2021 18th International Conference on Electrical Engineering, Computing Science and Automatic Control (CCE). Mexico City, Mexico. November 10-12, 2021

Influence of MMT Reinforcement Fraction Variation on the Mechanical Properties of a Polycarbonate Polymer Matrix with an ABS Additive

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Abstract— **Industries such as aeronautics, automotive, aerospace, require low density materials with high mechanical and thermal resistance as an alternative, for which polymer matrix composites are usually chosen. In this work, the effect of the percentage variation of the MMT clay fraction in a polycarbonate (PC) matrix on its mechanical and thermomechanical properties is studied. To obtain this composite, powdered clay was used as reinforcement, in percentages of 1;1;5;2;3;3 and 5%, and Acrylonitrile Butadiene Styrene (ABS) as an additive in 7/3 w/w proportions. Tensile, Charpy impact, load deflection temperature (HDT) and Rockwell hardness (HRB) tests were performed. The composites with 3 and 5% clay exhibited a 49% increase in tensile strength, 33% in toughness, 17% in load deflection temperature and 44.16% in HRB hardness, with respect to the unreinforced matrix. This new composite material represents an innovative alternative that significantly outperforms the mechanical and thermo-mechanical properties of traditional polymeric materials.**

Keywords— composite material, polymeric matrix, particulate reinforcement, MMT, ABS, PC, mechanical properties, thermo-mechanical properties.

I. INTRODUCTION

Composite materials have had a high impact during the last decades since their properties are the result of the combination of the most important characteristics of their constituents [1]. Industries such as automotive, aeronautics, aerospace, military and electrical are oriented to the innovation of composites that possess high stiffness and modulus of elasticity [2]; these properties can be obtained in particulate composites of polymeric matrices [3]. The use of particles makes the new compound show isotropic properties; it has also been proven that the addition of this type of inorganic material to polymeric matrices improves the resistance to compression and mechanical wear; however, the reinforcement effect depends on the size, shape, concentration and homogeneity in the dispersion of the added particle [4], [5]. Some authors such as [6]. conducted a study of the effects of nanoclay addition on the phase morphology and stability of polycarbonate/styrene-acrylonitrile blends, emphasized the compatibility and morphological stability of polycarbonate/styrene-acrylonitrile (PC/SAN) blends; whose results indicate that nanoclay reduces the size of the SAN phase domain and stabilizes the morphology of the system even without complete exfoliation. In this way [7]–[13] and [14] demonstrated the effectiveness of the methodology with other types of polymeric materials.

In other research, [15] evaluated the morphology and mechanical properties of bisphenol A/poly(styrene-co-acrylonitrile) polycarbonate blended with clay. The results indicated that the nanocomposites have a partially exfoliated and degraded structure and that the clay sheets were mainly in the SAN phase and at the boundary of the two phases. Also, [16] analyzed the synthesis and characterization of polycarbonate/ABS/montmorillonite nanocomposites whose results indicate improved thermal stability of the matrix [17]–[19].

For the development of this composite, polycarbonate was used as matrix because it provides excellent mechanical and physical properties that could be improved for particular cases with the addition of reinforcements such as minerals, inorganic fibers and other polymers, acrylonitrile butadiene styrene ABS as an additive because of its plasticity capacity that guarantees homogeneity in the distribution of the reinforcement and, MMT montmorillonite clay as reinforcement due to its high resistance to thermal interaction [20], [21]. This research was developed by means of an experimental correlational methodology where the independent variable is the chemical composition of the material, varying the percentage by weight of reinforcement between 1 % and 5 % and the dependent variables are the physical and mechanical properties evaluated.

This article presents the results of the evaluation of the mechanical, thermal and physical properties of the composite material based on the international destructive testing standards ASTM D638 -14, D6110 - 04, D785, D648 - 18. These tests were used to determine: tensile strength, toughness, hardness, heat distortion temperature (HDT) and density relative to samples with different percentages of reinforcement.

II. METHODOLOGY

This research was carried out under an experimental and quantitative methodology that proposed the development of a new composite material where two variables are involved. The mechanical and thermomechanical properties of the material were measured as a function of its chemical

978-1-6654-0029-9/21/$31.00 ©2021 IEEE

composition, the latter being the independent variable. In this sense, the main justification for this manuscript is to contribute to innovation in engineering processes and materials with an emphasis on composite materials since industries such as aeronautics, automotive, space, demand materials of low density, high mechanical and thermal resistance to favor the energetic processes of extraction, production and work.

