Compared with Angle –ply and Cross-ply Natural Fiber Orientation Pipe under Thermal Load

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Abstract. Experimental and analytical Solution using classical shell theory solve by Matlab software was used to found thermal stresses under thermal load for natural composite materials pipe. Jute fibres were used in this work and reinforcements with polyester-resin. The experimental work including the manufacturing of the test samples (jute fibres/polyester) with different types of fibres orientation (0°, 45°, 90°) by resin casting method. The volume fraction is 40%. Tensile and thermo-mechanical test were performing to find the mechanical properties of the specimens. The results showed that Angle –ply fiber orientation natural composite had the highest strain and stress compared with cross-ply fiber orientation natural composite.

1. Introduction

In recent years, the use of natural fibres as reinforcement is increasingly replacing the conventional inorganic fibres in polymer matrix composites [1-2]. Due to their low density, good thermal, low cost, ecologically friendly, mechanical and resistivity hardness, the interest in natural fibers has increased worldwide [3]. Tariq S Z and Abdullah F A (2020) [4] study the mechanical properties of jute fibres with different types of resin (epoxy and polyester resin). The results showed that, the composite of jute strengthened epoxy offered better properties of mechanical than composite of jute strengthened polyester. Qasim S M (2015) [5] studied composite and Nano composite pipes conduct under bending moment and internal pressure. The results showed that the maximum stresses for woven roving carbon are approximately four times equivalent to glass fiber (woven roving), but carbon (roving) is nearly twice equivalent to fiber glass (roving). Carbon and glass fiber (roving woven) specimens were also more tolerant to stress, deformation of the hoops and strain of the hoops than roving specimens. Abdulla F A et.al; (2018) [6] Studied the influence of filler of the ceramic (Al2O3) insertion on the physico-mechanical, and the absorption of water behaviour of composites of jute natural fiber strengthened epoxy with different rates of wight fraction. The results show mechanical properties of jute/epoxy increases with the increase in content of filler of Al2O3. Abdulla F A (2018) [7] studied the behavior of straight and curved composite pipes under bending moment and internal pressure. The results showed that the maximum carbon fiber stress at (4 mm) curved pipe thickness was significantly higher from the curved pipe fiber glass by (362%). The curved pipe with internal pressure only has stresses greater than curved pipe with in-plane bending and internal pressure. Abdul-Kareem H S, et al; (2019) [8] investigated properties of fiberglass, Pineapple leaf fibers, and Jute fibers with 1:1:1 ratio with polyester and epoxy resins. Results showed that, the glass fibers, Pineapple leaf, and Jute reinforced epoxy composites gave mechanical properties best than glass fibers, Pineapple leaf, and Jute reinforced polyester resin. In this work, the effect of increasing
thermal load on the thermal stress of two types of composite was investigated, the properties of composite were investigated.

2. Experimental Work
2.1 Material and Sample Fabrication

Jute fiber with polyester were used in this work, the predation of sample by using the wood open mold of thin wood plates, as schematically arranged in plate (4-5) the dimension of mold (30cm*30cm*0.5cm) figure (1) show the steps of sample fabrication.

![Figure 1. a- Wood Mold; b- Fix the Nails on either side of the wood mold; c- Extend the jute fiber in one direction in the Mold; d- Injection Resin; e- Distribution Resin; f- Rectangular shape](image)

The rectangular samples was cut utilizing a CNC cutting machine into two kind samples according to test (tensile and Thermo Mechanical Analyzer Tests) [9,10]. Table (1) show the dimensions, and shape of test samples.

2.2 Mechanical Tests

The mechanical properties have been found using ASTM D 638 standard [11]. A composite plate (20cm*30cm*0.5cm). The CNC cutting machine was used to desired the sample of tensile test [12]. Thermo Mechanical Analyzer (TMA) is the tool used to determine the thermal expansion coefficient [13], as shown in figure (2). The required TMA unit sample measurements are (2cm*0.5cm *0.4cm).
3. Analytical Solution

The displacement field, based on classical deformation theory for two dimension, is given by [14].

\[ u = u^o(x, \theta) - z \frac{\partial w^o(x, \theta)}{\partial x} \]

\[ v = (1 - \frac{2z}{R}) v^o(x, \theta) - z \frac{1}{R} \frac{\partial w^o(x, \theta)}{\partial \theta} \]

\[ w = w^o(x, \theta) - z \frac{1}{R} \frac{\partial v^o}{\partial \theta} \]

\[ \ldots (1) \]

in which \((^o)\) represents the components of displacement \((u,v,w)\) at the mid-surface position, while \((u^o,v^o,w^o)\) would be corresponding function of \((x, \theta)\) only.

