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**EVALUATION OF THE MECHANICAL AND INSULATION PROPERTIES OF A POLYMERIC COMPOSITE WITH CORN COB LOADS TRITURATED**

**EVALUACIÓN DE LAS PROPIEDADES MECÁNICAS Y AISLAMIENTO DE COMPUESTO POLIMÉRICO CON CARGAS DE MAZORCA DE MAÍZ TRITURADAS**

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**Abstract**

The objective of this work was to study the viability of the use of the crushed corn cob, employed as load in a composite polyester resin. The specimens were produced with 5, 10 and 20% by weight of the ground corn cob, as fine particles (FP), medium particles (MP) and large particles (LP) to investigate the influence of the loading content on the mechanical and thermal conductivity properties of the composite material. The results of the mechanical tests, the data of impact test presented a satisfactory result for all the composites. However, the photomicrographs of the composites through SEM indicated low mechanical load/matrix adhesion, with few signs of effective stress transfer between phases, noting that the most viable particle size is the fine particle (FP). The composites shown to be viable for thermal applications, with a thermal conductivity of 0.138 W/m lower than 0.21 W/m, being classified as thermal insulation.

*Palabras clave:* polyester resin, corn cob, modulus of elasticity, thermal conductivity, insulation.

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**Resumen**

El objetivo de este trabajo fue estudiar la viabilidad del uso de la mazorca de maíz triturada, empleada como carga en una resina compuesta de poliéster. Los especímenes se produjeron con 5, 10 y 20% en peso de la mazorca de maíz molido, como partículas finas (PF), partículas medianas (PM) y partículas grandes (PG) para investigar la influencia del contenido de carga en la mecánica y térmica propiedades de conductividad del material compuesto. Los resultados de las pruebas mecánicas, en impacto presentaron un resultado satisfactorio para todos los compuestos. Sin embargo, las fotomicrografías de los compuesto por los SEM indicaron una baja adhesión carga/matriz, con pocos signos de transferencia efectiva de tensión de las fases, señalando que el tamaño de partícula más viable es la partícula fina (PF). Los compuesto mostraron ser viables para aplicaciones en aislamiento térmico, con una conductividad térmica de 0.138W/m abajo 0.21W/m.

*Keywords:* resina de poliéster, mazorca de maíz, módulo de elasticidad, conductividad térmica, aislamiento.

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**1 Introduction**

The growing demand for ecologically viable materials has enabled the development of polymer matrix

materials with natural residues. The use of these residues in composites has been increasing in the industrial sector due to the low density, the good adhesion to matrix and the low costs of raw materials, originating from renewable and inexhaustible sources.

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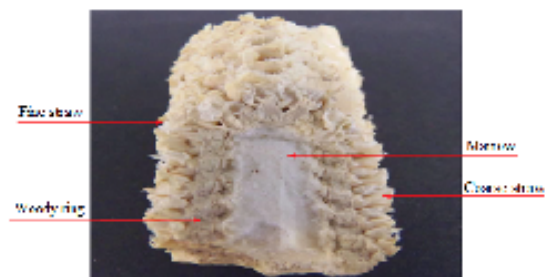


Fig. 1. Parts structures of corn cob.

According to Asokan *et al.* (2012), the physical properties of vegetable fibers are mainly determined by chemical and physical composition, such as fiber structure, cellulose, fibrils angle and degree of polymerization.

The application of these fibers as reinforcement for traditional thermoplastic and thermoset polymer composites requires a strong adhesion between the fiber and the matrix. Structurally the corn cob is divided into four fundamental parts, according to Figure 1, the thin straw or outer region of the cob, coarse straw or layer that follows the thin straw and marrow according to Obasi *et al.* (2012).

Thin straw accounts for approximately 4.1% of corn cob by weight; coarse straw 33.7%; the woody ring 60.3% and the medulla, 1.9%, as shown in Fig. 1. Natural cellulose residues, fibers, particles, (micro and nano), are attractive substitutes to be used as reinforcements and fillers when making plastic composites (Asokan *et al.*, 2012). This intense search for alternative and ecologically correct materials has enabled the development of materials with polymer matrices of natural residues, where these residues due to the low density, good adhesion to the matrix and the low costs. Second Alawar *et al.* (2009), the polymer-unsaturated polyester resin, called curing, carried out with initiator and in some cases with catalyst, forms

the cross-linked network which is better suited for the straw and resin ratio. At sufficiently large stresses, the large particles detach easily during the composition, so the reinforcement depending on the interfacial adhesion is practically low, independent of the initial characteristics of the lignocellulosic fibers, as related Faludi *et al.* (2013).

## 2 Materials and methods

The addition charges of crushed corn cob, fine particle (FP), medium particle (MP) and large particle (LP) were hand sieved to eliminate all or any type of impurities, generating particles with different granulometries, as shown in Fig. 2.

These particles were added and blended to a polyester matrix resin (adhesive lamination) composed of styrene monomer having a ratio of methyl ethyl ketone catalyst 5% by weight, purchased commercially.

### 2.1 Mechanical characterization

The mechanical tests such as tensile strength, flexural strength and impact strength aimed to collect data besides associating the insulating characteristics of this composite, to diagnose the mechanical characteristics related to the particle size of the inserted load.

#### 2.1.1 Tensile testing

The test specimens for the tensile tests were produced according to ASTM-D638 with a tie-type shape, with a total length of 165 mm; working length 80 mm; width of the narrow section 12.7 mm and the thickness 3 mm.



Fig. 2. Aspect of the particles inserted in the composite: (a) fine particle (b) medium particle (c) large particle.

Mechanical tensile tests were performed using a TIME GROUP INC universal testing machine with 100 KN load cell, test speed 1 mm/min and ambient temperature 25 °C.

### 2.1.2 Flexion test

The specimens for the three-point flexion tests were produced according to ASTM-D790 in the form of rectangular bars, with a total length of 80 mm; width 12.7 mm and thickness 3 mm.

They were performed using a universal test machine of the brand TIME GROUP INC with load cell of 100 KN, distance between supports 50 mm, speed of 2 mm/min and temperature 25 °C.