A. Materials

To obtain the composite material, polycarbonate of reference PC UR in fine resin SC-1220 was used as matrix, Acrylonitrile Butadiene Styrene of reference ABS natural SD-0150 as plasticizer, and montmorillonite clay in powder form was used as reinforcement. These clays have a cation exchange capacity ranging from 80 to 100 me /100 g. Montmorillonite (MMT) was obtained from the mineralogy laboratory of the University of Antioquia in Medellin - Colombia. The clay underwent a pre- and post-crushing granulometric analysis process to verify that its particle size was adequate to be mixed with the matrix.

B. Material processing (particle size analysis of MMT)

The procedure for the granulometric analysis of the MMT was mainly carried out in two stages:

1) Sieving

In this stage, the grain size analysis was carried out to calculate the average particle size before milling; this process was carried out for 15 minutes, in order to separate the solid particles according to their size. The Table I shows in detail the sieves used in this process. The granulometric analysis by sieving is carried out on particles larger than 0.075 mm, the sieve used in this work is Mesh No. 200 with an opening of 75 µm; under the ASTM E11 standard. The average particle size obtained after the sieving process was 1371.953 um.

TABLE I. SIEVING PARAMETERS

Granulometric processes				
Process	***Machine***	***Time (min)***	***Initial mass (g)***	***Final mass (g)***
Initial sieving	RO-TAP sieve shaker	15	210	208.50
Grinding	4 roll mills	25	208.50	203.50
Final sieving	RO-TAP sieve shaker	20	203.50	203.10

a. Equipment parameters for the granulometric process

2) Grinding

This part of the process was carried out in a 4-cylinder mill with the purpose of reducing the particle size of the clay and obtaining a better dispersion of the clay in the matrix. Sieving was carried out again for a period of 20 minutes. The average particle size obtained after the milling process was 681.896 um.

The raw material was mixed in an EVERPLAST twin-screw extruder with eight heating zones, adjusting the temperature profiles to avoid degradation of the mixture; at this point in the process, pellets were obtained to be used in the injector. A Welltec PET injector was used to obtain specimens for tensile, Charpy impact, HDT and Rockwell hardness tests.

To determine the extrusion parameters, an initial temperature profile of 195, 200, 205, 205, 210, 210, 210, 215, 215 and 215 °C and a screw speed equal to 60.2 rpm were used for mixtures with reinforcement additions of 0%, 1%, 1.5% and 2% of MMT clay, due to the processability and degradation temperature of the materials that make up the composite material, [22]. On the other hand, for mixtures with higher amount of reinforcement with additions of 3% and 5%, the temperature profile was 205, 210, 215, 220, 220, 225, 225, 225 and 225 °C. These parameters were established taking as a reference the study carried out by [6], [15], [16].

To establish the injection parameters, ASTM D4101 was used as a reference, which suggests maintaining a range of temperatures in the barrel between 200 and 205 °C and an injection temperature equal to 210 °C. From this point, temperatures of 240 to 270 °C were used in molds for mechanical tests under ASTM standardized norms for the preparation of the specimens. Reinforcement addition percentages of 0, 1, 1.5, 1.5, 2, 3 and 5% montmorillonite clay and a 7/3 w/w ratio of polycarbonate and ABS were considered.

C. Mechanical Tests

For the mechanical evaluation, a Grip-Manual Wedge Style universal testing machine, 10 KN with adjustable speed and a graphic register was used; for the Charpy impact tests, a Tremel machine model JQJ-50 was used, which has two initial energy levels, 300 Joules and 150 Joules; finally, the Rockwell hardness tests were carried out in a Wilson Hardness Tester model 4TTA RB. The composite specimens were subjected to tensile, Charpy impact and Rockwell hardness mechanical tests under ASTM D638-14, ASTM D6110-04 and ASTM D785 standards, respectively.

D. Thermomechanical Characterization

The thermomechanical characterization was performed on an institutionally manufactured machine owned by the University Pontificia Bolivariana. The heat deflection temperature (HDT) tests were carried out in a temperature range of 25°C to 220°C and with a heating rate of 1 °C/10 s. The HDT test was performed under ASTM D648. This test was performed according to ASTM D648.

III. Results and Discussion

The synthesis methodology of this material has been the result of the adaptation of different processes reported in the literature, taken as references. At this point it is possible to speak of a small but significant process innovation, where the researchers managed to adjust the method to an environment with different installed capacities and were able to obtain the same product.

A. Mechanical characterization

1) Tensile test

In this test, a working speed of 5 mm/min was used as described in its respective standard. Figure 1 shows the results of the tensile tests performed in triplicate for each chemical composition and Table II shows the modulus of elasticity and maximum stress for each composition.

