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# EXPERIMENT AND SIMULATION STUDY OF THE EFFECT OF FILLERS ON MECHANICAL PROPERTIES OF SUSTAINABLE COMPOSITE

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**Abstract:** Natural fiber reinforced polymer matrix composites are gaining increasing attention as engineering materials for advanced applications, including high performance ballistic armor components. This requires superior mechanical properties, such as toughness. Jute fiber reinforced composites are currently being explored as possible advanced engineering materials. Therefore, the objective of this study is to investigate the mechanical characteristics of epoxy composites reinforced with jute fibers and steel fillers. In the present study, three types of the composite of two-way jute carpet and steel fillers were reinforced with epoxy, with different rates of each material.

**KEYWORDS:** Jute fibre, Composites epoxy, fillers, Mechanical properties, tensile test, Finite element method (FEM)

## 1 INTRODUCTION

### Research Background

Polymer composites reinforced with glass and carbon fibers have replaced many conventional materials since the middle of the last century [1]. In the current century, however, these synthetic fiber composites are being called into question due to issues related to environmental and energy issues. [2]

Among the many natural fibers used as polymer composite reinforcement, that of jute extracted from Corchorus capsularis the plant is one of the most studied, which is composed of 60% cellulose, 22% hemi-cellulose and 16% lignin [3]. Jute fiber exhibits properties relevant for composite reinforcement, such as 393-773 MPa in tensile strength, 10-30 GPa in modulus of elasticity and a density of 1.44 g/cm3 [4]. However, some properties of specific composites reinforced with jute fibers have yet to be evaluated. In particular, toughness is a relevant property for applications which might be associated with impact conditions such as the aforementioned automobile accident [5]. Additionally, impact resistance is a basic requirement for the ballistic performance of armor using natural fiber composites [6].

### Outline of previous work

The results of an experimental study on epoxy reinforced jute samples were presented by Mofidi et al. They show that Composites with continuous and aligned jute fibers reinforcing an epoxy matrix exhibit a significant increase in toughness, measured by the Charpy impact test, depending on the amount of fiber. The values of the absorbed energy are among the highest

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obtained to date for composites of lignocellulosic fibers [6]. On the other hand, other experiment was carried out by the technique of manual lamination of an epoxy reinforced by different quantities of jute fibers (0%, 12%, 24%, 36% and 48%) by Vivek Mishra and Sandhyarani Biswas show that the minimum and maximum void content is pure epoxy and 12% fiber loading samples respectively. The study also shows that the void content decreases with increasing fiber load. They prove that the hardness, tensile properties and impact resistance of jute-epoxy composites increase with increasing fiber load. They also show that properties such as flexural strength and shear strength are strongly influenced by the void content of composites. It was found that these properties reduced the fiber loading from 0wt% to 12wt% and that with the reduction in void content from 12wt% to 48wt%, the properties were improved [7].

Ouchte et al. [8] investigated the effect of thermal treatment on mechanical properties of jute/epoxy. They found that the composite laminate obtained after treatment at the temperature of 60°C exhibits improved mechanical properties when compared to those obtained at both ambient temperature and 100°C. The numerical simulation based on FEM analysis, provided results in good agreement with the experimental ones for both stress and strain behaviors. Chafiq et al. [9] investigate into the tensile behavior of basalt/glass/carbon/hybrid fiber composite. They found that basalt fiber reinforced polymer (BFRP) composite shows mediocre results comparing with other composites. Thus, the glass fiber reinforced polymer (GFRP) composite is found more time dependent compared to basalt and carbon. In the other hand, the carbon fiber reinforced polymer (CFRP) is found to be loading rate in-sensitive. Based on the results of hybrid fiber reinforced polymer (HFRP) composite is concluded that the hybridization can enhance the elongation of basalt and gave a better result. Moreover, the low value of tensile strength can explain by the effect of delaminating and the process of hand layup. At low loading rate the CFRP and BFRP sample shows better response than the GFRP. The surface fracture tends to be flat due to better bonding between the fiber and the matrix.