### 2.1.3 Impact test

The specimens for the notched Izod impact test were produced according to ASTM-D256, with rectangular bar formats with a length of 63.5 mm, thickness; 12.7 mm; width 10 mm; and 2.54 mm notch. The mechanical impact tests were performed at room temperature 23 °C using a CEAST impact machine model IMPACTOR.

### 2.1.4 Thermal analysis

In the determination of the thermal properties, the compensated hot plate device method was used, as shown in Fig. 3, in which it is based on the ANSI/ASTM procedure C 177-76.

The method is applied for the permanent measurement of the thermal conductivity of solid materials.

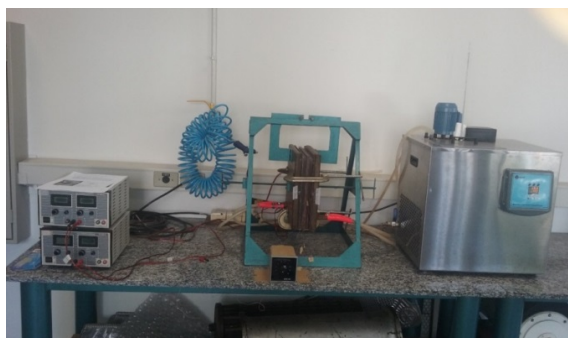


Fig. 3. Hot plate device compensated.

In this case, the usual procedure is to place the sample in the form of a flat plate, between a hot plate and a cold plate forming a “sandwich”, being subjected to temperature difference ( $T_1/T_2$ ), measurements carried out by means of thermocouples under conditions such that the heat flow through the sample is unidirectional.

Under steady state conditions, the thermal conductivity is calculated by measuring the heat flux and the mean temperature gradient throughout the sample.

### 2.1.5 Morphological characterization of the different granulometric of Corn Cob by Scanning Electron Microscopy (SEM)

The analyzes of maize cob fibers with different particle sizes were performed with the aid of the Carl Zeiss/EVO MA MEV, which allowed to identify all the constituent parts of the fiber internally. The load/matrix interface, distribution and dispersion of the various granulometric fractions of the corn cob in the matrix were analyzed by MEV, where the samples were fixed in a metallic support with carbon tape and then metalized with gold for microscopic analysis as shown in Fig. 4.

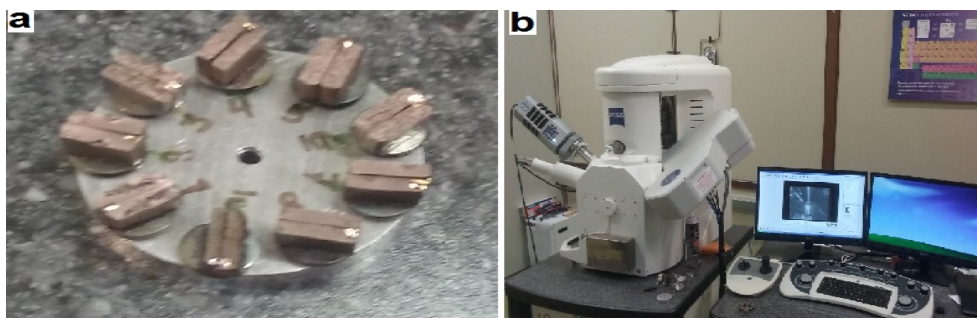


Fig. 4. MEV device where we have: (a) support of the samples (b) vacuum chamber for analysis of the scan.

### 3 Results and discussions

#### 3.1 Tensile testing

In this section the maximum tensile strength, modulus of elasticity and deformation of the composites were determined following ASTM D638 and Fig.5 shows the typical strength versus displacement curves of the tests for 0%, 5%, 10% and 20% of the volume fraction of the fine p particle size (FP) of corn cob.

The common appearance is that all composite curves have low plastic deformation, and that unexpected rupture indicates that pure resin (PR) and composites with the fine particle size (FP) compounds are relatively fragile materials.

From the conventional force versus displacement curves, the maximum tensile stress, maximum deformation and modulus of elasticity were calculated. Table 1 presents the mean values for these tensile properties for 0, 5, 10 and 20% of the corn cob fiber in volumes.

The data in Table 1 show that the mechanical behavior, such as maximum stress and strain at the fracture of the samples with the addition of 5%, 10% and 20% volume fraction of the fiber, compared to the PR sample, decreases with the increasing the percentage of reinforcement.

The resin sample with 5% FP, compared to the 0% sample, obtained a reduction of 24.4% in the maximum tension, and a reduction of 46% in the deformation of the composite; the sample of resin with 10% of FP obtained a decrease of 40.95% in the maximum tension and the deformation of the composite was of 59.2%, for the sample of resin with 20% of FP the reduction in the maximum tension reached 57.71%, and the reduction of the deformation of this composite was 71.6% compared to pure resin.

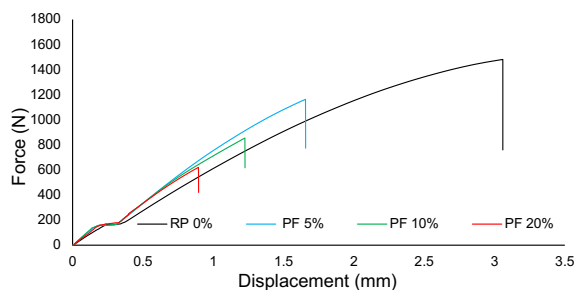


Fig. 5. Typical tensile strength curves for pure resin PR and load of 5, 10, 20% FP in volume of corn cob.

The decreases in mechanical properties are certainly related to the percentages and particle size characteristics of the aggregate particles in the polymer matrix. Ku *et al.* (2013) evaluated the mechanical behavior of tensile strength, elongation at rupture and modulus of elasticity of thermoplastics and thermosets composites at different load observed that there is a tendency of the reduction in the maximum tension and the elongation, that is to say, the greater the content of particulate in the composition, the lower the performance of the composite in response to the normal tension applied in the test.

Idowu *et al.* (2015) evaluated the mechanical characteristics by the tensile test of composites made from the terephthalic resin (dark) with addition of corn cob residue in the proportions 20% (FP, MP, LP), and compared them with pure resin.

The results of the pure resin showed tensile strength of 24.2 MPa and the composites with 20% FP, MP and LP of corn cob residue showed the respective tensile strength values: 3.25 MPa, 2.94 MPa and 2.80 MPa, showing that the percentage and particle size of the particles also influence the mechanical properties in this case, the tensile strength is lower than the pure resin.

