Investigation of Natural Composite Materials 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. Two types of natural fibers (eggshell and ash of fire wood) were used as reinforcements with polyester-resin. The experimental work including the manufacturing of the test samples (eggshell/polyester and ash of fire wood /polyester) by resin casting method with 40% volume fraction. Tensile and thermo-mechanical test were performing to find the mechanical properties of the specimens The results showed that eggshell natural composite had the highest strain ,stress, and good mechanical properties compared with ash of fire wood natural composite but regarding temperature withstand the ash of fire wood specimens had the highest compared with egg shell specimens.

Keywords: natural composite material ,egg shell, ash wood fire, thermal stresss.

List of symbols

| Symbol | Description                                      | Unit   |
|--------|--------------------------------------------------|--------|
| A      | Extensional stiffnesses                          | GPa    |
| B      | bending-extensional coupling stiffnesses         | GPa    |
| D      | Bending stiffnesses                              | GPa    |
| E      | Modulus of Elasticity                           | GPa    |
| \(k_x\) | Longitudinal middle –surface curvature           | …….   |
| \(k_\theta\) | Hoop middle –surface curvature                  | …….   |
| \(k_{x\theta}\) | (longitudinal, hoop )middle –surface curvature | …….   |
| \(M_x\) | Longitudinal Thermal moment                     | N      |
| \(M_\theta\) | Hoop Thermal moment                             | N      |
| \(M_{x\theta}\) | (longitudinal ,hoop ) Thermal moment            | N      |
| \(N_x\) | Longitudinal Thermal Force                      | N      |
| \(N_\theta\) | Hoop Thermal Force                              | N      |
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| Symbol | Description                                      | Unit   |
|--------|-------------------------------------------------|--------|
| \( N_{x\theta} \) | (longitudinal,hoop) Thermal Force                | N      |
| \( Q^s_n \) | transformed reduced stiffness                    | GPa    |
| \( R \) | Radius                                          | mm     |
| \( S \) | Number of Layers                                 | ....   |
| \( u \) | Displacement in x direction                       | mm     |
| \( v \) | Displacement in y direction                       | mm     |
| \( w \) | Displacement in z direction                       | mm     |
| \( u^0 \) | displacement at the mid-surface position in x direction | mm     |
| \( v^0 \) | displacement at the mid-surface position in y direction | mm     |
| \( w^0 \) | displacement at the mid-surface position in z direction | mm     |
| \( Z \) | Thickness of Layer                                | mm     |
| \( \sigma^s_x \) | Longitudinal stress for s layer                   | MPa    |
| \( \sigma^s_{\theta} \) | Hoop stress for s layer                          | MPa    |
| \( \sigma_{ult} \) | Ultimate Stress                                   | MPa    |
| \( \sigma_y \) | Yield Stress                                     | MPa    |
| \( \tau^s_{x\theta} \) | (longitudinal,hoop) shear stress for s layer     | MPa    |
| \( \varepsilon_x \) | Longitudinal Strain                              | ------ |
| \( \varepsilon_{\theta} \) | Hoop Strain                                      | ------ |
| \( \gamma^0_{x\theta} \) | ( Longitudinal,hoop ) shear strain               | ------ |
| \( \varepsilon^0_x \) | middle –surface Longitudinal strain              | ------ |
| \( \varepsilon^0_{\theta} \) | middle –surface hoop strain                      | ------ |
| \( \gamma^0_{xy} \) | ( Longitudinal,hoop ) middle –surface shear stress | ------ |
| \( \Delta T \) | temperature difference                           | ------ |
| \( \alpha \) | Coefficient of Thermal Expansion                 | m/mk   |
| \( \nu \) | