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Research Paper

Evaluation of circumferential properties of Jute/Epoxy tubes manufactured by filament winding based on the fiber orientation.

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ABSTRACT

The introduction of bio-composites in the manufacture of tubes by the filament winding technique poses a real challenge for design engineers. This study aims to evaluate the mechanical properties in circumferential traction and in circumferential compression of Jute-Epoxy tubes whose winding angle is considered to be variable. The experimental study is carried out on 6 tube configurations of 92 mm in diameter. The tubes tested are made of 4 layers. The selected α fiber winding angles are (50 °, 55 °, 60 °, 65 °, 75 °, and 90 °). Circumferential tensile and stiffness tests are established according to the specifications of ASTM D2290 and ASTM D2412 respectively. The results obtained allowed us to analyze the influence of the winding angle on the properties of the tubes.

1 Introduction

Environment concerns and resource preservation remain essential challenges for designers of novel materials in the context of sustainable development. Also, the rising demand for traditional metals (Steels, Al, Cu) and the need to find solutions to industrial needs have considered natural-reinforced composite materials as an essential alternative. In addition to their lightweight, mechanical performance and corrosion resistance, the advantages of composites reinforced with natural fibers lie in their respect for the environment and their biodegradability [1].

The future for these materials looks promising. They are used in various applications including the aerospace and the automotive industry. Research studies enumerate the use of long natural fiber composites (LNFC), in particular in the manufacture of composite tubes using the filament winding process [2].

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Composite tubes produced by the filament winding technique are susceptible to several parameters. Colombo et al [3] established an analytical study for the optimization of the manufacturing parameters of a composite tube by filament winding. They found that the optimum winding angle is in fact variable within the range ± 44.5°. ± 52.5°. While for the volume fraction establishing an optimum of Vf at 45 ÷ 60 %. Composite tubes have different shapes, whether circular, square, or hexagonal. Natural reinforcements such as kenaf, jute, sisal have been studied due to their mechanical properties [2, 4-6].

Developments have been made in the field of natural fibers such as kenaf, hemp, jute, sisal, flax, and silk to promote their use in composites and polymers for industrial applications [7, 8]. Improving the energy absorption capacities of composite tubes reinforced with natural fibers has been widely studied [9, 10], including the effect of geometry (shape and diameter of tubes) [11-13]. Impact resistance, such as peak load, the effect of impact energy, and impactor size on composite tubes have been the subject of several research [14, 15]. Composites tubes incorporating jute fiber and under axial compression were analyzed by Moyo and Velmurugan, and Othman and Ismail [16, 17].

Misri et al [18] investigated the effect of winding angles on the crushing behavior of polyester tubes reinforced with kenaf fibers produced by the filament winding technique. The two winding angles studied were ±45° and ±90°. They concluded that the composite wound at 45° with an aluminum tube shows a good energy absorption capacity. The same tubes were tested in torsion and compared to numerical analysis with Abaqus [19]. A good agreement with experimental results has been found. They observed that kenaf fiber-reinforced composite tubes oriented at 45° and with an aluminum mandrel shown the highest torsional strength and fractured at a twist angle of 30°. Misri et al [20] also studied the same tubes by replacing the aluminum with a PVC mandrel. Experimental results of split disc tests according to ASTM D-2290 indicate the winding angle has a significant impact on the circumferential tensile strength. They concluded the reinforcement with the PVC mandrel improved the circumferential tensile strength by more than 25%.

Studies were made on kenaf reinforced polyester tubes of square and cylindrical shapes and subjected to axial compression loads [21, 22]. Ismail et al [23] developed kenaf fiber composite tubes hybridized with glass fiber on a bare aluminum tube associated with a polyester resin. Glass fibers and kenaf fibers are combined with volumetric ratios 0, 25, 50, 75, and 100% and oriented at [± 15°], [± 30°] and [± 45°]. The tubes were subjected to axial crushing. They concluded that tube hybridization improves compressive strength. Fiber orientations of [± 0°] and [± 45°] induce higher energy absorption capacities.

Heckadka et al [24] studied glass/Jute and Glass/Banana reinforced epoxy tubes with a configuration [90°/0°/90°/0°/90°]. Manufactured tubes of 50 mm diameter and 500 mm in length were subjected to axial compression and flexural tests according to ASTM D5449 and ASTM D7264 respectively. They concluded that the composites containing glass/Jute fibers could withstand more load, both in compression and flexural. The mechanical properties of epoxy tubes having glass fiber and flax fiber reinforcements were compared by Lehtiniemi et al [25]. The tubes were tested in circumferential traction (split disc) and in Charpy impact tests. The results showed that the flax fiber composites were relatively stiff. However, their circumferential tensile properties were only 25-29% of the properties of E-glass fiber composites.

The behavior in axial compression of epoxy tubes reinforced with hemp fibers was analyzed by Wecławski et al [26] for orientation angles of 10°, 30°, 45°, 60°. They found that the 10° orientation gives the highest values in stress and Young's modulus and they are four times higher than composites with reinforcements oriented at 90°. It was concluded that the fracture modes were related to the orientations of the natural long LNF fibers and to the wall thickness. The compressive modulus and ultimate compressive strength decrease with increasing orientation angle. Eshkoor et al [27] studied the effect of static crushing on a composite reinforced with hemp fibers. Results show that the failure of the specimens begins in two stages, namely the start of the crack, propagation of the crack, which results in progressive buckling and delamination.

Natural fiber composites have many advantages that make them very attractive for the design of innovative structures, from smart insulation building systems to composite flooring, ceilings, beams, columns, and even complete hybrid building systems. Significant development has been made to innovate in natural fiber composites, ranging from the fundamental interface of natural fibers and the matrix to super-light, including sustainable and complete bio-composites with both natural fibers and biopolymers. Our work consists of giving added value to natural Jute fiber by developing jute/epoxy composite tubes shaped by filament winding technique for possible industrial or domestic use. The tubes produced have an internal diameter of 92 mm with 4 stacking layers and different winding angles (50, 55, 60, 65, 75.90 degrees). We studied in this work the influence of winding angles on the mechanical characteristics under circumferential tensile and Parallel-Plate loading.

2 Matériel and manufacturing procedure

2.1 Materials

The tubes were produced using the filament winding technique. The fibers used are bundles of jute type 920TEX having an average diameter of 0.85 mm [28]. Jute fibers are supplied in coil form by textile companies TEXALG ABEJE, Bejaia, Algeria. The resin used is of the epoxy type marketed under the name "LORN CHEMICAL" and a specific hardener. The resin and hardener were mixed with ratio 65:35 by weight according to supplier specifications. The main physical characteristics are presented in Table 1.

Table 1 – Resin Characteristics

Characteristics	Epoxy resin « LORN CHEMICAL »
Density at 23° C (kg/cm^3)	1.5
Viscosity at 23° C (Cpa)	1200
Young's modulus (MPa)	1100
Max stress (MPa)	28

2.2 Tube manufacturing

The production of jute reinforced tubes using the filament winding process consists of winding fibers on a rotating and synchronized mandrel of two-axis machine (Fig. 1). The fibers pass through a yarn guide to be impregnated inside a resin tank and then scraped (removing excess resin) before being wound at the desired angle. The mandrel has an internal diameter of 92 mm. It was covered with a Teflon film in order to facilitate the demolding of the finished product.

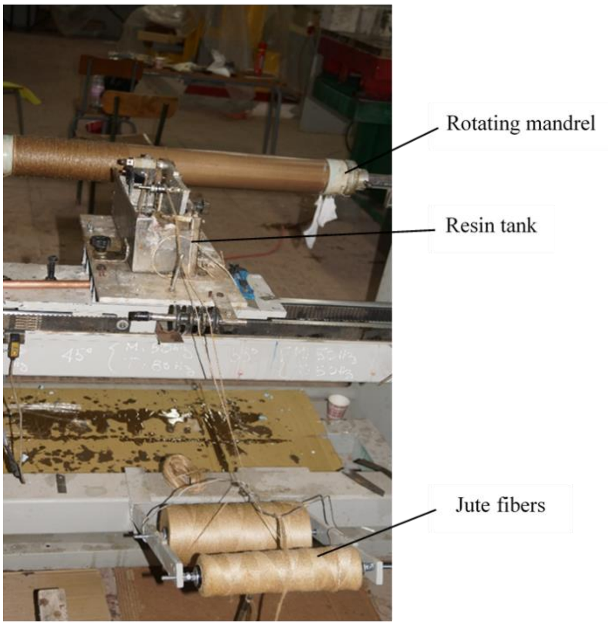


Fig. 1 – Manufacturing of composite tubes

Fig. 2 – Manufactured jute reinforced epoxy tubes

The tubes are structured in 4 layers of jute / epoxy. The first and the fourth layer are always wound at 90 °, while the second and third are wound at different angles α, namely: 50°, 55°, 60°, 65°, 75°, and 90° having respectively the designations

(90 / ± α / 90). The different tube configurations are given in table 2. The average mass fractions of the fibers varied from 46% to 53%. The mass fraction of the fibers is often influenced by several parameters, such as the processing method, the tension of the fibers and the properties of the constituents. We attribute this variation also to winding angle of the tubes. All the tubes formed are then polymerized at room temperature for 15 days (Fig. 2).

Table 2 – Tube configurations

N°	Orientation Angle (deg)	Thickness (mm)	Designation
1	50	4.1	(90 / ± 50 / 90)
2	55	3.5	(90 / ± 55 / 90)
3	60	3.8	(90 / ± 60 / 90)
4	65	3.3	(90 / ± 65 / 90)
5	75	3.4	(90 / ± 75 / 90)
6	90	3.4	(90)4

3 Specimens and test procedures

The specimens of the different jute reinforced epoxy tubes were tested for stiffness and hoop tension as specified in ASTM D2412 and ASTM D2290 respectively (Fig. 3).

Fig. 3 – Specimens for stiffness and hoop tension

3.1 Stiffness test "Ring compression"

Stiffness tests, also called ring compression, are carried out in accordance with ASTM D2412. The test machine is of type STM YL-28, equipped with a load cell of 65 kN. This test method involves in determining the characteristics of the tubes under the effect of the loading of two rigid parallel plates (Fig.4 (a) et (b)). These tests consist in applying a radial force to the tube with a speed of 2.5 mm/min up to 5% deformation of its diameter. The test machine is equipped with software capable of recording the equivalent load and deflection data. The data is then used to determine stiffness properties.

The stiffness characteristics can be determined according to ASTM D2412 as follows:

$$S = \frac{f \times F}{L \times y \times 10^6} \quad (1)$$

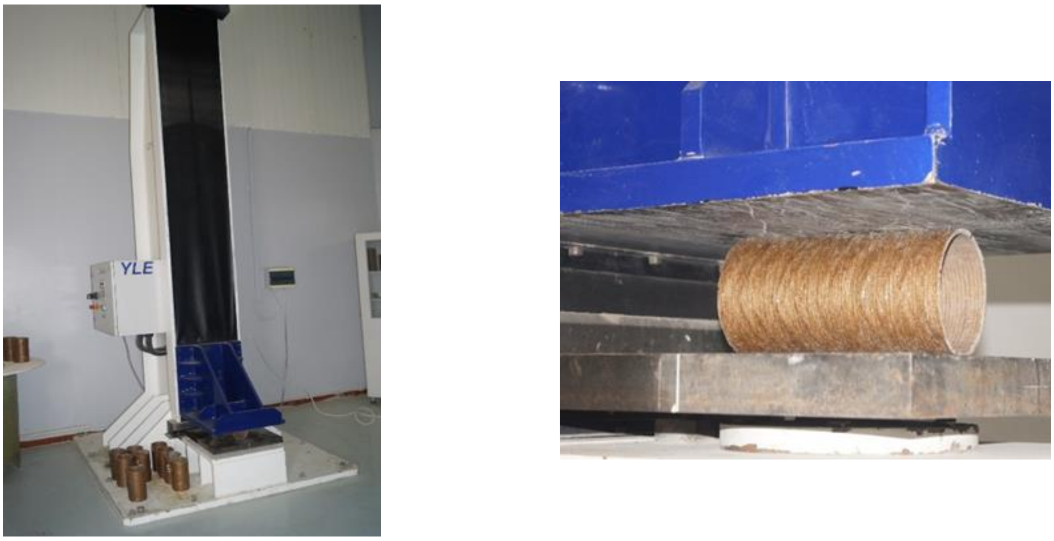
$$E_{cc} = S \times D^3 / I \quad (2)$$

$$f = 0.0186 + (0.025 \times y) / D \quad (3)$$

$$y = 0.05 \times D \quad (4)$$

$$I = t^3 / 12 \quad (5)$$

where : S : the specific stiffness of the tube (N/m²); E_{cc} : the modulus of elasticity in circumferential bending (N / m²); F : the force corresponding to the maximum deflection at 5% of the tube diameter (N); y : maximum allowable long-term deflection (mm); D : average diameter; L : length of the test specimen L = 200 mm and t : thickness of the test specimen (mm).



(a) (b)

Fig. 4 – (a) Testing equipment, (b) Stiffness specimen

(a) (b)

Fig. 5 – (a) Hoop testing equipment, (b) Hoop specimen

3.2 Circumferential tensile test

Circumferential tensile test « Hoop test » is performed according to ASTM D2290, using a split disc test accessory (Fig. 3). The tests are carried out on a universal machine type UTM-YLE equipped with a 100 kN load cell. The test specimen is mounted on two half-discs (Fig. 3 b) and subjected to circumferential tensile caused by the progressive separation of the discs at a speed of 2.5 mm/min until failure. The machine is equipped with a control system and load indicator allowing the measurement and storage of the load and the corresponding displacement.

The apparent circumferential tensile strength σ_{tc} is calculated using the following equation:

$$\sigma_{tc} = F/\left(2 \times t \times b\right) \tag{6}$$

where: F : the ultimate force (N); b : is the average width of the test specimen (mm); and t : is the thickness of the specimen, (mm).

The circumferential modulus of elasticity (E_{tc}) is calculated from the linear part of the stress-strain curve

4 Results and discussion

4.1 Stiffness characteristics

Figure 6 shows the results obtained by the stiffness test for the six configurations of jute fiber reinforced epoxy tubes. The load-deflection curves for (90/±α/90) show the same linear pattern up to the maximum deflection (5% of the tube diameter).

