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# Mechanical Flexural Characterization of Composite Materials with Photopolymer Matrix Reinforced with Abaca and Cabuya Fibers Using 3D Printing

# Caracterización mecánica a flexión de materiales compuestos con matriz fotopolimérica reforzados con fibras de abacá y cabuya mediante impresión 3D

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## Abstract

Composite materials and 3D printing currently constitute an alternative for manufacturing automotive parts. The objective of the present research was to characterize a material composed by a photopolymer resin matrix reinforced with natural abaca and cabuya fibers and made by 3D printing, for its application in auto parts manufacturing. The directional grid of the air conditioning duct of an automotive is selected as the subject of study, and its mechanical characteristics are compared by means of experimental analysis and computational simulation. A composite volumetric reinforcement fiber with a fraction of 20% in the two types of fibers, was proposed for manufacturing the test specimens, and the bending test was carried out according to the ASTM 790 standard.

## Resumen

Los materiales compuestos y la fabricación por impresión 3D son en la actualidad una alternativa en la fabricación de autopartes. La presente investigación tuvo como objetivo caracterizar el material compuesto con matriz de resina fotopolimérica reforzada con fibras naturales de abacá y cabuya fabricados por impresión 3D, para su aplicación en la fabricación de autopartes. Como objeto de estudio se seleccionó la rejilla direccional del ducto de aire acondicionado de un automotor; mediante análisis experimental y simulación computacional se compararon sus características mecánicas. Para la fabricación de las probetas de ensayos se propuso una fracción volumétrica de fibra refuerzo del composite del 20 % en los dos tipos de fibras, el ensayo a flexión se procedió según la norma ASTM 790.

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As a result of the mechanical characterization of the manufactured materials, it was obtained that the maximum bending stress of the compounds reinforced with abaca (77.53 MPa) and cabuya (83.26 MPa) decreased with respect to the matrix material (92.77 MPa), while the modulus of elasticity to bending of the compounds reinforced with abaca (2211,33 MPa) and cabuya (1806,03 MPa) increased with respect to the matrix material (1689,64 MPa). This indicates an increase in the rigidity of the characterized materials, making possible the substitution of the matrix material.

***Keywords***: composite materials, 3D printing, abaca fibers, cabuya fibers, photopolymer matrix.

Como resultado de la caracterización mecánica de los materiales fabricados se obtuvo que el esfuerzo máximo a flexión de los compuestos reforzados con abacá (77,53 MPa) y cabuya (83,26 MPa) disminuyeron con respecto al material matriz (92,77 MPa). El módulo de elasticidad a la flexión que presentaron compuestos reforzados con abacá (2211,33 MPa) y cabuya (1806,03 MPa) aumentaron con respecto al material matriz (1689,64 MPa), lo que se traduce en un aumento de la rigidez de los materiales caracterizados, haciendo posible la sustitución del material matriz.

***Palabras clave***: materiales compuestos, impresión 3D, fibras de abacá, fibras de cabuya, matriz fotopolimérica.

## 1. Introduction

Natural fibers are used as reinforcement of polymers in different places worldwide for manufacturing auto parts, due to their features of light weight, low cost, good mechanical properties, easy recycling which reduces waste and, since the vehicle becomes lighter, they enable reducing contaminant emissions and saving fuel, thus contributing to the worldwide environmental policies [1, 2].

Faruk *et al.* [3] state that in recent years the automotive industry has focused in the elaboration and utilization of composite materials, integrating natural fibers as a reinforcement element, for manufacturing external and internal parts of the vehicle, contributing to the environment by adequately utilizing the natural fibers with the best mechanical properties. In 2015 Ahmad *et al.* [4] analyzed the use and application of natural fibers such as jute, bamboo and abaca, as reinforcement for composite materials in the manufacturing of auto parts, from the analysis of its chemical, physical and mechanical properties. In addition, Roshdestwensky *et al.* [5] remark that the use of these new materials is consolidating in the aerospace and naval areas, favoring its application in the manufacturing sector in particular the automotive, employing natural fibers as replacement of synthetic fibers present in the vehicle, reducing the weight and cost of the automobile.

Guo and Leu [6] studied composite polymers reinforced with natural fibers in industrial applications, evaluating the viability of fibers of data palms for the automotive industry, obtaining an improvement in the door panels of a Class E Mercedes-Benz regarding the mechanical properties of the original material; this was achieved utilizing an epoxy resin as matrix material and embedding fibers of linen/sisal, reducing the original weight in 20 %.

Li and Huang [7] researched about the application of the fast prototyping technology in the manufacturing of automotive parts, applying different methods of 3D printing technology, such as stereolithography (SLA), fused deposition modeling (FDM) and selective laser sintering (SLS). The manufacturing times were reduced, even for elements whose development is geometrically complex; this enabled manufacturing companies to reduce production times and costs, obtaining significant economical earnings in series production.

Berchon and Luyt [8] stated that the 3D printing technology brings benefits, such as: decrease of manufacturing times, obtaining geometries of elements of great complexity, reduction of the production chains or stations, saving in the material utilized and decrease of residues of the manufacturing process, compared with conventional production methods.

Bonada, Muguruza and Ramis [9] stated that additive manufacturing may generate 3D parts or elements, adding material layer by layer to manufacture complex geometries without utilizing specific accessories or tools. The PolyJet technology is a 3D printing method that offers a superficial finish of better quality compared to other methods of additive manufacturing, with a great variety of materials for different industries and requested applications [10].