Table 1. Measures referring the properties of the tensile test of the composite according to the percentage of corn cob fiber.

Volume of corn cob fiber (%)	Maximum tensile stress (MPa)	Modulus of elasticity (GPa)	Maximum deformation
PR 0%	37.00±2.46	1.48±0.21	2.50±0.33
FP 5%	27.96±2.61	2.06±0.16	1.35±0.26
FP 10%	21.85±0.90	2.12±0.05	1.02±0.02
FP 20%	15.65±1.60	2.19±0.25	0.71±0.11

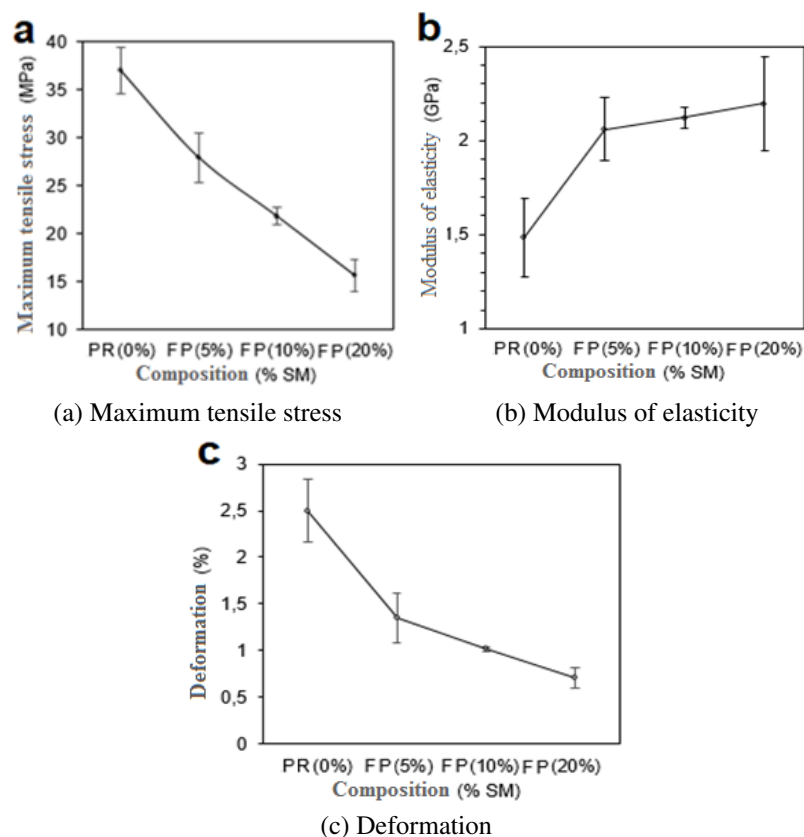


Fig. 6. Values of mechanical properties of traction, maximum stress (a), modulus of elasticity (b) deformation (c) for sample compositions PR 0%, 5%, 10% and 20% FP of corn cob

According to the results of Nirmal *et al.* (2015), the pure orthophthalic polyester resin showed tensile strength of 37.87 ( $\pm 2.24$ ) MPa and the polyester composites 15.5% and polyester powder 25% of other fiber powder presented the respective values of tensile strength, 18.27 ( $\pm 0.49$ ) and 18.87 ( $\pm 1.21$ ) MPa, showing that the increase in the volume of fibers was indifferent to the resistance, but comparing the result of the pure resin with the composites, it was observed that a tensile strength reduction of 50.2% occurred, similar to the one found in this work.

In the same way, Mostefai *et al.* (2015) who analyzed through mechanical tensile tests, composites of orthophthalic unsaturated polyester matrix reinforced with lignocellulosic fibers and compared them with glass fiber reinforced composites, the same one reports that the tensile strength of composite materials constituted by fibrous reinforcements depends on some factors, such as mechanical resistance, orientation, content and length of the fibers, besides the chemical stability of the matrix and the fiber-matrix interface.

On the other hand, the modulus of elasticity increases when compared to the pure resin. This is due to the increase in the proportions of particles distributed along the cross-sectional area of the specimen, that is, a larger fraction of the cross-sectional area consists of corn cob particles, thus reducing effective resistance and increasing the modulus of elasticity of the composite.

According to Oladele *et al.* (2014), he shows in his studies that the increase in stiffness and the reduction of composite flexibility are related to corn cob particles, because they act on the polymer as a nucleating agent in the polymer matrix, thus increasing the degree of crystallinity of the same; this was observed in differential scanning calorimetry (DSC) analyzes. According to Carneiro *et al.* (2013), the rupture deformation in polymer matrix composites reinforced with lignocellulosic fibers decreases with the addition of in natural fibers, and this is due to the fact that the fibers have less deformation and greater stiffness than the polymer matrix.

The sample with 20% FP showed a higher modulus of elasticity and lower tensile strength in relation to the other samples, due to the increase of the percentage of particles in the composite, this behavior is attributed to the defects such as bubbles and voids analyzed in the MEV tests, contributing negatively to the performance of the composite. The 5% FP sample, compared to the other samples (10%, 20%), obtained a better mechanical behavior; this leads us to understand that this composite had a more homogeneous mixture, having a smaller percentage added to the matrix.

The composition of the best result in relation to the maximum stress compared to the pure resin was the 5% FP sample of the fiber volume. However, the Fig. 6 shows the variations of the maximum tensile of traction, modulus of elasticity and deformation, presented in Table 2 for samples, RP 0%, 5%, 10% and 20% of FP, who underwent flexion testing. It can be seen from Fig. 6 above that the addition of corn cob particles, as already explained, increases the modulus of elasticity of the composite and causes the decrease in strength and deformation of the composite.

The modulus of elasticity calculated for lignocellulosic fibers observed in literature varies greatly, as shown (Satyanarayana *et al.* 2011) in other reinforcing fibers, but in our case the fact was repeated.

As already mentioned, these results show that corn cob added to the polyester resin will serve as a filler in order to reduce the amount of the polyester resin used and should be used in applications where the amount added in the case is 5% does not compromise its mechanical performance (Sepe *et al.* 2018).