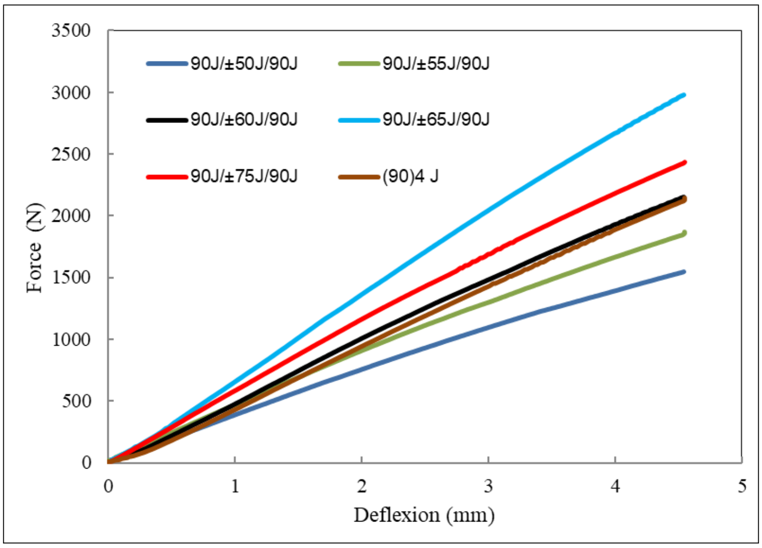


Fig. 6 – Load-deflection curve of the jute/epoxy tubes under parallel-plate

The histograms (Fig. 7), showing the maximum load obtained at 5% deformation of the diameter of the tube as a function of the orientation angle α, have a bell shape. We found that the greatest value of the load was 2.98 kN corresponding to the tube (90J / ± 65 / 90J). While the lowest values were recorded by the tubes (90J / ± 50 / 90J).

The effect of the winding angle α on the specific stiffness with their dispersions is shown as a histogram (Fig. 8). The maximum stiffness of the jute fiber reinforced epoxy tubing was 65.74 kPa given by the laminate (90J / ± 65J / 90J).

The effect of the tube winding angle α on the circumferential compression elastic modulus (E_{cc}) is shown as a histogram (Fig. 9). The results obtained shows that the elastic modulus for the tube wound at 90° gives the best result with a value of 10.42 GPa. The values obtained are proportional to the ply winding angle α. We can conclude that the circumferential compression elastic modulus E_{cc} is significantly influenced by the tube winding angle.

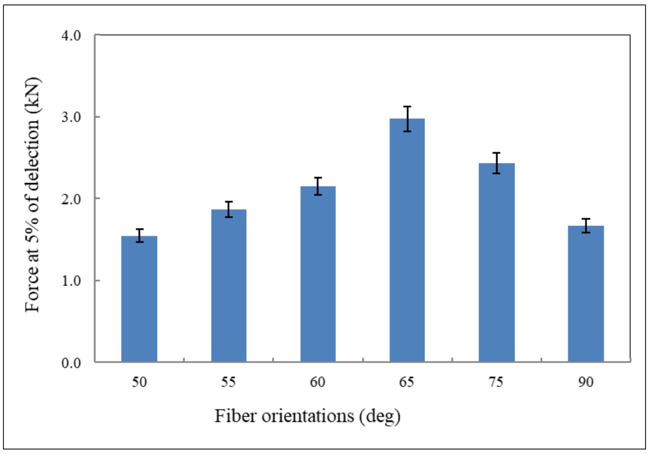


Fig. 7 – Force at 5% of deflection versus fiber orientation angle

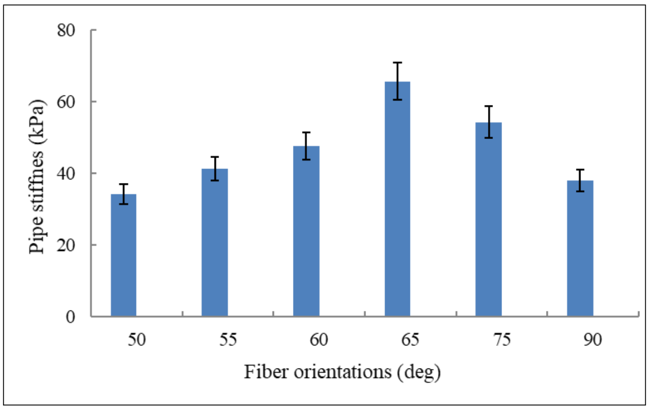


Fig. 8 – Stiffness versus fiber orientations of jute reinforced epoxy tube under parallel-plate loading.

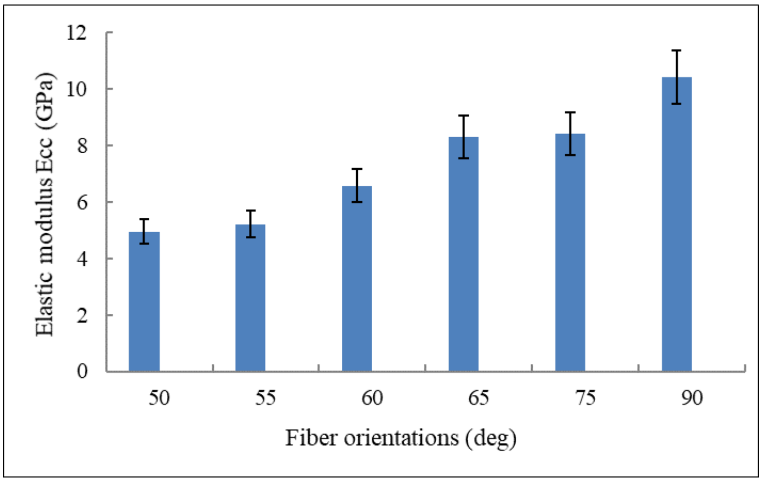


Fig. 9 – Elastic modulus E_{cc} *versus fiber orientations of jute reinforced epoxy tube under parallel-plate loading.*

4.2 Circumferential tensile tests.

The results of the circumferential tensile tests on the different specimens allowed us to distinguish the behavior at fracture of the tubes tested and to determine, for each of the tubes, the maximum stress σ_{cc} and the modulus of elasticity E_{cc} . Figure 10 illustrates the evolution of the stress as a function of the circumferential tensile strain. The curves showed almost the same shape for different tube configurations. a linear evolution was observed with a transition zone up to the maximum load, followed by a brittle fracture for all orientations angle α.

Figure 11, in the form of a histogram, represents the ultimate stress (σ_{tc}) and the modulus of elasticity (E_{tc}) as a function of the orientation of the fibers (α) subjected to circumferential tension. The results show that the mechanical properties of composite tubes reinforced with jute fibers are influenced by the orientation of the plies. In the case where α equals 90°, the maximum values of stress σ_{tc} and modulus E_{tc} were 79.4 MPa and 29.16 GPa respectively. These values are 45% lower when α equals 50 degrees. It can be concluded that the circumferential tensile properties are very sensitive to the variation of the orientation angle.

The results obtained by the tests presented, relating to the stiffness and circumferential tensile of jute fiber reinforced epoxy tubes, which is summarized in: specific rigidity, the tensile stress, the elastic modulus in circumferential tensile and in circumferential compression, show that these properties are remarkably influenced by the winding angle. In the literature, comparable results were found by Misri et al [3] during their study on tubes with a diameter of 90 mm and reinforced with

Kenaf fiber. They studied the split-disk properties whose fibers were oriented at (± 90) and (± 45). In this study, the values found for tubes coiled at (± 90) were greater than those coiled at (± 45). They concluded that the orientation on fiber angle has a significant impact on the hoop tensile strain, hoop tensile modulus, and hoop tensile strength properties.