Callister [11] mentioned that the final properties of the composite materials depend on the characteristics of the two main components: matrix, interface and reinforcement, taking into account in the latter the shape, size, distribution and orientation; besides, suggests that one of the main combinations of composite materials are those reinforced with fibers that exhibit excellent mechanical properties: resistance to the traction and elevated specific modulus, from low density base elements both in the matrix and in the fiber. In addition, the orientation, quantity and distribution of the composite material, directly influence the final mechanical properties of the composite [12], as shown in Figure 1.

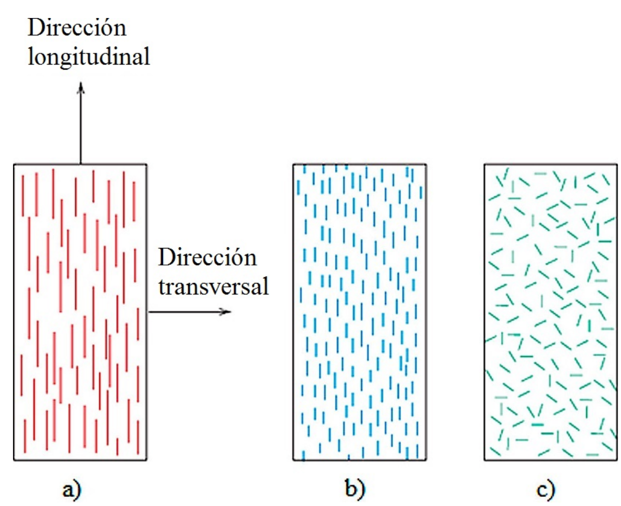


**Figura 1.** Possible orientations of the reinforcement in a composite material: a) continuous and aligned fibers, discontinuous and aligned fibers, and c) randomly oriented discontinuous fibers; taken from [11].

Thanks to the advantage over traditional manufacturing techniques, the samples manufactured using 3D printing exhibit better mechanical properties than fused models, thanks to the correct matrix-fiber interface adhesion of the printed samples [13].

In current automotive vehicles, manually regulated grilles are employed to direct the flow of air conditioning; due to this, breaks are produced. Replacing them by originals is occasionally not feasible, thus the use of composite materials and manufacturing by 3D printing results an attractive option.

From what has been previously explained, the objective of this study is to characterize the composite material with photopolymer resin matrix reinforced with abaca and cabuya natural fibers and made using 3d printing, by means of computational simulation and mechanical tests, for its application in manufacturing of auto parts.

## 2. Materials and methods

The process of obtaining composite materials by means of additive manufacturing technologies, to improve mechanical properties according to the abaca and cabuya reinforcement fibers with a 20 % volumetric proportion, is shown in Figure 2.

The constitutive materials of the composite were two types of natural fibers (abaca and cabuya as reinforcement elements), and a photopolymer element as the matrix for manufacturing the composite.

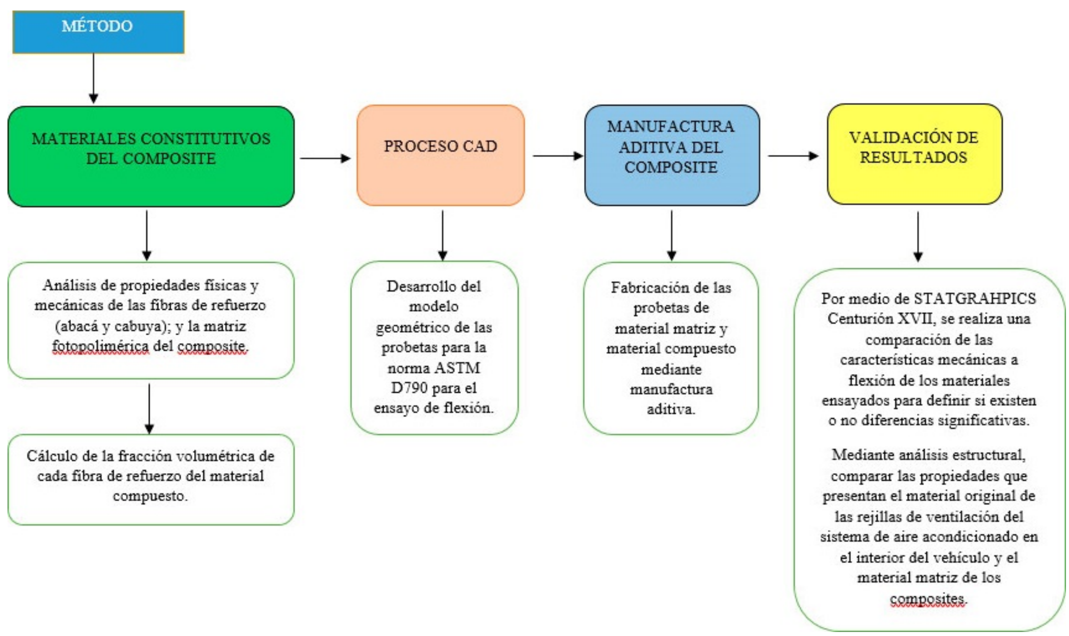


**Figura 2.** Steps for obtaining and validating the composite material.

### 2.1. Calculation of the fiber density of the abaca and the cabuya

The procedure proposed by [13] is employed, which determines the density of the pineapple fiber finding the density of the resin by means of the construction of test specimens, and then the construction of test specimens with composite material. The density of the fiber is determined as the difference.

