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# Comparative study of the mechanical and vibratory properties of a composite reinforced with fique fibers versus a composite with E-glass fibers

# Estudio comparativo de las propiedades mecánicas y vibratorias de un material compuesto reforzado con fibras de fique frente a un compuesto con fibras de vidrio-E

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**ABSTRACT**

In the following research, the mechanical and dynamic vibratory properties between a fique fiber reinforced composite and a composite with E-glass fibers were compared. The materials were fabricated trough a vacuum infusion manufacturing technique using a bioepoxy resin. The mechanical properties were obtained by tensile tests according to the ASTM standards for each configuration. The results demonstrated higher values in stiffness and strength for the composite with E-glass fiber. Experimental modal analysis was used for the dynamic vibrational study, obtaining very similar behaviors for each material. The interface between the materials was studied by scanning electron microscopy, in which a low adhesion between the natural fiber and the resin was evidenced; affecting the mechanical and dynamic properties of the fique composite compared to the E-glass composite.

**KEYWORDS:** Modal Analysis; composite; fique; E-glass; scanning electron microscopy; tensile test.

**RESUMEN**

En la presente investigación se compararon las propiedades vibratorias mecánicas y dinámicas entre un compuesto reforzado con fibras y un compuesto con fibras de vidrio - E. Los materiales se fabricaron a través de una técnica de fabricación de infusión al vacío utilizando una resina bioepoxi. Las propiedades mecánicas se obtuvieron por ensayos de tracción según las normas ASTM para cada configuración. Los resultados demostraron valores más altos en rigidez y resistencia para el compuesto con fibra de vidrio - E. Se utilizó el análisis modal experimental para el estudio vibratorio dinámico, obteniendo conductas muy similares para cada material. La interfaz entre los materiales se estudió mediante microscopía electrónica de barrido, en la que se evidenció una baja adhesión entre la fibra natural y la resina; que afecta las propiedades mecánicas y dinámicas del compuesto fique en comparación con el compuesto de vidrio - E.

**PALABRAS CLAVE:** Análisis modal; compuesto; fique; vidrio - E; microscopía electrónica de barrido; ensayo de tracción.

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## 1. INTRODUCTION

Synthetic fiber-reinforced composites, such as fiberglass, have played a major role in the manufacture of products over the last century. In some cases, synthetic fiber reinforced composites have replaced conventional materials due to their low density, high rigidity, easy installation, resistance to fatigue and environmental agents [1].

However, due to the oil prices variability and an increasing ecological awareness for the natural resources conservation, a new trend has been initiated using reinforced composite materials with natural fibers [2], [3].

Diverse natural fibers have been used for the composite manufacture, such as: jute [4], [5], sisal [6], [7], kenaf [8], [9] y el fique [10], [11].

Natural fibers biocomposite application has increased in industrial sectors such as automotive (manufacturing instrument panels, insulation elements, doors and backs), nautical, and construction [12].

The production of fique fiber in Colombia is of approximately 30,000 tons/year [13], and it is commonly used for the manufacture of ropes and coffee bags [14].

Recently, some researches regarding the properties of fique fiber composites have been carried out. Hidalgo et al [15] executed an analysis of the physicochemical, mechanical and thermal properties of fique fibers subjected to superficial modifications from chemical treatments, through FTIR, TGA, and tensile strength test. On the other hand, Mina et al [16] performed DMA, Pull-out, SEM, and stress tests to a composite with Cassava starch matrix.

In the literature, there are investigation evaluating the metallic and industrial composite material's vibratory dynamic behavior [17], [18] but few applied to natural fibers composites [19]. For this purpose, a comparative study was carried out between the mechanical and dynamic properties of two thermosetting matrix composite materials, reinforced with fique fiber and E-glass fibers. The interface of the materials was also evaluated by scanning electron microscopy.

## 2. METHODS

### 2.1. Materials

As a natural biocomposite reinforcement, fique fibers were used in random configuration, with a weight of 130 g / m$^2$ supplied by Coohilados del Fonce LTDA.
The fique employed had an average length of 1.76 ± 0.53 mm and a diameter of 0.0253±0.0033 mm. The figure 1 show the fique configuration in SEM pictures.