The strains are [15]

\[ \varepsilon_x = \varepsilon_x^o + z k_x \]

\[ \varepsilon_\theta = \varepsilon_\theta^o + z k_\theta \]

\[ \gamma_{xy} = \gamma_{xy}^o + z k_{xy} \]

\[ \ldots (2) \]

Where the \(( \varepsilon^o )\) is the middle –surface strains:-

\[ \varepsilon_x^o = \frac{\partial u^o}{\partial x} \]

\[ \varepsilon_\theta^o = \frac{1}{R} \frac{\partial u^o}{\partial \theta} + \frac{w^o}{R} \]

\[ \gamma_{xy}^o = \frac{\partial v^o}{\partial x} + \frac{1}{R} \frac{\partial u^o}{\partial \theta} \]

\[ \ldots (3) \]

and \((k)\) is the middle –surface curvatures [16, 17]:-

\[ k_x = -\frac{\partial^2 w^o}{\partial x^2} \]

\[ k_\theta = \frac{1}{R} \frac{\partial v^o}{\partial \theta} - \frac{\partial^2 w^o}{\partial \theta^2} \]

\[ k_{xy} = \frac{1}{R} \frac{\partial \varepsilon_\theta^o}{\partial x} - 2 \frac{\partial \gamma_{xy}^o}{\partial x \partial \theta} \]

\[ \ldots (4) \]

While \(z\) is the thickness of layer.

The lamina stress-strain relation is [18] & [19].
\[
\begin{bmatrix}
\sigma_x \\
\sigma_y \\
\sigma_\theta \\
\sigma_{x\theta}
k
\end{bmatrix}
= \begin{bmatrix}
Q_{11} & Q_{12} & 0 & 0 \\
Q_{21} & Q_{22} & 0 & 0 \\
0 & 0 & Q_{66} \\
0 & 0 & 0 & Q_{66}
k
\end{bmatrix}
\begin{bmatrix}
\varepsilon_x^T \\
\varepsilon_y^T \\
\varepsilon_\theta^T \\
\gamma_{x\theta}^T
\end{bmatrix}
+ Z \begin{bmatrix} k_x \\ k_y \\ k_\theta \\ k_{x\theta} \end{bmatrix} 
\]...

...(5)

\[
\begin{bmatrix}
\varepsilon_x^T \\
\varepsilon_y^T \\
\varepsilon_\theta^T \\
\gamma_{x\theta}^T
\end{bmatrix}
= \begin{bmatrix} A & B & 0 & 0 \\ 0 & 0 & 0 & 0 \\ A & B & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}
\begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_\theta \\ \gamma_{x\theta} \end{bmatrix} 
\]...

...(6)

4. Result and Discussion
4.1. Thermo-Mechanical Test and Tensile Test
The isotropic samples properties (poisson ratio, modulus of elasticity, yield stress, ultimate stress, and coefficient of thermal expansion) concluded from the thermo-mechanical test and tensile test are listed in table 2. The jute fibers in 0° composite sample illustrates has greater mechanical properties compared with other angles of samples composite.

| Table 2. Mechanical Properties of Jute Fibers/Polyester Samples |
|---|
| $\alpha_1$ (m/km) | $\alpha_2$ (m/km) | $E_1$ (GPa) | $E_2$ (GPa) | $v$ | $\sigma_y$ (MPa) | $\sigma_{ult}$ (MPa) |
| 3.34E-06 | 3.68E-06 | 12.6 | 4.2 | 0.329 | 25.61 | 30.42 |

4.2 Analytical Result
Figures (3), (4) and (5) are shows the relation between number of layers and strain (longitudinal strain, hoop strain and shear strain), it can be seen that the strain decrease when number of layers increased which the maximum value of maximum strain for two layers and minimum value of maximum strain in ten layers also can be noticed the arrangement of fibers orientation (angle-ply) give maximum strain Comparison with (cross-ply) fibers orientation.

Figures (6), (7), (8) and (9) are shows the relation between number of layers and stress (longitudinal stress, hoop stress and shear stress, von mises stress), it can be seen that the stress decrease which the maximum value of maximum stress for two layers and minimum value of maximum stress in ten layers.
5. Conclusions
   a. When number of layers increased the strain was decreased for Angle –ply and cross-ply fiber orientation.
   b. When number of layers increased the stresses were decreased for Angle –ply and cross-ply fiber orientation.
   c. Angle –ply fiber orientation show the maximum strain and stress in two layers comparison with cross-ply fiber orientation.

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