### 2.2. Photopolymer matrix

The element used as organic/polymer matrix of the composite material, is a photopolymer utilized in additive manufacturing with PolyJet technology VeroClear RGO8 10) whose properties are shown in Table 1.

**Tabla 1.** Physical and mechanical properties of the matrix material of the composite

| Material | Density (g/cm$^3$) | Resistance to traction (MPa) | Resistance to bending (MPa) | Young Module (GPa) |
|---|---|---|---|---|
| Photopolymer matrix | 1.181 | 50-65 | 75-110 | 2-3 |

The rule of the mixtures for composites reinforced with fibers, is utilized for calculating the volumetric fraction of the reinforcement fiber (cabuya and abaca, respectively).

### 2.3. Rule of the mixtures for composites reinforced with fibers

«The rule of the mixtures will always give the density of the composite reinforced with fibers» [14,15], which shows the mathematical expression to obtain the density of the composite material, relating the volumetric fractions and densities of the matrix and reinforcement fiber as observed in Equation 1, where $\rho_c$ = density of the composite material, $f_m$ = volumetric fraction of the matrix, $\rho_m$ = density of the matrix, $f_f$ = volumetric fraction of the fiber and $\rho_f$ = density of the fiber

$$\rho_c = f_m \cdot \rho_m + f_f \cdot \rho_f \tag{1}$$

considering

$$f_m = 1 - f_f \tag{2}$$

For the analysis, it is proposed a 20 % volumetric fraction of the reinforcement fiber in the composite of the two types of fibers, namely abaca and cabuya, from previous studies which reference the best results for a volumetric fraction of fiber between 20 and 23 %.

### 2.4. Development of the geometrical model of the test specimens

For the geometrical development of the test specimens of the composite material, the ASTM 790 standard for the bending test was applied with dimensions 153.6 × 13 × 4 mm.

### 2.5. Additive manufacturing of the test specimens

The additive manufacturing of the test specimens was carried out in a 3D printer, injecting photopolymers on a surface, deposited layer by layer with a 0.1 mm resolution. An ultraviolet treatment between layers is further applied hardening the resin; the printing is paused to place a fiber layer with a volumetric fraction of 20 %, and then the printing is resumed, as shown in Figures 3, 4 and 5.

**Figura 3.** Additive manufacturing of the bending test specimen with base material.

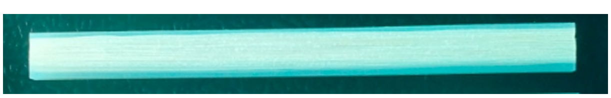

**Figura 4.** Additive manufacturing of the bending test specimen with the composite material reinforced with abaca fibers.

**Figura 5.** Additive manufacturing of the bending test specimen with the composite material reinforced with cabuya fibers.

### 2.6. Equipment

1) Universal test machine. The test machine Metrotec, MTE 50 series, with a capacity of 50 kN, was employed to conduct tests for polymeric materials, composite and light metals.
2) 3D Printer. The PolyJet technology, model Objet 30 PRO, which works with various engineering materials and has a net printing capacity of 300 x 200 x 150 mm, was used for additive manufacturing of all test specimens.
3) Stove. Used for drying the fibers. It enables the digital visualization of the temperature.
4) ASPEX Scanning electron microscope. Is employed to obtain micrographs of the transverse sections of the test specimens tested for bending, considering the three configurations carried out in a detection range from 500 nm to 5 mm.

NX 10, which is a powerful engineering simulation tool, was the software employed for the structural simulation of the materials.

The results of the analysis and the graphs were obtained using the statistical software STATGRAPHICS Centurion XV (Trial version 15, StatPoint Inc., USA). A factorial experimental design was utilized, in which the effects of the abaca and cabuya fibers are studied regarding the mechanical properties of the composite materials with photopolymer matrix.

## 3. Results and discussion

The average density obtained for the abaca fiber was 1.226 g/cm$^3$ and for the cabuya 0.665 g/cm$^3$. The results obtained in the characterization of the base material, and of the composite materials reinforced with the two types of fibers, namely abaca and cabuya, are presented in the following.

### 3.1. Results of the bending test on the matrix material

The additive manufacturing of five test specimens was carried out for the bending test of the matrix material under the ASTM 790 standard, with the purpose of obtaining reference values. Figure 6 shows the test specimens which, as can be seen, were fractured after the test.

**Figura 6.** Test specimens of the matrix material.

Table 2 shows the values of the bending test carried out on five test specimens of the matrix material of the composite. The average value of the maximum bending stress is 92.77 MPa, with a standard deviation of 9.67 MPa; of the modulus of elasticity secant to bending is 1689.64 MPa with a standard deviation of 216.59 MPa, and of the deflection is 8.72 mm with a standard deviation of 0.96 mm.

**Tabla 2.** Results of the bending test on the matrix material

| Material | Recount | Average | Standard Deviation |
|---|---|---|---|
| Maximum Force (N) | 5 | 189,33 | 19,58 |
| Maximum bending stress (MPa) | 5 | 92,77 | 9,67 |
| Modulus of elasticity secant to bending (MPa) | 5 | 1689,64 | 216,59 |
| Maximum deformation (%) | 5 | 5,13 | 0,61 |
| Deflection (mm) | 5 | 8,71 | 0,96 |

Note. The bending specimens of the composite matrix material manufactured with 3D printing and PolyJet technology.