### Research Rationale

This work presents a finite element (FE) study by the Abaqus code of simulation of a standard dimension specimen according to ISO3167 of epoxy reinforced by jute and loads of steel chips subjected to tensile strength at 2000N. This specimen was produced with similar loading conditions for the modeled specimen which is subjected to monotonic tensile loading on the first tool and embedding in the second tool until failure. All the mechanical properties of the test specimen used in our simulation are obtained from our experience.

## 2 MÉTHODOLOGIE

### Materials and Method

The reinforcement used is a superposition of three kinds of two-way jute fiber reinforcement mat was obtained from local sources as the reinforcement material for each sample, the dimensions are the same for each sample.

The fillers chosen for our study are Entangled Elemental Chips, the steel shavings are made from premium quality steel. In this study, epoxy resin was used as the matrix material with a hardener. Polymer composites are made by a manual layering technique.

First, we start by mixing the hardener with the resin while using an electric mixer for a period of a few minutes. We cut the different jute bags manually with a scissor according to the dimensions of the mold. For this purpose, an open type boiling roller made of mild steel sheet was used. The eco-composites are impregnated at room temperature.

For this, a Mylar sheet is placed on the bottom part of the mold for a good surface finish and easy removal of the composite from the mold in addition to the wax is also used to coat the surface of the Mylar sheet for easy removal. of the composite of the Mylar sheet.

Table 1 Sets of masses of materials used

| | Masse | JECF5 | JECF7.5 | JECF13.5 |
|---|---|---|---|---|
| Total | (%) | 100 | 100 | 100 |
| | (g) | 114 | 119 | 91.5 |
| Fibre | (%) | 22 | 22.5 | 16.5 |
| | (g) | 25 | 27 | 15 |
| Matrix | (%) | 73 | 70 | 70 |
| | (g) | 83 | 83 | 64 |
| Fillers | (%) | 5 | 7.5 | 13.5 |
| | (g) | 6 | 9 | 12.5 |

After ¼ of the epoxy resin has been deposited on the sheet and spread by a boiling roller. Then place the first burlap on the sheet and the second ¼ of the resin is impregnated with the roller to remove air bulls. Then we put half of the load manually in a discrete way on top of the first layer. And then we repeat the same steps for the second and third layers.

Then the samples are placed on or under a concrete cylinder of a large enough mass under special pressure to compress the jute fiber with the epoxy resin and fillers at room temperature. They left for 72 hours for curing.

Finally, we tried to cut the prepared plates into test pieces first in parallelepiped form using a mechanical device, and afterwards in the form of dumbbells manually using a saw blade with respect to the direction of the molding according to the ISO3167 standard.

Table 2 Dimension of the test piece according to the ISO3167 standard

| Norme | $I_3$ | $I_1$ | $b_2$ | $b_1$ | h | $L_0$ | L |
|---|---|---|---|---|---|---|---|
| ISO3167 | >150 | 60 ∓ 0,5 | 20 ∓ 0,2 | 10 ∓ 0,2 | 4 ∓ 0,2 | - | - |

**Physical and mechanical characterization**

Density: To calculate the experimental density of the developed bio-composite and hybrid composites, the water immersion method based on Archimedes' principle is used. The theoretical density of composites can be obtained in terms of weight fractions and densities of constituents, and is given by the following equation:

$$\rho_{th} = \frac{1}{\frac{\xi_r}{\rho_r} + \frac{\xi_m}{\rho_m} + \frac{\xi_f}{\rho_f}} \quad (1)$$

The volume fraction of voids in composites is given by the relation:

$$\Delta v = \frac{\rho_{th} - \rho_{ex}}{\rho_{th}} \times 100 \quad (2)$$

***Hardness*:** In our study we tried to measure the different samples we use shore-A, shore-D durometers and Brinell type durometer equipped with an HB5 steel ball indenter of 5mm in diameter with a load of 125 Kgf equivalent of 1226.25N, and Rockwell type durometer fitted with a 1.588 mm (1/16 inch) diameter HRB steel ball indenter with a load of 100 Kgf equivalent to 981N.

For this purpose, it was necessary to prepare the test pieces by polishing by grinding with water using abrasive papers with a grain size index increasing up to 600, only the face which is the subject of the coating is prepared. test for each sample, at least 5 values are obtained.

