled carbon fiber prepreg with PP contains 40% recycled carbon fibers and 60% of PP and has a weight between 100 and 500 g m^{-2} . The second type of recycled carbon fiber was a nonwoven constituted only by this raw material.

In Fig. 1, it is possible to see the appearance of this materials before being processed.

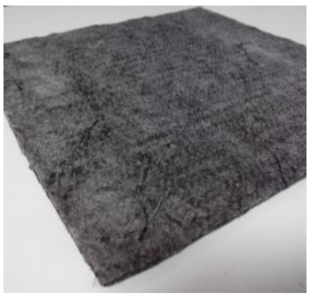

Fig. 1. Material with recycled fiber before being processed.

B. Composite Materials Production

The composite materials was obtained by a compression moulding process in a specific equipment, showed in Fig. 2, in two steps at 220ºC. Firstly, it was used 2 tons of pressure during 10 minutes. Secondly, 6 tons of pressure during 10 minutes too. After this heating steps, the samples were cooled in the equipment, turning on the cool water circulation to hot plates, keeping 6 ton pressure, for 5 minutes. Finally, the final composite was removed after the pressure withdrawal.

In both samples, the ratio of recycled carbon fiber and PP were approximately 45:55, respectively. In the first sample 10 layers of recycled carbon fiber prepreg with PP were used to produce the composite. In the second sample, 8 layers of fibers and 9 layers of PP were required to produce the composite.

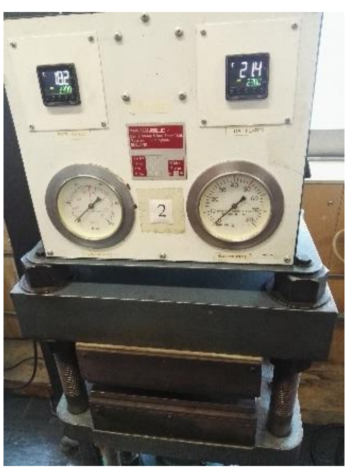

Fig 1. Compression Moulding equipment

C. Characterization Tests

The composite materials obtained were subsequently subjected to physical, mechanical, thermal and fire resistance tests. The physical tests were carried out in order to determine the density and the ability of the samples to absorb water. For that, quadrangular samples with 10 mm width were cutted. According to EN ISO 178 and EN ISO 179 standards, it were determined the flexural and impact strength properties, respectively. Through standard EN ISO 178 it is possible to determine the flexural strength of the samples. To perform this test, the force applied at each instant was measured by a 2500 N load cell, at a crosshead speed of 5 mm min^{-1}. The tests were performed at a temperature of 22ºC. Through standard EN ISO 179 it is possible to determine the impact strength properties, using an Izod impact equipment, showed in Fig. 3. Izod impact consists of measuring the amount of energy absorbed by a sample when subjected to a shock through a pendulum.

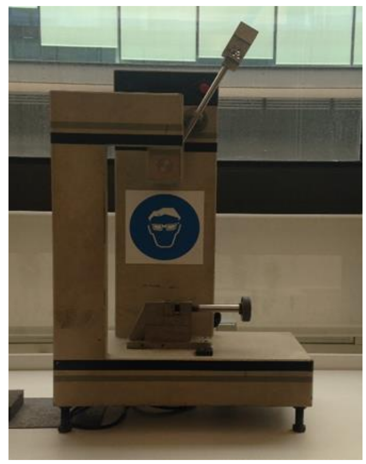

Fig 2. Impact Izod equipment

The thermal tests were made on Alambeta device and allows to determine the thermal conductivity of samples. The fire resistance test was performed according to FMVSS 302 standard. The standard determines the combustion rate of a component of the automotive sector after being exposed to a small flame. The test is conduct inside a test chamber where the test specimen is mounted horizontally. The test specimen is exposed to the flame during 15 seconds. The burnt distance and the time taken to burns this distance is measured during the test.

III. RESULTS AND DISCUSSION

The samples processed have a thickness between 3.85 – 4.00 mm. The physical properties obtained are presented in Table I, where the sample 1 and 2 corresponds to the different types of raw materials used. The sample 1 corresponding to a recycled carbon fiber prepreg with PP and the sample 2 corresponding to recycled carbon fiber combined with PP nonwovens. All results were compared with neat PP to understand the effect of the carbon fiber reinforcing polymer.

TABLE I
PHYSICAL PROPERTIES

Sample	Density (g cm^{-3})	Moisture Absorption (%)
PP	0.91	1.57
1	1.01	4.17
2	1.07	1.95

Through the obtained physical properties, it was verified a slight increase of the density when there are added approximately 45% of reinforcement fibers to the PP. Relatively to moisture absorption, the sample only with PP has the capacity to absorb 1.57%. Adding reinforcement fibers, it was observed an increase of moisture absorption. In the sample of recycled carbon fiber and PP nonwovens, the absorption rate was 1.97% and in the other sample, the absorption rate was 4.17%.