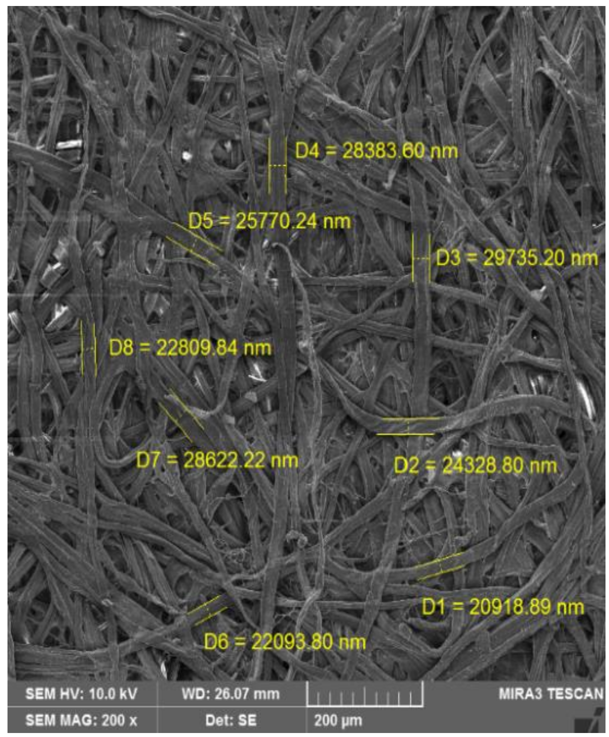


**Figure 1**. Random fique configuration. **Source.** Own.

For the E-glass composite, random configuration fibers were used; and they were supplied by Ingequimicas LTDA. The fiber employed had an average length of 12.85 ± 2.15 mm and a diameter of 0.013±0.0017 mm. The figure 2 show the E-glass configuration in SEM pictures.

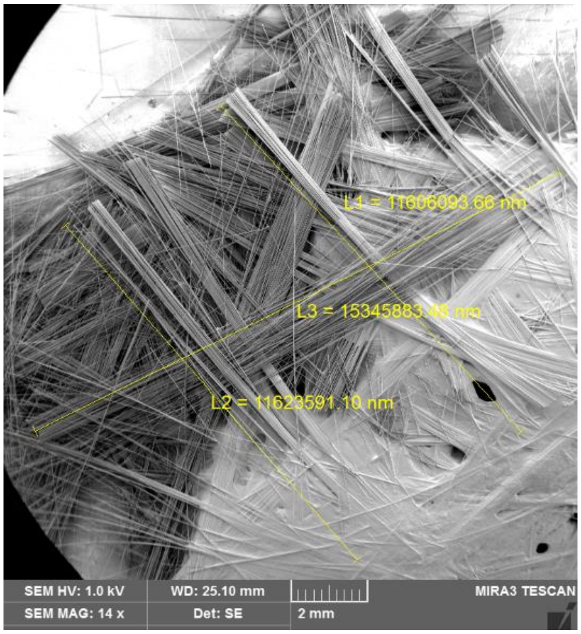


**Figure 2.** Random E-glass configuration. **Source.** Own.

The matrix used to manufacture both materials was the SuperSap®, epoxy resin from renewable materials. It was supplied by Entropy Resins. The percentage of resin catalyst (by weight) was 100: 33.

### 2.2. Composite manufacturing

Both composites (Natural and industrial) were manufactured using vacuum infusion technique, applying one bar of pressure, which guarantees the elimination of internal defects in the materials. The curing was performed at room temperature for 24 hours.

For the fique composite, four layers were applied, corresponding to 49% by weight and for the E-glass, four layers were applied, corresponding to 51% by weight.

The final geometry of the fique composite specimens was 25.3± 0.17 mm x 252±2.2 mm x 2.52 ±0.08 mm with a density of 929.7 ±12.3 kg/m$^3$. For the E-glass composite, the final geometry was 25.1± 0.21 mm x 254±2.7 mm x 2.49 ±0.09 mm with a density of 969.7 ±15.7 kg/m$^3$.