### 3.2. Scanning electron microscopy of the matrix material

Figure 7 shows the micrographs of the transverse section of the photopolymer resin, matrix material of the composite materials.

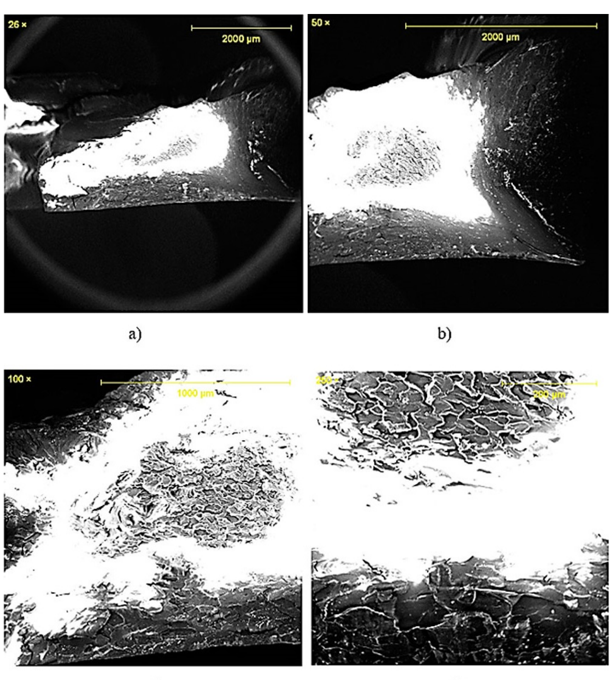


**Figura 7.** Photopolymer resin of the matrix material of the composite materials: a) 26X, b) 50X, c) 100X and d) 250X.

The micrographs shown were taken at different magnifications to one of the test specimens after the bending test, with the purpose of verifying if the test specimen presents internal cracks between the printed layers. The micrograph taken with a magnification of 250X, enables verifying that the sample tested is homogeneous and does not have internal fissures, thus consolidating the values of mechanical properties of the matrix material obtained after the bending test.

The additive manufacturing of five test specimens of the composite material reinforced with abaca fibers was carried out, for bending tests under the ASTM 790 standard. Figure 8 shows the test specimens after the test, where it can be observed a partial tear of the matrix material in the tested zone.

**Figura 8.** Test specimens of the composite material reinforced with abaca fibers.

Table 3 shows the results obtained on the bending test, under the ASTM 790 standard, to the composite material reinforced with 20 % of abaca fibers, manufactured by 3D printing and PolyJet technology. The following average values of the material reinforced with abaca fibers were found: maximum bending stress 77.53 MPa, modulus of elasticity secant to bending 2211.33 MPa and deflection 5.60 mm.

**Tabla 3.** Ensayo de flexión del material compuesto reforzado con fibra de abacá

| Material | Recount | Average | Standard deviation |
|---|---|---|---|
| Maximum force (N) | 5 | 153,99 | 20,73 |
| Maximum bending stress (MPa) | 5 | 77,53 | 11,88 |
| Modulus of elasticity secant to bending (MPa) | 5 | 2211,33 | 225,41 |
| Maximum deformation (%) | 5 | 3,25 | 0,50 |
| Deflection (mm) | 5 | 5,60 | 0,89 |

### 3.3. Scanning electron microscopy of the composite material reinforced with abaca fibers

Figure 9 shows the scanning electron microscopy taken to one of the test specimens tested, in the area of fracture after the bending test.

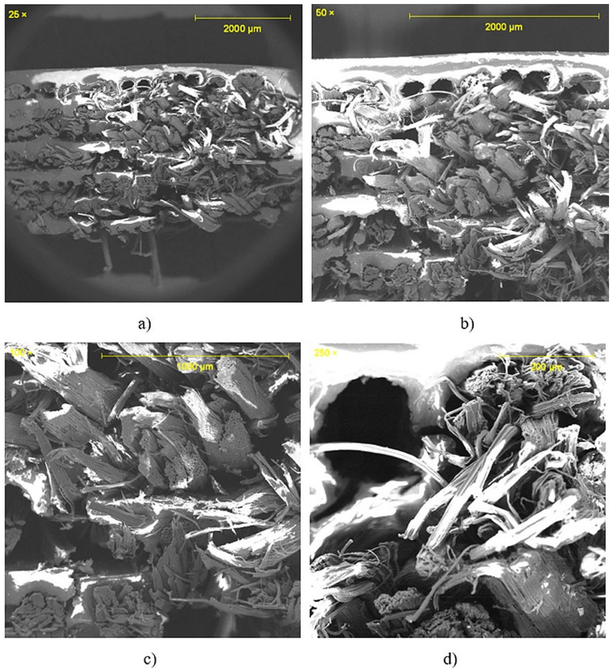

**Figura 9.** Composite material reinforced with abaca fibers: a) 25X, b) 50X, c) 100X and d) 250X.

The micrographs were taken at different magnifications to one of the test specimens of the composite material after the bending test. The micrograph taken with a magnification of 250X, shows the poor adherence between the reinforcement fibers and the matrix material of photopolymer resin, namely, there is not a good interface in the composite material.