TABLE II. TENSILE TESTING

Tensile testing		
Composition	***Modulus of Elasticity (MPa)***	***Yield Strength (MPa)***
PC	1 343,606	36,715
PC/ABS	1 302,267	51,335

PC/ABS + 1% MMT	1 309,071	52,885
PC/ABS + 1,5% MMT	1 248,223	49,742
PC/ABS + 2% MMT	1 302,267	51,335
PC/ABS + 3% MMT	1 349,065	54,928
PC/ABS + 5% MMT	1 285,268	52,550

b. Tensile testing values for each sample executed

Table II shows that the polycarbonate without any addition presents the lowest maximum stress among all the defined compositions. It can be inferred then that the material improves its mechanical behavior with the addition of the plasticizer and the particulate reinforcement.

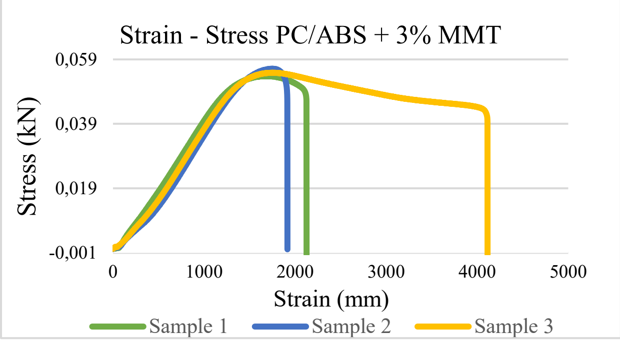

Fig. 1. Stress-strain plot of the triplicate test of the 3% MMT composite.

For the execution of the tension tests, a sample was determined as a number of specimens suggested by the ASTM standard respectively, which states that a minimum of 3 elements should be tested in each test in order to have greater certainty in the data obtained. It is clear that the material reinforced with 3% clay is the one that presents the best maximum tensile strength. Furthermore, it is evident that this last percentage also represents the maximum saturation of the reinforcement, since at higher percentages the values decrease.

2) Tensile elastic modulus as a function of chemical composition.

To measure the ductility or brittleness of the material, the elastic modulus is taken into account. In Table II, it is possible to identify that a behavior similar to that observed with the maximum stress is presented where the composition with 3% reinforcement has the maximum value in its elastic modulus. However, the polycarbonate without any additive has a value very close to that of the latter composition; this may be due to the absence of plasticizer, causing the material to have a brittle behavior, which is evidenced by a high elastic modulus.

3) Charpy impact test

According to the results obtained in this test, it was corroborated that it complies with the principle of repeatability, which indicates a uniform trend. Figure 2 shows the results of the impact resistance of the composites obtained. According to the results shown in Table III, the impact resistance of the 3 and 5% compositions increases 26.5% and 33.7% respectively, compared to the material without any reinforcement. Figure 2 represents the proportional increase in absorbed energy as a function of material composition. The impact resistance increases as a function of the clay content, since the latter has a large amount of organic component, which makes it more compatible with the matrix and the energy received can be better dispersed.

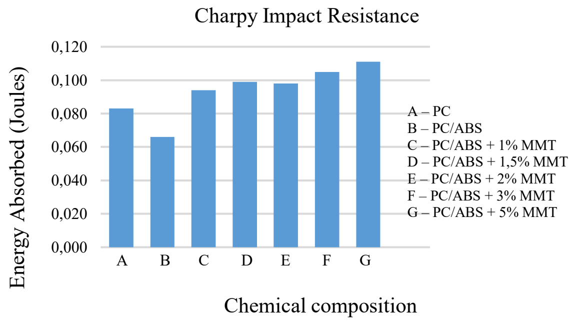

Fig. 2. Charpy test chart for each established composition.

In the case of polycarbonate mixed with ABS, values outside the trend described above are presented; this may be due to the plasticizing nature of ABS since this type of additives are not characterized by their high toughness.

4) Rockwell hardness test (HRB)

Figure 3 shows the hardness results for the different composites. In the graph obtained, an increase of up to 44.16% of the hardness values with respect to the unreinforced material is observed. This is due to the fact that montmorillonite is a raw material associated with ceramic materials, which are characterized by their relatively high hardness; so, by increasing the fraction of this reinforcement in the matrix, the composite material presents an increase in this property.

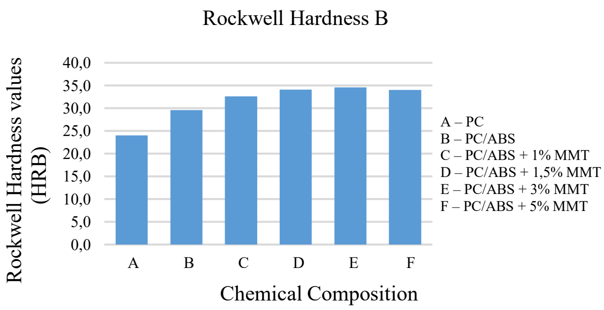

Fig. 3. HRB hardness values of the composite with different reinforcement fractions.