On the other hand, the addition of PF from corn cob will lead to a significant reduction in the use and accumulation of the polyester resin in the environment.

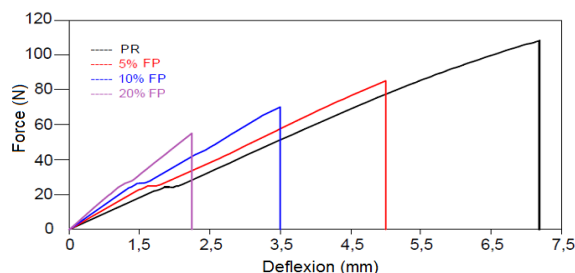


Fig. 7. Typical deflection curves for pure resin PR, with 5, 10 and 20% FP in volume of corn cob.

### 3.2 Flexion testing

The flexural strength, flexion modulus and deflection values of the composites were determined by the flexion test of the specimens made and tested according to ASTM-D790.

The mechanical behavior under the flexion test of the pure resin specimens and resin with 5%, 10%, 20% FP of the corn cob under the three-point bending test are illustrated by the force/displacement curves.

Figure 7 shows the bending curve of the pure resin, which was linear, due to the elastic regime of the polymer, which until the rupture maintained a fragile behavior. With the data, we set Table 2 of maximum flexion stress and modulus of elasticity, for the composites with 5%, 10% and 20% by volume of fine particles of corn cob.

The resin sample with 5% FP, compared to the sample without particle, obtained a reduction (~21.6%) in the flexural stress, and a reduction (~32.8%) in the composite deflection, whereas the resin sample with 10% FP obtained a decrease (~35.42%) in the flexural stress and with a larger composite deflection (~52.96%). However, for the 20% FP resin sample there was a reduction in flexural stress (~50.17%), and a reduction in deflection (~69.76%) compared to the pure resin.

Table 2. Mechanical properties obtained by flexion tests as a function of the composite load percentage.

Volume of corn cob fiber (%)	Flexion tension (MPa)	Modulus of elasticity (GPa)	Deflection (mm)
PR 0%	75.25	1.405	7.44
FP 5%	59.00	1.640	5.00
FP 10%	48.60	1.929	3.50
FP 20%	37.50	2.315	2.25

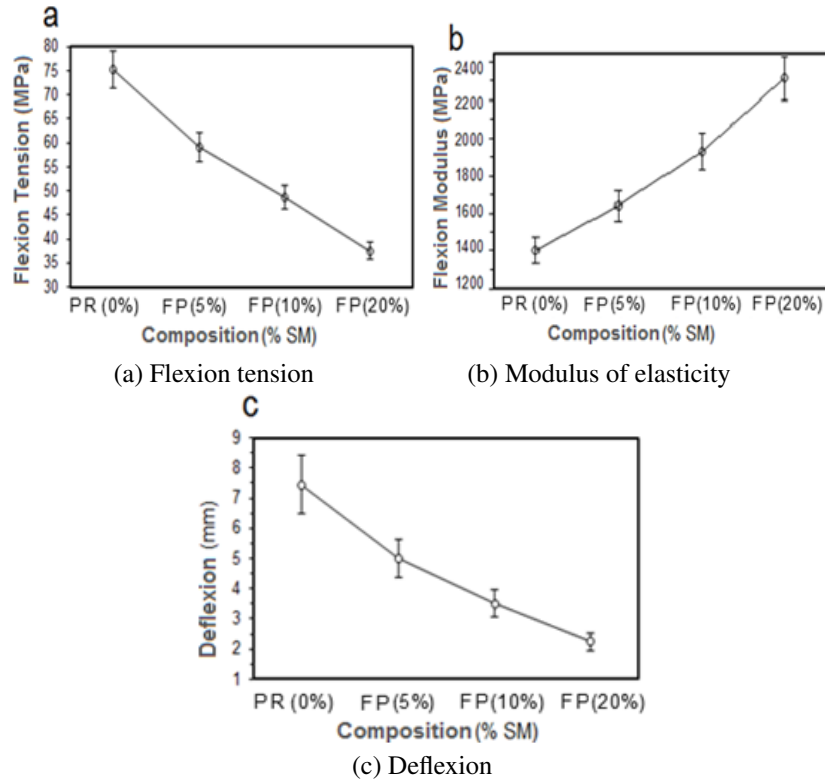


Fig. 8. Values of mechanical properties flexion tension (a) flexion modulus (b) deflection (c) for sample with PR 0% and with load of 5%, 10% , 20% FP of corn cob.

According to Fig. 8, we also observed that the higher the content of the particles inserted in the resin, the greater the modulus of elasticity and the lower the properties of resistance to flexion (flexural stress) and deflection (Faruk *et al.*, 2012).

Therefore, we can confirm that composite with 20% FP, has modulus of elasticity (2.315 GPa for 1.640 GPa) an increase of 41.15% in relation to the composite with 5% FP, and higher 64.76% than that of pure resin due to poor load/matrix interaction.

Table 3. Mechanical properties obtained by Izod impact test as a function of the composite load percentage.

Volume of corn cob fiber (%)	Impact Resistance (J/m)
RP 0%	8.03
RP 5%	8.33
RP 10%	9.72
RP 20%	10.30

According to Borsoi *et al.* (2014), when the fiber content is increased, the tensions become more evenly distributed, thus increasing the strength of the composite, as well as the rigidity of the material.

### 3.3 Impact testing

The impact resistance in composite materials is important to help detect possible failures during their use. The Izod impact tests on polymer matrix were performed according to ASTM D256, reinforced with different volumetric fractions of corn cob fibers. The results obtained in the Izod impact tests of the composites with the fine particles are shown in Table 3.

According to the results found in Table 3, the specific energy variation (J/m) of the Izod impact test, comparing the pure polyester resin and the composites with 5, 10 and 20% fine particles, the performance of the composite has its increased impact resistance. Figure 9 shows a curve of the variation of the energy absorbed in the impact as a function of the relative volume of fine particles of the matrix.