The additive manufacturing of five test specimens of the composite material reinforced with cabuya fibers was carried out, for bending tests under the ASTM 790 standard. Figure 10 shows the test specimens after the test. It can be observed that the test specimens did not present a total tear, only a partial tear of the matrix material in the tested zone.

Table 4 shows the results obtained on the bending test, under the ASTM 790 standard, to the composite material reinforced with 20 % of cabuya fibers. The following average values of the material reinforced with cabuya fibers were obtained: maximum bending stress 83.26 MPa, modulus of elasticity secant to bending 1806.03 MPa and deflection 7.93 mm.

**Figura 10.** Test specimens of the composite material reinforced with cabuya fibers.

**Tabla 4.** Bending test of the composite material reinforced with cabuya fibers

| Material | Recount | Average | Standard deviation |
|---|---|---|---|
| Maximum force (N) | 5 | 185,86 | 13,54 |
| Maximum bendign stress (MPa) | 5 | 83,25 | 6,48 |
| Modulus of elasticity secant to bending (MPa) | 5 | 1806,03 | 220,52 |
| Maximum deformation (%) | 5 | 4,67 | 0,74 |
| Deflection (mm) | 5 | 7,93 | 1,27 |

Note. The bending test specimens of the composite were manufactured with 3D printing and PolyJet technology.

### 3.4. Microscopía electrónica de barrido del composite reforzado con fibra de cabuya

En la Figura 11 se muestra una microscopía electrónica de barrido realizada a una de las probetas ensayadas en el área de la fractura posterior al ensayo de flexión.

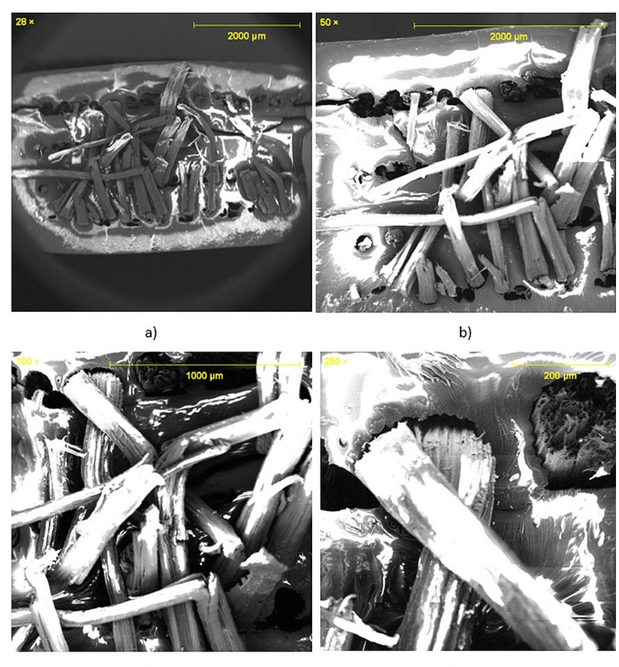

**Figura 11.** Composite material reinforced with cabuya fibers. a) 28X, b) 50X, c) 100X and d) 250X.

The micrographs were taken at different magnifications to one of the test specimens of the composite material after the bending test, with the purpose of verifying if there is a good interface between the polymeric matrix and the cabuya natural fiber. The micrograph taken with a magnification of 250X, enables to verify that there is a poor adherence between the reinforcement fibers and the matrix material of polymeric resin, namely, there is not a good interface in the composite material.

It should be considered that there is no previous study in this field, thus the results given by the scanning electron microscopy that show a deficient adherence between the fibers and the matrix material is a referent for further works.

### 3.5. Results of the structural simulation of the air conditioning grilles as application

The structural simulation is performed with the aid of the NX 10 software by Siemens, with the purpose of observing the values of nodal displacement and elemental stress presented by both the original material of the air ducts and the matrix material of the composite materials.

1) Polypropylene air conditioning grilles. Figure 12 shows the values of the maximum nodal displacement generated in the air conditioning grilles, with an average value of 0.026 mm.

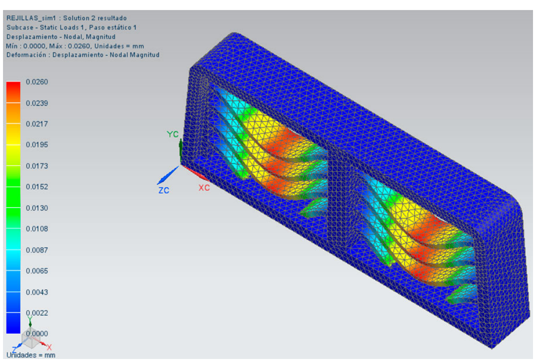


**Figura 12.** Graph of nodal displacement of the air conditioning grilles.

Figure 13 displays the maximum values of stresses generated on the air conditioning grilles, under the Von Mises failure analysis or criterion, resulting in a maximum stress of 0.204 MPa.

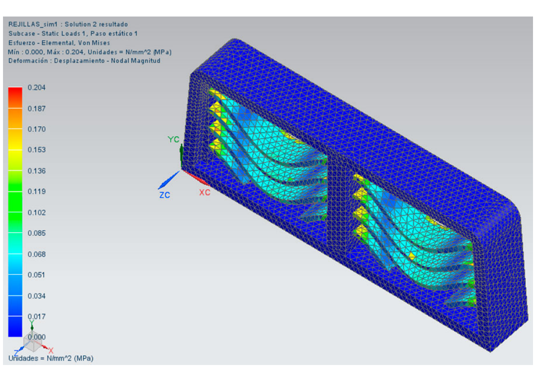


**Figura 13.** Graph of stresses generated on the air conditioning grilles.

2) Air conditioning grilles of the matrix material of the composites. Figure 14 shows the values corresponding to the maximum nodal displacement generated in the air conditioning grilles, resulting in an average value of 0.048 mm.