B. *Thermomechanical characterization*

1) The heat deflection temperature (HDT)

Figure 4 shows the results of heat deflection temperature for the different compositions of the composite material obtained. Figure 4 represents the proportional increase of the heat deflection temperature as a function of the material composition; in this test it is clear that montmorillonite clay improves the thermal stability of the polycarbonate/ABS/clay composite, which has been verified in previous studies by thermogravimetric analysis (TGA).

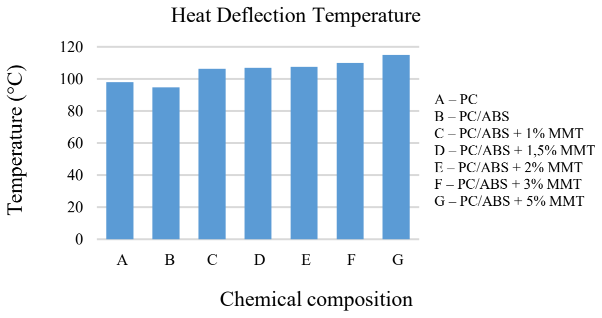

Fig. 4. Data of the thermomechanical behavior of composite with different reinforcement fractions.

The heat distortion temperature of polycarbonate reinforced with 5% clay is 17.3% higher than that of unreinforced polycarbonate, which represents a great advantage for a thermoplastic material, since they are very sensitive to temperature changes.

Finally, the mechanical and thermomechanical tests were effective in establishing the advantages of this new material. Table III shows a summary of the tests carried out with the variation of the MMT fraction in the composite, which punctually indicates the values acquired for each property evaluated with their respective standards.

TABLE III. SUMMARY OF TESTS PERFORMED

Test Summary				
Composition	***Tensile (MPa)***	***Charpy impact (J)***	***HDT(°C)***	***Hardness (HRB)***
PC	36,715	0,083	98,000	24,000
PC/ABS	51,335	0,066	95,000	29,600
PC/ABS + 1% MMT	52,885	0,094	106,000	32,600
PC/ABS + 1,5% MMT	49,742	0,099	107,000	34,100
PC/ABS + 2% MMT	51,335	0,098	107,500	------
PC/ABS + 3% MMT	54,928	0,105	110,000	34,600
PC/ABS + 5% MMT	52,55	0,111	115,000	34,000
	ASTM D638-14	ASTM D6110-04	ASTM D648	ASTM D785

c. Summary of test performed for each sample produced.

IV. CONCLUSIONS

Once the phases of the research project were completed, the following conclusions were reached:

- When making mixtures with different chemical compositions, which vary according to the percentage of reinforcement added, the processing parameters of the material change. By having higher fractions of clay in the compound, the temperature profile must be progressively increased to achieve a homogeneous mixture in the extruder and for injection into the mold.
- By adding clay as a reinforcing material to the composite, the thermal properties of polycarbonate and ABS were improved, since at the time of extruding and injecting the material, the degradation temperatures of both polymeric materials were exceeded. Therefore, the distortion temperature of the composite material increases as a function of clay reinforcement content.
- The polycarbonate with the addition of the plasticizer and the particulate reinforcement manages to improve the tensile strength, obtaining the highest value in the material reinforced with 3% clay. On the other hand, the elastic modulus does not present representative changes comparing both compositions.
- The toughness of the material increases as a function of clay content. The content of organic matter in the clay makes it more compatible with the matrix and therefore favors the dispersion of the energy received in the impact.
- As shown by the quantitative data of the mechanical tests described above, it is evident that the new material designed with polycarbonate matrix and ABS and Montmorillonite reinforcement exceeds the limits of resistance to hardness, traction, distortion temperature of commercial polymeric materials such as: Polyamide 6 - PA6, Polyamide 66-PA66, Polyether ether ketone (PEK), Polypropylene (PP), Polyamide- 612, Polyoxymethylene (POM).

This represents an innovation for the development of elements such as gears, ball bearings, clips, nozzles, flanges, polymer cages, among others. In addition, it is an alternative to reduce the environmental impact without reducing the purpose of its purpose.

ACKNOWLEDGMENT

To the University Francisco de Paula Santander Ocaña, the Research and Extension Division, University of Antioquia and the "Centro de Diseño y Manufactura del Cuero (SENA) Antioquia" for supporting the exploration of new technological advances.

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