***Tensile test:*** The specimens are stressed in monotonic traction on a universal testing machine type universal testing machine equipped with a force sensor and controlled by a computer. The force applied to the specimen is 25000 N. At least five tests are carried out for each type of specimen, with a test speed adjustable from 12mm / min to 170mm.

The test carried out at room temperature 20 ° C is to subject a standardized test piece to a gradual extension in the direction of the length until the rupture is obtained.

**Simulation procedures**

The finite element method (FEM) is applied widely in the evaluation of structures with reliable results [10-13]. Numerical tests were carried out using commercial finite element software Abaqus (CAE 6.13-1) with ISO3165 standard specimens. In this study the model selected for the cracks of the specimens is an isotropic elastoplastic static model because this technique has the potential to represent the complete inelastic behavior due to the specimen in tension. In addition, it is the only model that can be used both in Abaqus / Standard and Abaqus / Explicit and thus allow the transfer of results between the two.

Similar loading conditions were achieved for the model specimen which is subjected to monotonic tensile loading on the first tooling and embedding in the second tooling until failure.

Our mesh choice fell on the first order hexahedral element (linear shape functions) at 8 nodes with a C3D8R reference, because it is very efficient for simple geometry problems.

All the mechanical properties of the test specimen used in our simulation are obtained from our experience.

## 3 RESULT AND DISCUSSION

**Physical and Mechanical Properties**

***Density*:** The theoretical density varies gradually; it decreases when the content of the fillers increases from 0% to 6%. This is due to the decrease in the value of the density of the fillers.

For the void fraction (in percentage) also note a decrease with the increase the content of the fillers increases from 0% to 6%, this explains the significant presence of vacuum in the Control sample (at 0% of the charged). Void formation in polymer composites can occur due to air entrapment during resin system preparation and moisture absorption during material processing or storage. It was calculated on the basis of the differences in theoretical and experimental densities for each composite.

Table 3 Percentage of materials used in each sample and their calculated density values

| Specimen | Fibre % | Matrix % | Filler % | Theo. density ($g/cm^3$) | Exp. density ($g/cm^3$) | Vacuum fraction % |
|---|---|---|---|---|---|---|
| JEFCT | 0,24 | 0,76 | 0 | 1.184 | 1.125 | 4.9 |
| JEFC5 | 22% | 73% | 5% | 1.125 | 1.08 | 4.15 |
| JEFC7.5 | 22.5% | 70% | 7.5% | 1.125 | 1.075 | 3.2 |
| JEFC13.5 | 16.5% | 70% | 13.5% | 1.0787 | 1.047 | 2.9 |

***Hardness**:* The hardness behavior of jute reinforced epoxy composites and steel chip fillers was performed using the Shore-A, Brinell and Rockwell hardness tester. And it is shown in histograms 6a, 6b and 6c. Five sets of values can be taken for each combination and their average value can be reported. In general, the surface hardness value decreases with the decrease in the percentage of added fillers from 13.5% to 5%.