### 2.3. Tensile test

Both materials tensile test was performed according to ASTM D3039 / D3039M in a 10 KN, MTS universal machine model C43.104 at a speed of 2 mm / min with a temperature of 24.2 ° C. For each materials, five specimens were tested, taking into account the average of each of the properties. In figure 3, the jaw system used during the test is shown.

### 2.4. Dynamic vibratory test

The dynamic vibratory test was performed experimentally according to ISO 7626-2 "Mechanical vibration and shock Experimental determination of mechanical mobility Part 2: Measurements using single-point translation excitation with an attached vibration exciter".

The Modal shop electromagnetic shaker (Excitation element) was placed in a fixed way, generating a sinusoidal sweep up to 300 Hz. The excitation being measured with a reference PCB force sensor 208C02, and the response with a PCB accelerometer reference 352C68, which was translated by five measurement points distributed evenly over the total specimens surface. Figure 4 shows the assembly.

**Figure 3**. Fique composite tensile test. **Source.** Own.

The test specimens were assembled in a free way (without restrictions), using elastic elements.

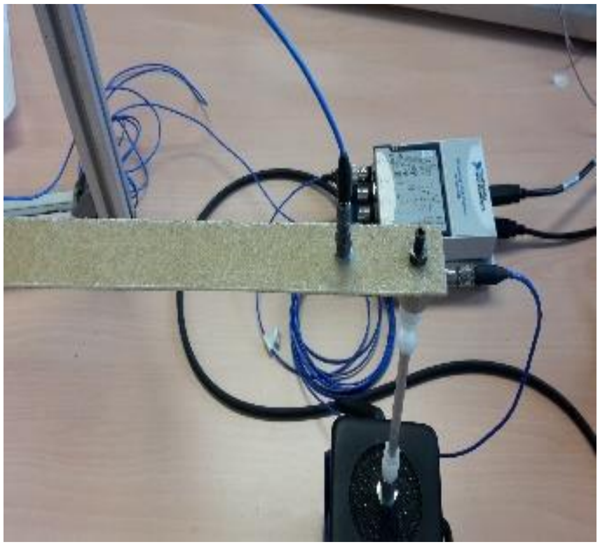

**Figure 4**. E-glass composite Dynamic vibratory test. **Source.** Own.

### 2.5. Scaning electron microscopy

Scanning electron microscopy was performed using a Tescan microscope model MIRA 3 FEG-SEM with secondary electron detector model A65c SED.

Initially, values were adjusted to 3 KV acceleration voltage. Also, the wild field scan mode was used, obtaining images at few increases in the samples. Subsequently, the scan mode was changed to resolution, varying the conditions to obtain images between 20 X to 5000 X (range from 2 mm to 20 microns), and electron acceleration voltage of up 10 kV.

A small gold layer covered the composite materials in order to improve the electrical conductivity.

## 3. RESULTS

### 3.1. Tensile test

Figure 5 shows the stress-strain curve of both composites.

According to the strain-deformation diagram, an elastic-linear behavior is evidenced for both materials because of the nature of their thermostable matrix.

In the case of the reinforced fique composite, a maximum tensile strength of 36.2 MPa ±8.5 MPa and a modulus of elasticity of 1272,98 ± 41.2 MPa were reached, while for the composite with glass fiber a tensile strength of 153.5 ± 17.5 MPa, and a modulus of elasticity of 4290 ±131.2MPa were obtained.