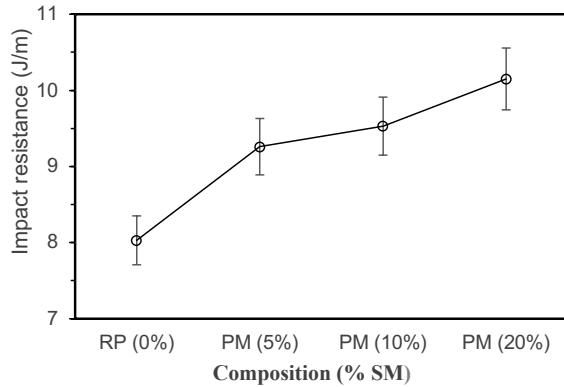


Fig. 9. Izod impact strength values for PR and composite with load of 5, 10 and 20% FP of corn cob.

### 3.4 Morphological Evaluation by Scanning Electron Microscopy

Thus, based on the photomicrographs we were able to evaluate the different parts of the maize cob fiber, in Fig. 10 we observed the composition of the fine particle (FP), it is constituted, (1) fibers of the woody ring, (2), (3) of the marrow and a large percentage of fine straw.

However, Fig. 12 shows the composition of the large particle (LP) which is constituted in large percentage by the nucleus (marrow) which is the micro tubes of the central region of the corn cob. Thus, we can conclude that the grain size range used for the production of the composites contemplates practically all components of crushed corn cob.

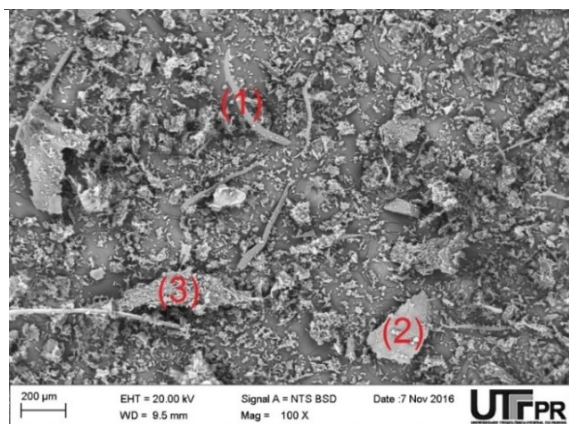


Fig. 10. Photomicrographs in MEV of the fibers of the ground corn cob fine particle (FP).

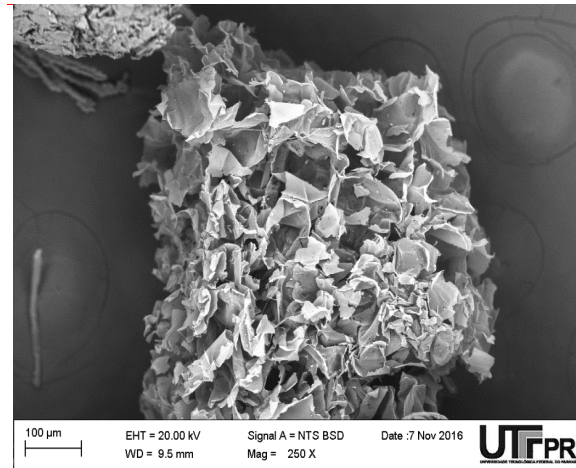


Fig. 11. Photomicrographs in MEV of the fibers of the ground corn cob medium particle (MP) with a good part consisting of fine straw.

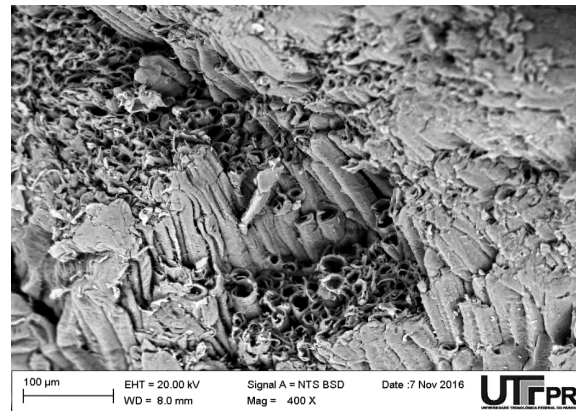


Fig. 12. Photomicrographs in MEV of the fibers of the ground corn cob large particle (LP).

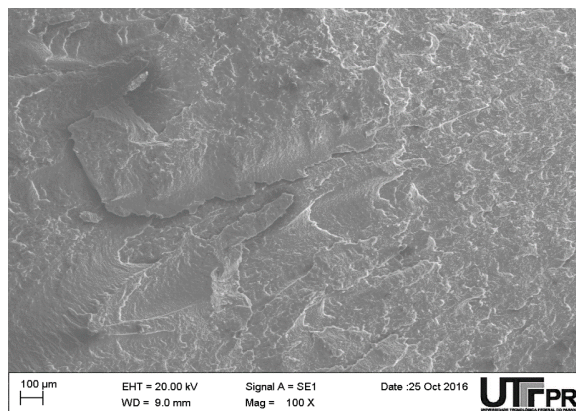


Fig. 13. Photomicrography in MEV of the pure resin sample (PR).



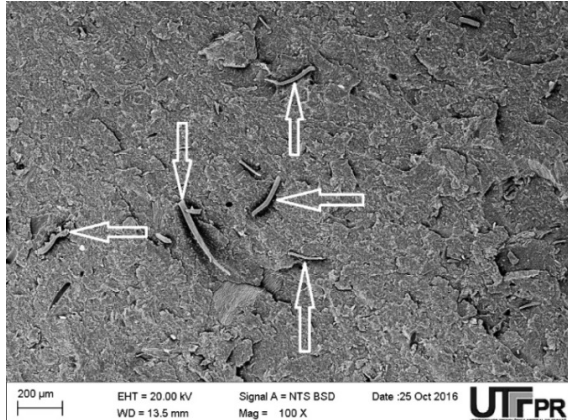


Fig. 14. Photomicrography in MEV of the sample (PR) + 5% (FP) of corn cob.