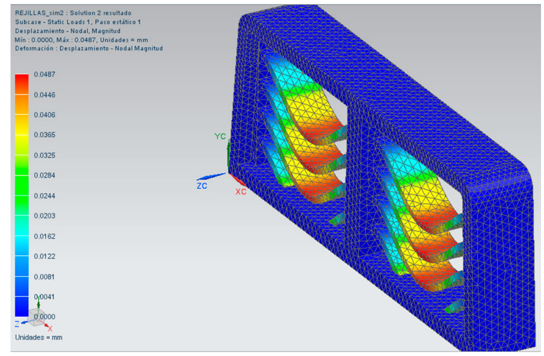


**Figura 14.** Graph of nodal displacement of the air conditioning grilles.

Figure 15 shows the maximum values of stresses generated on the air conditioning grilles, under the Von Mises failure analysis or criterion, resulting in a maximum stress of 0.21 MPa.

In the two types of structural analysis, an average force of 5 N was applied as load on the element; such value was calculated idealizing a grille as a beam placed on two supports, and placing a mass (0.49 kg) which multiplied by the acceleration of gravity (9,81 m/s2) generates an average value of 5 N.

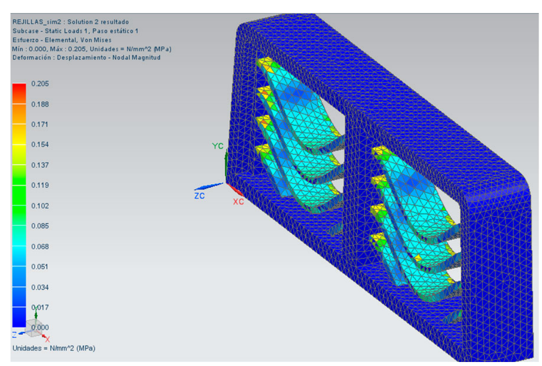


**Figura 15.** Graph of stresses generated on the air conditioning grilles.

The software Statgraphics Centurion XVII was used for assessing the mechanical properties obtained for the tested composite materials and matrix material. An ANOVA variance analysis and Fisher method of least significant difference (LSD) were applied to discriminate between the means of the studied variables, and perform multiple comparison [16]. Table 5 applies a multiple comparison procedure, to determine which means of maximum bending stress are significantly different than others among the manufactured materials.

**Tabla 5.** Fisher method of least significant difference (LSD), with 95 % confidence.

| Material | Cases | Mean | Homogeneous groups |
|---|---|---|---|
| Matrix material (1) | 5 | 92,77 | X |
| Composite reinforced with cabuya (2) | 5 | 83,25 | X |
| Composite reinforced with abaca (3) | 5 | 77,53 | XX |

Note. In the analysis each material was identified with a number.

It can be seen that between materials (1) and (2), there are statistically significant differences with a confidence level of 95 %. Material (3) does not possess a significant difference with the other two. This is graphically shown in Figure 16.

Ponton and Guerrero [12] obtained a maximum stress to bending in a composite material with a matrix of polyester reinforced with a 20 % volumetric fraction of longitudinal fiber of abaca, by means of manual stratification, which increased with respect to the matrix material. On the contrary, in this study the obtained value of maximum bending stress, of the composite material reinforced with a 20 % volumetric fraction of longitudinal fiber of abaca manufactured using 3D printing, decreased with respect to the matrix material, even though this decrease was not statistically significant.

In the aforementioned study of the composite material reinforced with fiber of abaca, the fibers were pre-wet with polyester resin diluted with styrene at 10 % v/v and the catalytic system constituted by octoate and cobalt and MEKP in concentrations of 0.5 and 0.75 %, which favored the adhesion of the reinforcement fibers on the matrix of such composite material [12].

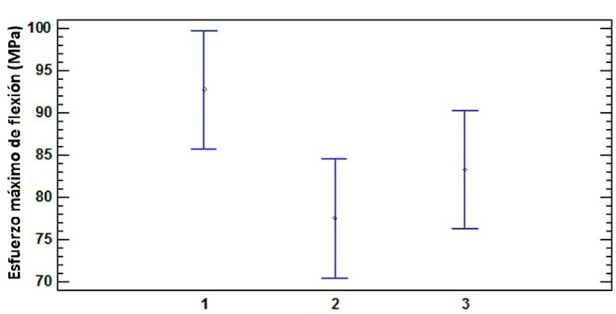


**Figura 16.** Mean comparison using the LSD test with 95 %.

The study carried out in [15] establishes that the maximum bending stress of a composite material with polyester matrix reinforced with a volumetric fraction of 23 % of longitudinal fiber of cabuya, by means of manual stratification, decreased with respect to the matrix material; this coincides with the results obtained in this study, where the maximum bending stress of the composite material reinforced with a 20 % volumetric fraction of longitudinal fiber of cabuya manufactured using 3D printing, also decreases with respect to the matrix material.

The decrease of this mechanical property of the composite materials with respect to the matrix material, is directly related with a poor interface between the matrix material and the reinforcement fiber, as shown in the scanning electron microscopy.