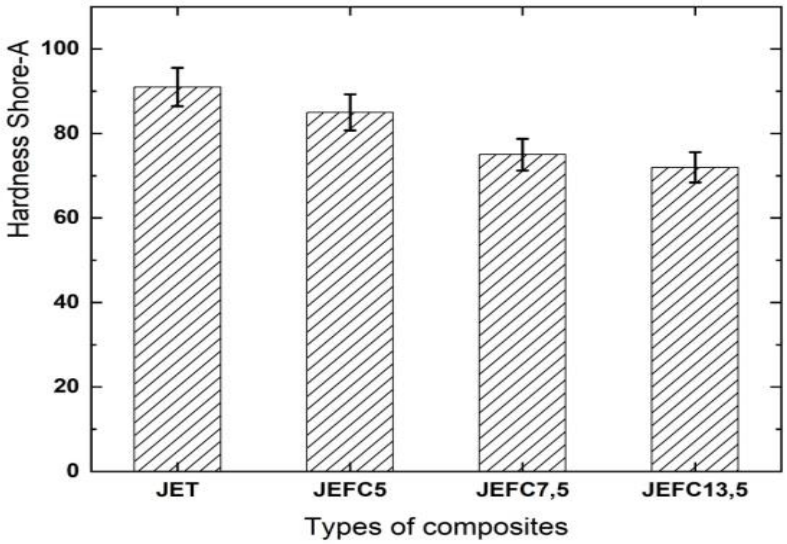



Fig. 1 Shore-A typical density histogram

Indeed, the hardness behavior of the composite material depends on the type of reinforcement and its properties (physical, mechanical and chemical), the level of adhesion and the load of the fiber from these values, the JET composite has reached a maximum hardness of 91.5 Shore-A. The minimum hardness value is obtained from JEFC5 composite with 70.33 Shore-A. This implies that the loadings of the steel chips are a weak adhesive with the jute / epoxy composite which increases the diameter of the impression left by the ball, and as a result the composite becomes less rigid and low resistance to the applied force. This explains why the jute / epoxy composite always reaches a higher hardness value than the composite which contains fillers.

***Tensile test:*** The following figure gives the evolution of the stress applied according to deformation of the test specimens taken for the same length of reference L0, for various test specimens and for the four composites (JEFC5, JEFC7.5 and JEFC13.5), in the case of static tests, requested in traction. In the case of the different types of composite structure tested, the behavior in traction is similar and can be broken down into 3 main phases, namely:

An elastic linear part: with a slope that differs from one material to another, thus explaining on the one hand that the addition of the reinforcement stiffened the polymer matrix with steel loads

(JEFC5, JEFC7.5 and JEFC13.5) and on the other hand, this effect is not the same from one material to another. JET (unloaded) composite has the steepest slope compared to other composites, so it is the stiffest material.

The second phase of nonlinear behavior, in which the maximum load is reached.

This non-linear behavior is explained by progressive damage which is mainly due to the presence of the jute fabric. The determination of the modulus of elasticity E is done by measuring the slope of the linear elastic part of the stress-strain curve.

The third and final phase where the appearance of matrix cracks before failure is at the origin of the nonlinearity of the behavior curves. A decrease in the applied load is observed until the test specimen is completely broken.