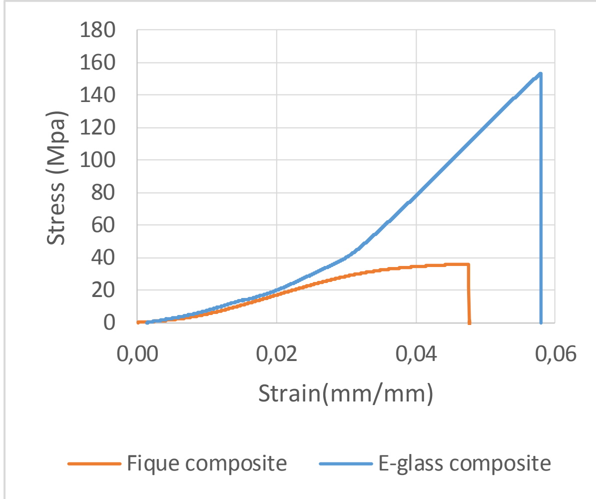


**Figure 5.** Fique and E-glass composites stress-strain curve. **Source.** Own.

This difference is due, in part, to the natural fiber inherent properties, because 2000 to 3000 MPa tensile stress values are reported for the E-glass fiber [20] while for fique, the reports are of the order of 50 to 500 MPa [15].

Additionally, the E-glass fiber composite has longer continuous fibers which allow a better transmission of stresses which is not interrupted due to the size of the fibers.

The mechanical properties of both materials were affected by the amount of fibers that were located in the direction of application of the load, which supporting the generated tensile.

### 3.2. Dynamic vibratory test

Figure 6 shows the amplitude of the frequency response measurement of both composites up to the 300 Hz.

Each peak on Figure 6 represents the tested material natural frequencies, because a higher response (Acceleration) is obtained at the same input (Force), indicating that the material at this frequency is in resonance. The values obtained for each material are shown in Table 1.

As it is shown in Table 1, the natural frequency values of both materials had similar behavior.

E-glass composite have natural frequency greater than the fique composite, this is because E-glass composite has greater body rigidity, which does not allow the material deflected avoiding the transmission of vibration although has more mass, which is opposed to the force that is applied.

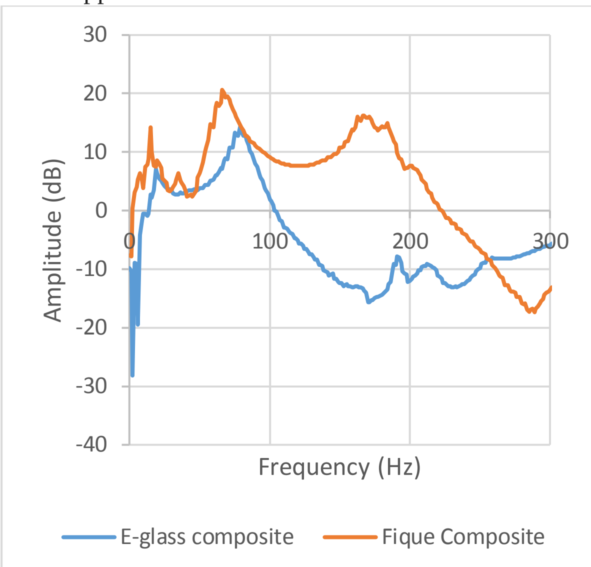


**Figure 6.** Fique and E-glass composites frequency response measurement. **Source.** Own.

**Table 1.** Composites natural frequencies.

| Modes | Natural Frequency (Hz) | |
|---|---|---|
| | **Fique composite** | **E-glass composite** |
| Mode 1 | 15 ± 2.1 | 18 ± 2.6 |
| Mode 2 | 77 ± 3.4 | 78 ± 2.6 |
| Mode 3 | 183.75 ± 8.1 | 191 ± 5.4 |

**Source.** Own.

However, fiber content, friction between the resin and the fibers, and the thickness of the interface also affect the dynamic behavior playing a key role the manufacturing process. [21]

### 3.3. Scaning electron microscopy

Figures 7 and 8 show the morphology images of the biocomposite bioepoxy/fique at different magnifications. The microstructure reveals spaces between the constituents of fique fibers and the matrix additionally show resin agglomerations, indicating that there was a low adhesion. This is due to the hydrophobic nature of the matrix, the hydrophilic fibers' characteristics and the manufacturing system indicating that the pressure, prepreg and curing time not allowed good bonding between the components. This generate porosity in the fique composite surface wich was reduced increasing the pre impregnation time.