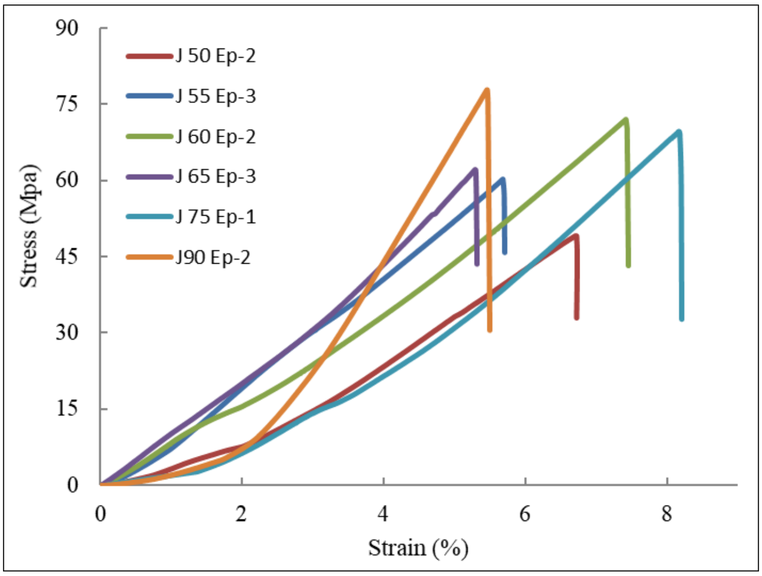


Fig. 10 – Evolution of stress-strain curves in circumferential tensile

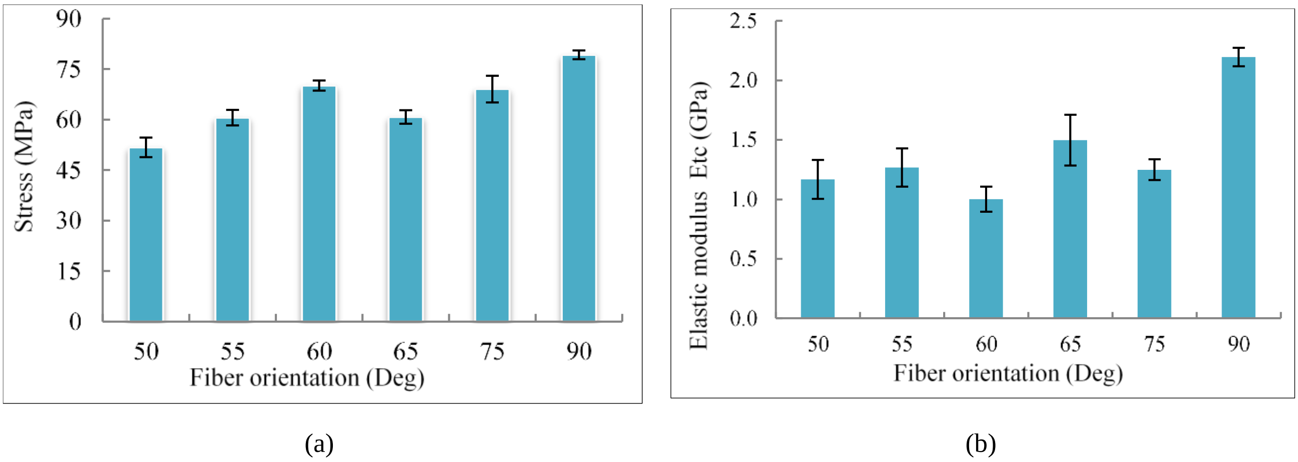


Fig. 11 – Stress and elastic modulus versus fiber orientations s under circumferential tensile loading.

5 Conclusion

The experimental study was carried out on composite epoxy tubes reinforced with Jute fibers shaped by filament winding. From experiments, the mechanical properties such as stiffness and circumferential tensile properties of jute/epoxy tubes (90/±α/90) where α namely: 50°, 55°, 60°, 65°, 75°, and 90° are successfully determined. The results of the experiments concluded that the specific stiffness depends on the winding angle α. The tubes at an angle of 65° have the greatest specific stiffness. The maximum circumferential compressive elasticity was 10.42 GPa recorded for the tube wound at 90°. This is about twice that of tubes wound at 50°. The elastic modulus in circumferential compression is strongly influenced by the winding angle. The maximum value of the apparent circumferential tensile strength σ_{tc} , of jute/epoxy tubes, is at the 90° angle and is strongly influenced by the winding angle of the fiber. The orientation angle of the fibers directly influences the mechanical characteristics of composite tubes produced by filament winding. The circumferential tensile strength increases each time the winding angle increases.

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