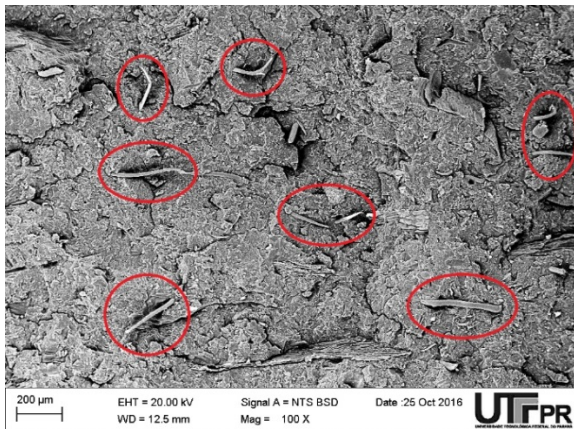


Fig. 15. Photomicrography in MEV of the sample (PR) + 10% (PF) of corn cob.

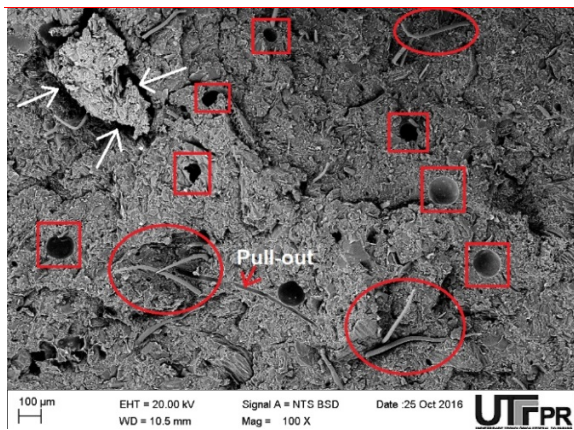


Fig. 16. Photomicrograph in MEV of the sample (PR) + 20% (FP) of corn cob.

### 3.4.1 Morphological Evaluation by Scanning Electron Microscopy in Composite with 5%, 10% and 20% of FP

In this section we will present and discuss the results of scanning electron microscopy analysis of fine particle composites, where we wanted to observe the influence of the load on the matrix.

In Fig. 13 it is observed that for the test specimen without fiber addition a fragile fracture occurs without any compromising deformation, but that may have led to the development of a crack.

The direction of movement of this possible crack is approximately perpendicular to the direction of applied tensile stress, and produces a relatively flat fracture surface on the specimen. This observation occurs in all photomicrographs of the pure resin, due to this the photomicrography of the resin will be commented only in this topic.

However, in Fig. 14, photomicrography of the sample with 5% fine particle (FP) resin, it is verified that the particle interacts well with the matrix, thus obtaining a good homogeneity, which leads to good load/matrix adhesion, as shown by the arrows in white.

Figure 15, resin with 10% of the fine particle (FP), can be analyzed a larger quantity and a better distribution of the particles, even with a good interaction with the matrix, good charge/matrix junction signal, as shown in areas circled in red, but with low mechanical resistance. The tensile strength at rupture decreases with the increase of the percentage of corn cob meal in the composite, this theory is true, as we saw in the traction tests presented in this paper.

In Fig. 16, the resin sample was observed with 20% of the fine particle (FP), we analyzed a higher concentration of particles in the matrix, we observed in the areas surrounded in red, the defects as voids and bubbles, defects not found in the samples with 5% and 10% (FP), these defects occur due to a failure of the matrix to the mixture, since the mixture is made manually and the percentage of 20% of load is greater, thus making this mixture difficult. The white arrows show the weak interaction between the larger particles (LP) and also a pull - out signal. These irregularities or structural imperfections have a great influence on the properties of the materials, especially on the mechanical properties, such as the tensile stress, which in this sample was the lowest compared to the others with the same type of load (particle size).

The fiber matrix adhesion and pull-out tendency of the fiber are related to fiber quality and size. (Yue *et al.*, 2005) The fiber pull-out from the matrix was by

scanning electron micrographs, which indicates that improving adhesion at the fiber-polymer interface may increase mechanical properties (Frydrych *et al.*, 2002)

Thus, it is concluded that the fine particle used for the production of the composites has a good interaction and a good distribution with the polymer matrix, however we also observe that if we increase the percentage of load in the matrix, in the case of 20% of load, this would have resulted in the formation of defects having a negative influence on the composite.

### 3.4.2 Morphological Evaluation by Electron Microscopy Scanning in Composites with 5%, 10% and 20% of MP

In this section will be presented and discussed the results of scanning electron microscopy analyzes of the composites with medium particles, where it was desired to observe the influence of the load on the matrix. Figure 17 shows the SEM of the sample fractured by the tensile test of the resin with 5% medium particle (MP).

The pull-out signal of the extract (granule) of the matrix indicates low fiber/matrix adhesion and low degree of wettability and, consequently, low mechanical energy transmission between matrix and particle, but also it is possible to see that the corn cob particle was ruptured leaving only a part in the sample of the analyzed matrix, this shows that there is a certain degree of surface wettability between the average particle and the matrix and therefore a certain anchorage between the phases. Figure 18 shows the SEM of the sample fractured by the tensile test of the resin with 10% medium particle (MP).

In Fig. 19 we can analyze a better distribution of the load, compared to Figure 17 in which we have the 5% load composite (MP), because its shows signs of pull-out of the particles in the matrix which (Wong *et al.*, 2010), that the quality of the interface can be determined by the chemical and physical factors that determine the quality of the interface. In turn, are related to surface area, purity of reinforcement, matrix wettability and differences in the thermal and mechanical properties of the constituent materials. Thus, weak bonding may be responsible for the detachment of the fiber in the matrix causing ruptura, being as possible to notice that the corn cob particle was fragmented with only a part of the analyzed matrix sample, this shows that there is a level of surface wettability between the medium particle and the matrix, so a certain contact between the phases.

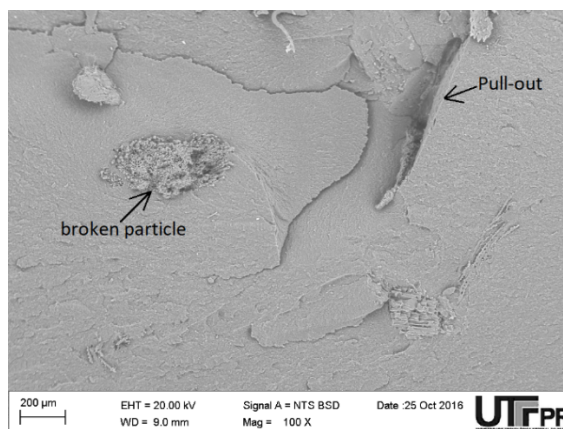


Fig. 17. Photomicrography in MEV of the sample (PR) + 5% (MP) of corn cob.