This low adhesion affected the fique composite's mechanical and dynamical properties, as it is observed in Figure 5 and figure 6. This behavior is due to the low charge transmission between the resin and the fiber, and the porosity stress concentrators.

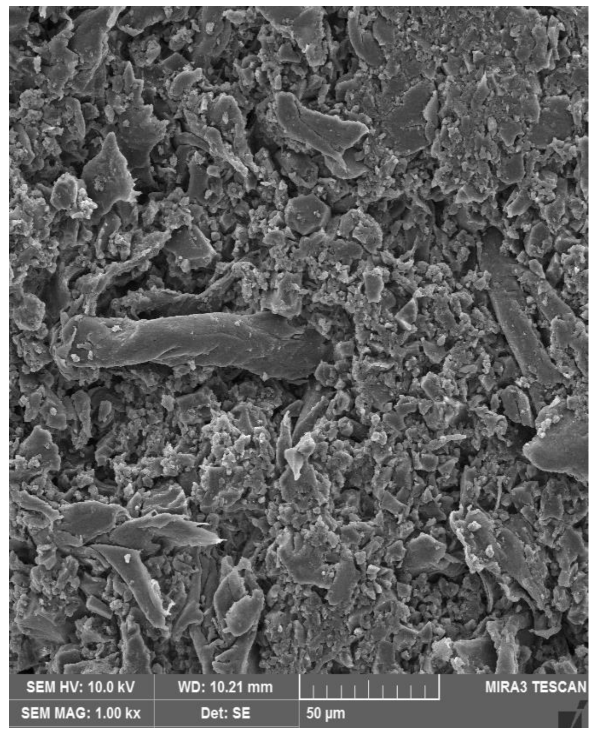


**Figure 7.** Scanning electron microscopy, Fique composite at 1000 X. **Source.** Own.

In contrast, as it is shown in Figures 9 and 10, in the E-glass fiber composite the fibers and matrix had a good adhesion with a better bond between the two components.

## 4. CONCLUSIONS

The mechanical properties obtained from the E-glass fiber reinforced composites exceeded those of the composite reinforced with fique fibers. This is due to the natural fiber inherent properties, because for the E-glass, superior stresses tension values were reported. Additionally E-glass fiber composite has longer continuous fibers which allow a better transmission of stresses which is not interrupted due to the size of the fibers as shown Sumaila [22] in short banana fiber epoxy composite. The results obtained are comparable to the study carried out by Rodriguez et al [23], where a fiberglass composite exceeds in mechanical properties a Banana/plantain composite.