Table 6 applies a multiple comparison procedure, to determine which means of the modulus of elasticity secant to bending are significantly different among the materials subject of study. It can be seen that materials (1) and (3) show statistically significant differences with a confidence level of 95 %, with respect to material (2).

Figure 17 graphically shows the comparison of the means of the modulus of elasticity secant to bending of the materials subject of study.

**Tabla 6.** Fisher method of least significant difference (LSD), with 95 % confidence.

| Material | Cases | Mean | Homogeneous groups |
|---|---|---|---|
| Matrix materiañ (1) | 5 | 1689,64 | X |
| Composite reinforced with cabuya (3) | 5 | 1806,03 | X |
| Composite reinforced with abaca (2) | 5 | 2211,33 | X |

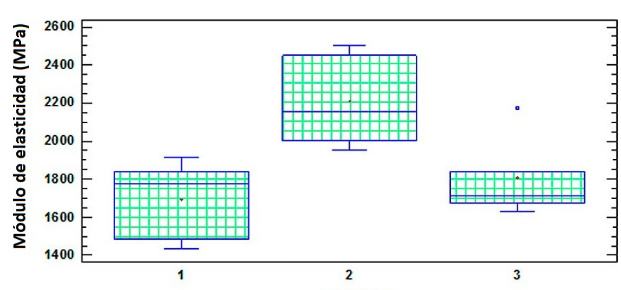


**Figura 17.** Box and moustache plots for the modulus of elasticity secant to bending.

As it can be seen in Figure 18, the modulus of elasticity secant to bending of the composite materials reinforced with longitudinal fiber of abaca and cabuya, increased with respect to the matrix material of photopolymer resin.

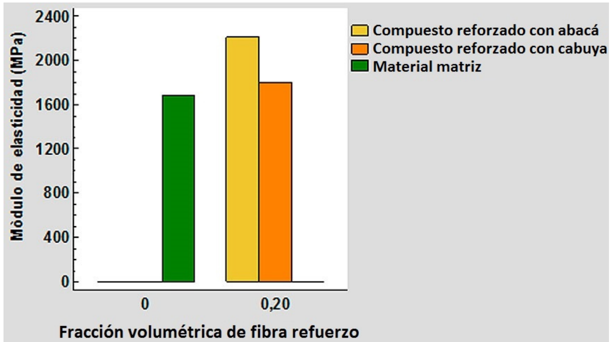


**Figura 18.** Modulus of elasticity secant to bending of the composite materials depending on the volumetric fraction of reinforcement fiber.

The increase of the modulus of elasticity for the composite material reinforced with longitudinal fiber of abaca was 31 %, while such increase was 7 % for the composite material reinforced with longitudinal fiber of cabuya.

It is important to remark that in the study carried out in [15], the modulus of elasticity of a composite material with biodegradable polymer matrix reinforced with a 20 % volumetric fraction of longitudinal fiber of abaca, by means of molding with manual compression (5570 MPa), increases with respect to the matrix material, which is comparable with the result obtained in this study of the modulus of elasticity of the composite material reinforced with a 20 % volumetric fraction of longitudinal fiber of abaca manufactured using 3D printing (2211.33 MPa), which similarly increased with respect to the matrix material. In addition, in the study carried out in [17] the modulus of elasticity increased with respect to the matrix material analyzed in that study.

Figure 19 shows, in a box and moustache plot, the comparison of the means of the deflection by means of the Fisher method of least significant difference (LSD), with 95 % confidence.

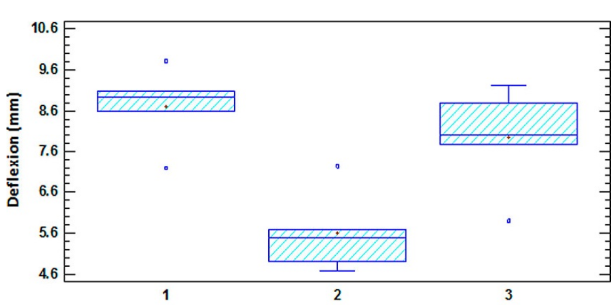


**Figura 19.** Box and moustache plot for the deflection.

It can be observed that materials (1) and (3) exhibit statistically significant differences with a confidence level of 95 % with respect to material (2).

As it can be seen in Figure 20, the deflection presented by composite materials reinforced with longitudinal fiber of abaca and cabuya, decreased with respect to the matrix material of polymer resin.

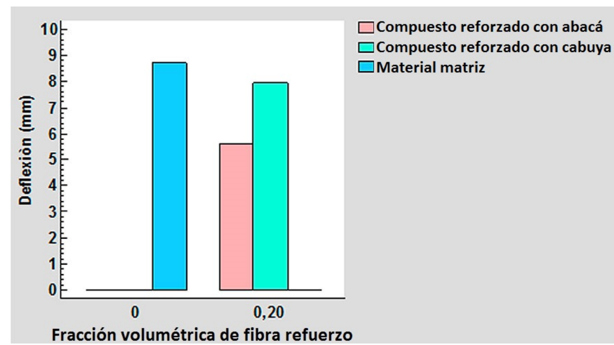


**Figura 20.** Deflection of the composite materials depending on the volumetric fraction of the reinforcement fiber.

The deflection decrease for the composite material reinforced with the longitudinal fiber of abaca was 36 %, while such decrease was 9 % for the composite material reinforced with longitudinal fiber of cabuya.