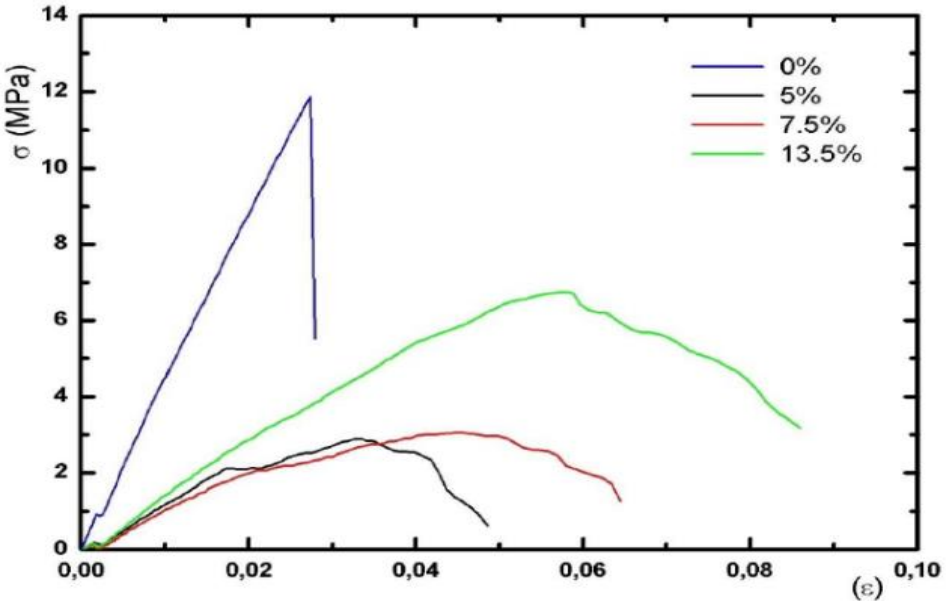



Fig. 2 the evolution of the applied stress as a function of strain

**Simulation procedures**

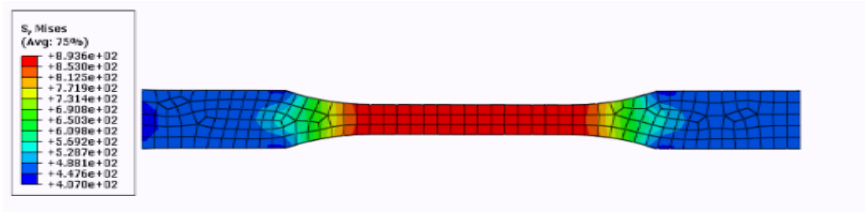



Fig. 3 Stress evolutions in composites respectively JET

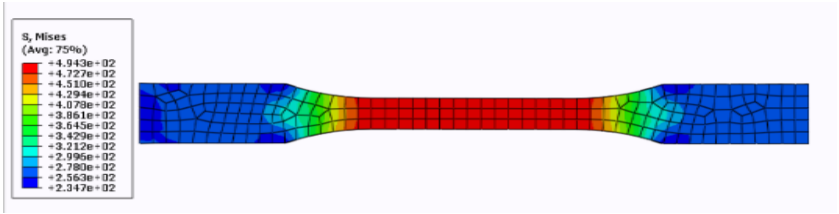



Fig. 4 Stress evolutions in composites respectively JECF5

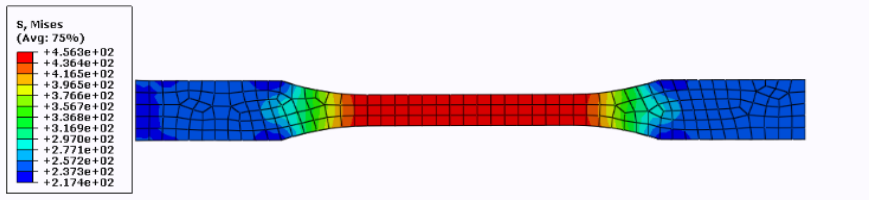



Fig. 5 Stress evolutions in composites respectively JECF7.5

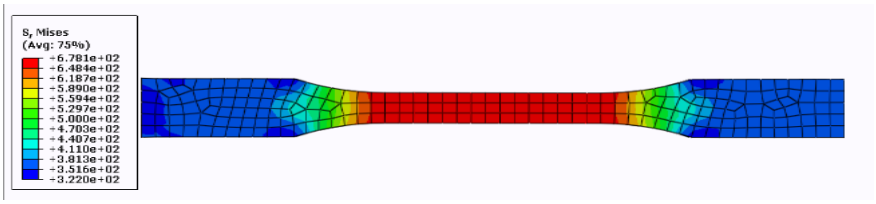



Fig. 6 Stress evolutions in composites respectively JECF13.5

The evolution of the applied external loading leads to a significant evolution of the stress field in all composites. The stress field first appears in the region of the reference length, then

it propagates with a very high speed according to inclined rods in the mortar core until failure. Towards the end of the loading the stress field is located at the level of the tools (wide zone), the speed of propagation of the stress field is greatly reduced.

In the case of the epoxy composite reinforced with jute fabric without loads the stresses supported reach greater values than in the case of the composites belongs loads.

For the latter, the stresses supported increase during the increase in the percentages of the loads (5%, 7.5%, 13.5%).

The maps also show that the materials of the steel shavings are more stressed in tension if its content is increased. But they are a weak adhesive with jute / epoxy.

## CONCLUSION

In this study, the effects of the process of filling steel chip fillers with different percentages on the mechanical, impact and hardness behaviors of the treated jute fabric reinforcing laminate composites were investigated.

And by conclusion it was concluded from the results obtained that it has a drop in Young's modulus and tensile strength of the JEFC composite compared to the jute / epoxy composite, with an increase in these last two properties during the increase in the percentage of charges added. On the contrary, there is a progressive increase in the elongation at break of composites with the increase in the percentage of fillers (from 0% to 13.5%).

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## NOMENCLATURE

$\Delta \boldsymbol{\nu}$ : volume fraction percentage
$\boldsymbol{\xi}$ : weight fraction
$\boldsymbol{\rho}$ : density

**Subscripts:**
***th*** theories
***ex*** expérimental
***f*** fillers
***m*** matrix
***r*** renforcement