In the table II are shown the mechanical properties of the samples.

TABLE II
MECHANICAL PROPERTIES

Sample	Flexural Modulus (GPa)	Impact Resistance (kJ m^{-2})
PP	0.88	-
1	13.03	58.91
2	8.51	77.34

The mechanical properties shows that sample 1 – recycled carbon fiber prepreg with PP – has a flexural modulus higher than sample 2. This can be explained by the fact that the polymeric matrix in sample 1 is already dispersed in the prepreg. This aspect contributes to a better impregnation of the matrix in the reinforcement fibers and become the composite material more homogeneous. On the other hand, in sample 2, it were obtained better results on impact resistance, compared with sample 1. In the sample 1 the value of the impact resistance is 58,91 kJ m^{-2} and the value of sample 2 is 77,34 kJ m^{-2}. This difference between the samples can be explained by how the samples are processed. In the case of sample 1, the various layers are always of the same material. However, in sample 2, the composite was produced by intercalating recycling carbon fiber layers and layers of PP nonwovens. Placing the carbon fibers interspersed with the PP creates layers of material. The layers of material allow to increase the resistance to the impact of the composite. Besides that, this trend is related with the increase of mechanical reinforcement properties. When the mechanical properties such as Young's Modulus or Flexural Modulus increase, the material becomes more fragile, thus decreasing the impact resistance.

In the table III are demonstrated the thermal properties of the samples.

TABLE III
THERMAL PROPERTIES

Sample	Thermal Conductivity (W m^{-1} K^{-1})	Thermal Resistance (m^{2}K W^{-1})
PP	0.25	15.9
1	0.18	23.1
2	0.15	25.4

In table III it is possible to see that the thermoplastic material (PP) has a thermal conductivity of 0,25 W m^{-1} K^{-1}. Adding carbon fibres, it is possible to see a reduction of the thermal conductivity of samples 1 and 2, between 0.25 W m^{-1} K^{-1} to 0.18 and 0.15 W m^{-1} K^{-1}, respectively. So, with an introduction of carbon fibers, there is a reduction of the thermal conductivity.

In the Table IV are presented the obtained results in fire tests.

TABLE IV
FIRE TEST

Sample	Fire Resistance
PP	-
1	√
2	√

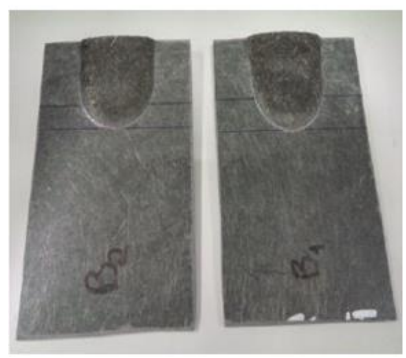

Fig 4. Fire-tested samples

Both samples were submitted to a fire test. As can be seen in the Table IV, the samples meet the specific requirements in the FMVSS 302 standard. In sample 1, the flame was extinguished before reaching the reference mark draw of 38 mm from the free end of the specimen where the flame had been applied. In sample 2, the flame self-extinguished after exceeding the reference mark as it possible to verify in the Fig. 4. However, the combustion rate was below of the 102 mm min^{-1} specified in FMVSS 302. Therefore, both samples meet the requirements of standard FMVSS 302.

IV. CONCLUSIONS

The composite materials using thermoplastics polymers allows the reuse of the product at the end of its life cycle, contributing to the sustainability of the planet. Through this study, it was demonstrated that with a fiber introduction, there was a slight increase in matrix density. However, when compared to metallic materials, their density is lower. This is an aspect of extreme importance for the automotive sector because it allows to produce lighter parts. It has also been found that recycled carbon fiber with PP prepregs have higher mechanical properties than recycled carbon fibers and PP nonwoven. Trough the thermal characterization tests carried out on the samples, it was verified that the one that offers the best thermal properties is the recycled carbon fiber and PP nonwoven.

Finally, the fire behavior of the samples produced was evaluated. Though this test it was concluded that the samples comply the requirements of standard FMVSS 302. These materials can therefore be used to produce parts for the automotive sector.

With this work, it is concluded that it is possible to produce parts for the automotive sector using recycled carbon fibers in thermoplastic matrix.

ACKNOWLEDGEMNETS

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REFERENCES

[1] A. P. a. R. P. Akshat Patila, "An overview of Polymeric Materials for Automotive Applications," *5th International Conference of Materials Processing and Characterization* , pp. 3807-3815, 2017.