### 3.6. Comparison of the bending mechanical properties of the composite materials manufactured by 3D printing, with other materials

The present section presents a comparison of the mechanical properties to bending, obtained in the characterization of composite materials reinforced with fibers of abaca and cabuya and manufactured by 3D printing, with other composite materials reinforced with different natural fibers and matrices and other manufacturing processes, as well as with plastic materials utilized in the automotive industry. Table 7 shows the values of maximum bending stress, modulus of elasticity, type of process utilized for manufacturing the material, volumetric fraction of the reinforcement fiber, type of matrix and orientation of the reinforcement fiber.

**Tabla 7.** Mechanical properties to bending of different composite and plastic materials utilized in the automotive sector.

| Designation the material | Typo of material | Matrix material | Reinforce ment fiber | Manufacturing process | Volumetric fraction of reinforcement | Orientation of reinforcement fiber | Maximum bending stress (MPa) | Modulus of elasticity of bending (MPa) |
|---|---|---|---|---|---|---|---|---|
| ***MCFI20%AL*** | *Composite material* | *Photopolymer* | *Abaca* | *3D Printing* | *20%* | *Longitudinal* | *77,534* | *2211,33* |
| ***MCFI20%CL*** | *Composite material* | *Photopolymer* | *Cabuya* | *3D Printing* | *20%* | *Longitudinal* | *83,256* | *1806,03* |
| **MCPE20%AL** | Composite material | Polyester | Abacá | Stratification manual | 20% | Longitudinal | 100 | 10000 |
| **MCPE23%CL** | Composite material | Polyester | Cabuya | Stratification manual | 23% | Longitudinal | 51,39 | 2355,58 |
| **Polyester** | - | Polyester | - | - | - | - | 56,62 | 1867,82 |
| **MCPB20%AL** | Composite material | Biodegradable polymer | Abacá | By compresion | 20% | Longitudinal | 104,4 | 5570 |
| **PLA** | - | Biodegradable polymer | - | - | - | - | 69 | 2755 |
| **MCP20%AT** | Composite material | Polyester | Abaca | - | 20% | Tejido | 62,4 | 3976 |

Note. A code was assigned to each material depending on the type of material, matrix material, reinforcement fiber, manufacturing process, volumetric fraction of the reinforcement fiber and orientation of the reinforcement fiber.

The data are presented through an X-Y dispersion plot of the different materials, which contains the values corresponding to maximum bending stresses in the Y-axis, and the values corresponding to the modulus of elasticity to bending in the X-axis (see Figure 21).

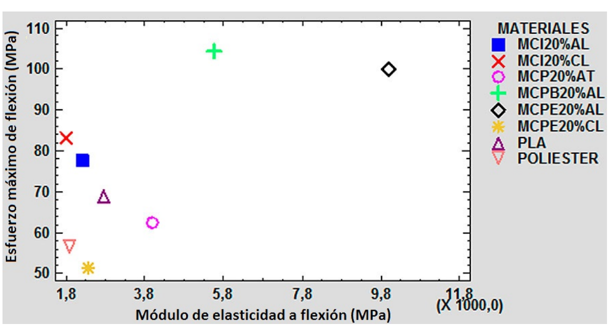


**Figura 21.** Comparison of the mechanical properties to bending of the different materials.

The composite materials reinforced with fibers of abaca and cabuya, and manufactured using 3D printing, exhibit better bending mechanical characteristics compared to the composite materials of polyester matrix and base materials such as biodegradable polymers and resins.

From the structural analysis using simulation, it is important to mention that the polypropylene air conditioning grilles had a nodal displacement of 0.02 mm, while the air conditioning grille with the matrix material of the composites had a nodal displacement of 0.048 mm. This indicates the existence of a difference between the nodal displacements of these two simulated materials.

The structural analysis performed through simulation in the polypropylene air conditioning grilles, resulted in a maximum stress of 0.204 MPa, while the air conditioning grille with the matrix material of the composites had a maximum stress of 0.206 MPa; therefore, there is no significant difference between these two simulated materials.

Based on what has been previously mentioned where the composite materials reinforced with fibers of abaca and cabuya, the matrix material and the original material of the air conditioning grilles do not exhibit significant differences between them, it is proposed the option of replacing the original material, with composite materials reinforced with fibers of abaca and cabuya, manufactured in Ecuador.

## 4. Conclusions

The maximum bending stress of the composite materials reinforced with a 20 % volumetric fraction of fibers of abaca and cabuya obtained by means of 3D printing, decreased with respect to the matrix material. This is possibly caused by the lack of previous study in the compatibility of the materials employed.

The reduction in certain mechanical properties of the composite materials obtained by additive manufacturing with respect to the matrix material, were due to the low level of adherence of the reinforcement fibers with the matrix material, which generated a poor interface between those constitutive elements.

The modulus of elasticity of the analyzed reinforced composite materials increased with respect to the matrix material, which results in an increased rigidity of the characterized materials.

The composite materials manufactured by means of 3D printing are an alternative for manufacturing auto parts, since in some cases their mechanical characteristics are better than other materials considered in the automotive industry.

The computational simulation of the air conditioning grilles subject to a load, enables verifying the significant differences between these two analyzed materials regarding nodal displacement, and besides enabled verifying that there is no significant difference between the simulated materials in the analysis of stresses.

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