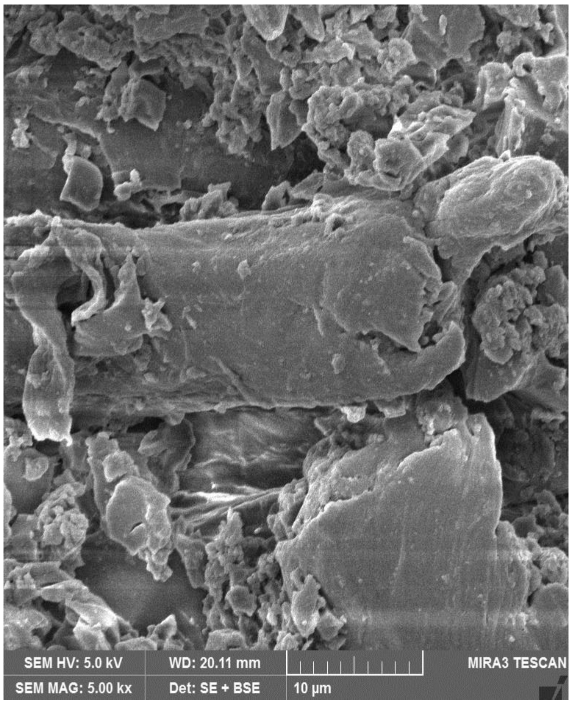


**Figure 8.** Scanning electron microscopy, Fique composite at 5000 X. **Source.** Own.

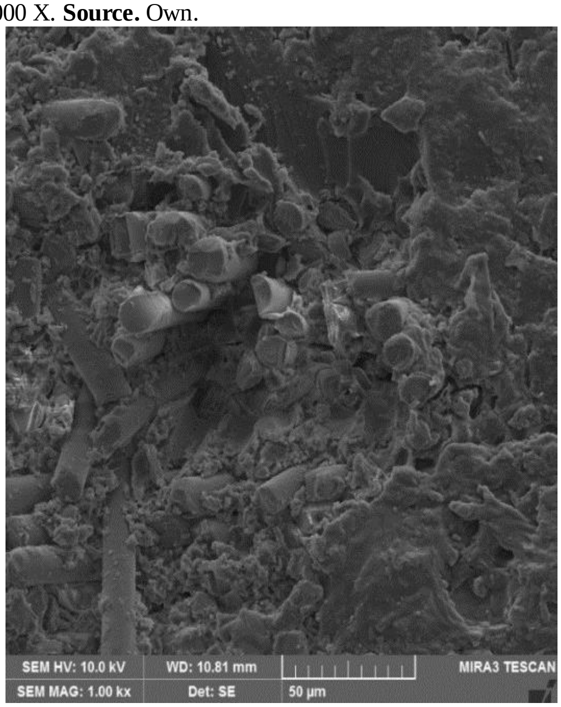


**Figure 9.** Scanning electron microscopy, E-glass composite at 1000 X. **Source.** Own

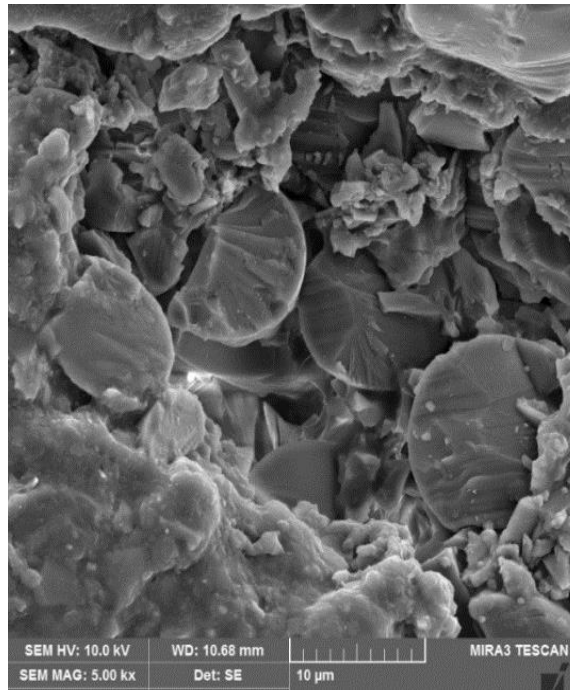


**Figure 10.** Scanning electron microscopy, E-glass composite at 5000 X. **Source.** Own.

The dynamic characterization presented a similar response behavior for both materials. However, the E-glass fiber composite presented natural frequencies greater than fique composite, due to its higher body rigidity although has a little greater mass. Pitchaimani et al [24] obtained similar results in a woven banana/jute polyester composite, which had better dynamic behavior as relatively stronger fiber was oriented along the loading direction.

On the other hand, as it was observed in the SEM scanning electron microscopy, there is low adhesion for the fique composite due to its matrix hydrophobic nature and the fibers hydrophilic characteristics. Those characteristics led to a low resin load transmission to the fiber affecting the mechanical and dynamic properties. Additionally surface porosities was detected in the fique composite because air bubbles were trapped when the catalyst resin mixture was made, this phenomenon was reduced increasing the pre impregnation time. This manufacturing system anomaly is reported in similar composite investigation[25]–[28]. In order to reduce these imperfections for future works it is recommended to implement mitigation techniques as indicated by Lee Hamill et al [29].

Apply a chemical treatment such as alkalinization to the fique fiber as indicated by Gañan [30] in order to improve the adhesion with the matrix is also recommending.

In the present work, only specimen bending modes are presented by their geometry in the dynamic analysis. So, in subsequent investigations, the torsional modes must be evaluated.

## 5. ACKNOWLEDGMENTS

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