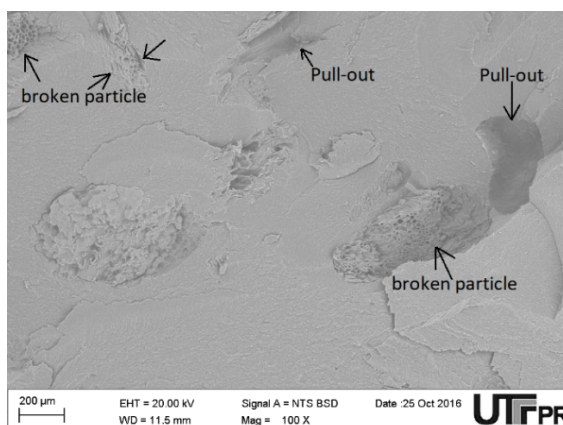


Fig. 18. Photomicrography in MEV of the sample (PR) + 10% (MP) of corn cob.

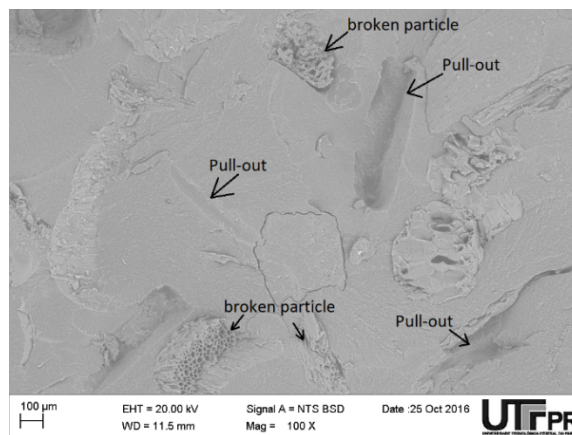


Fig. 19. Photomicrography in MEV of the sample (PR) + 20% (MP) of corn cob.

It shows a greater amount of pull-out signals of the particle in the matrix which shows, lack of adhesion between charge/matrix, but it is also possible to notice that there are broken corn particles broken only one part in the sample of the matrix analyzed, this shows that there is a minimum possibility of contact between the particle and the matrix. Thus, we can observe that the medium particle, which in its composition consists of fine straw, in the production of the composites has a low fiber/matrix interaction, but with a good distribution in the polymer matrix, however we also observe that if we increase the percentage of load in the matrix, this would lead to the formation of defects, negatively influencing the mechanical properties of the composite (Nirmal *et al.*, 2015).

### 3.4.3 Morphological Evaluation by Composites Scanning Electron Microscopy in composites with 5%, 10% and 20% of LP

In this section will be presented and discussed the results of scanning electron microscopy analyzes of composites with large particles, where it was desired to observe the influence of the load on the matrix. Figures 20, 21 and 22 shows the SEM of the fractured samples by the tensile test with 5, 10, and 20% large particle.

In Fig. 20, resin with 5% large particle, shows the particle pull-out signal in the matrix, which indicates little fiber/matrix interaction and low degree of wettability, suggesting a poor fixation of the load in the matrix, not obtaining an effective transmission of mechanical energy between load/matrix.

Figure 21 shows the composite, with 10% of the large particle, also the pull-out signal of the particle in the matrix indicating low fiber/matrix adhesion and low degree of wettability. The reason for this behavior is apparently a consequence of poor resistance at the fiber/matrix interface.

Comparing the value of the interfacial shear stress of composites matrix/resin with others reported in the literature, such as Monteiro *et al.* (2010), it can be assumed that the fiber/matrix relationship discussed in this work is very promising, corroborating the trend of the use of these lignocellulosic fibers as reinforcement and insulation in polymeric composites.

Figure 22, resin with 20% large particle, shows the pull-out signal of the particle in the matrix which also indicates little fiber/matrix adhesion. The reason for this behavior is apparently a consequence of poor resistance at the fiber/matrix interface.

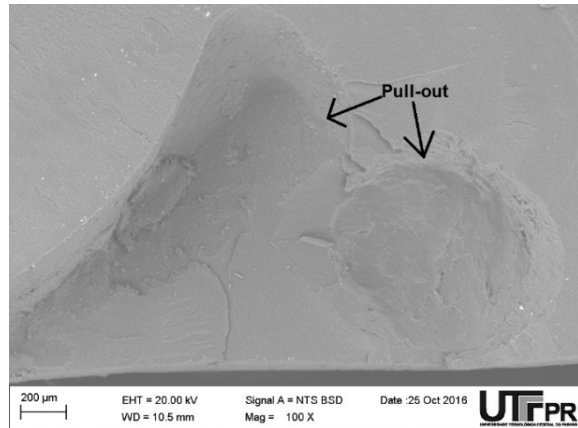


Fig. 20. Photomicrography in MEV of the sample (PR) + 5% (LP) of corn cob.

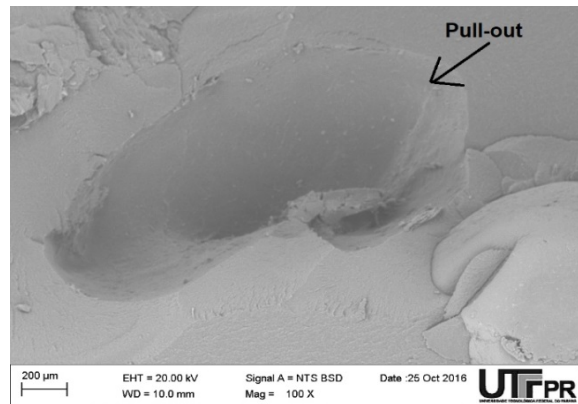


Fig. 21. Photomicrography in MEV of the sample (PR) + 10% (MP) of corn cob.

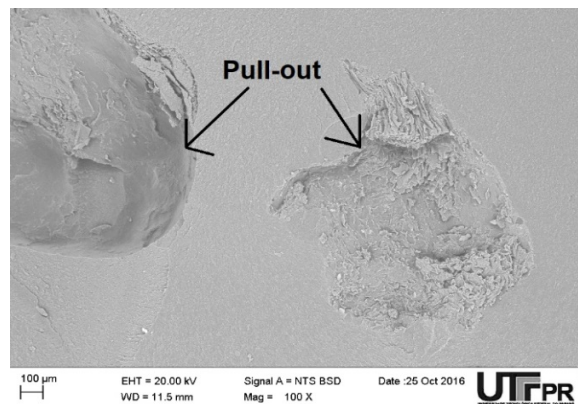


Fig. 22. Photomicrography in MEV of the sample (PR) + 20% (LP) of corn cob.

Table 2. Thermal properties obtained by compensated hot plate device method as a function load percentage of the composite.

Volume of corn cob fiber (%)	Right Plate Thermal Conductivity (W/m.k)	Left Plate Thermal Conductivity (W/m.k)	Thermal Conductivity (W/m.k)
RP 0%	0.171	0.171	0.171
PF 5%	0.1379	0.1380	0.138
PF 10%	0.1359	0.1360	0.136
PM 5%	0.1429	0.1430	0.143
PG 20%	0.1369	0.1370	0.160

As observed by Rokbi *et al.* (2011), one of the drawbacks in the use of lignocellulosic fibers in polyester matrix is its hydrophilic nature, due to the water absorbed at the surface of the fiber, because its in polyester matrix, form a weak fiber/matrix interaction.

Thus, it can be concluded that there is no fiber/matrix interaction, in the production of composites with large particle, and that this particle in all its compositions do not have good mechanical properties in relation to the composite.

### 3.5 Thermal analysis

To study the thermal properties, specifically the thermal conductivity of this composite was used the compensated hot plate device method, which is based on the procedure ANSI/ASTM C 177-76. Table 4 presents the results of the thermal behavior of the composite material studied, that is, the thermal conductivity. The analyzes were carried out in order, in the pure resin, and in the composites whose values of tensile strength came closest to the pure resin (PR), which were the composites with 5% FP, 10% FP and 5% MP. It was also done in the composite with 20% LP, because it is a larger and more porous particle compared to the others.

According to Callister (2015), the magnitude of the thermal conductivity depends on the degree of crystallinity, and thus, a highly crystalline and ordered structure polymer will have higher conductivity than the equivalent amorphous material. Particle size, e.g., the size of these particles may also have influenced the thermal conductivity, which leads to a clear contribution of corn cob particles in the potentiation of the polymer as thermal insulation. In the case of composites with 5% PF and 10% PF, the behavior of the composites showed a linear tendency to decrease the thermal conductivity values of the composites, which presented the lowest values of thermal conductivity.

The effective thermal conductivity of composite materials depends on the properties and the volumetric fractions of the constituent phases (Pietrak *et al.*, 2015), and it is concluded that the increase of the thermal conductivity of the composites occurs with the increase of the particles of the fiber, fact that results from the facility or not found for the conductive paths formation, the interfacial adhesion matrix/load and until synergy between the components of the system. The Fig. 23 shows a diagram of the thermal conductivity variation as a function of the relative volume of the fine, medium and large particles inserted in the matrix. It should be noted that the values for thermal conductivity of the composites with 5% PF and 10% PF are close, the composite with 10% PF presents a smaller value compared to the composite with 5% PF, only 1.5% in its reduction and, therefore, does not make it significantly more thermal insulation than the composite with 5% PF. However, the same behavior did not present the composites with 5% PM and 20% PG, they presented discrepant values, likely because this could have happened due to the fact of a higher crystallinity of these composites, compared to those of 5% PF and 10% PF.

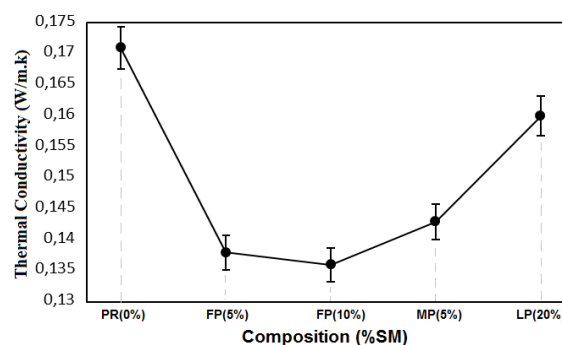


Fig. 23. Graph of the thermal conductivity variation as a function of the relative volume of the fine, medium and large particles inserted in the matrix.

The behavior of the composite's conductivity is inversely proportional to the fraction of the fiber in the polyethylene polymer matrix, with values lower than the pure resin (Abdullah *et al.*, 2011).

Analyzing Fig. 23, it was possible to verify that the corn cob particles had a positive influence on the thermal conductivity of the pure resin, the composites that obtained the lowest values of thermal conductivity were, with 5% PF, 10% PF of corn cob, presented a reduction in the thermal conductivity of 19.3% and 20.5%, these results are quite significant compared to pure resin. In relation to the composites already studied and shown by the literature of thermal insulation materials, the composite studied had a thermal conductivity lower than 0.21 W/mk, that is, in the order of 0.136 W/mk, which concludes that this material presents important thermal insulation (Gutierrez *et al.*, 2018).

## Conclusions

As the granulometry increases and the percentage of load in the composite there is a decrease in its resistance and an increase in the modulus of elasticity. However, if we compare the results of the three mechanical tests performed, the most significant values of resistance to pure resin (RP) purchased were the Izod impact test with about 11% reduction; flexion with 21% reduction and finalizing the traction test with 24.5%. Therefore in the samples where the fine particles (FP) were inserted, the results of the mechanical properties presented were the closest ones to the pure resin (PR), which in the SEM analysis showed good adhesion between the load/matrix. The composites analyzed by MEV of the samples with resin + 5% fine particles and resin + 10% fine particle (FP) are the ones that best interact with the matrix, thus obtaining a good distribution and consequently good charge/matrix adhesion, since the formulation with 20%, bubbles occurred due to the production process of the specimens being made manually. The resin samples with 5%, 10% and 20% large particle (LP) showed signs of total pull-out of the particle in the matrix indicating little fiber/matrix interaction little energy between load/matrix. However, we can conclude also that the presence of fine particles (FP), were more efficient as thermal insulation, because the composites that presented the lowest values of thermal conductivity, with values of 0.138 W/mk.

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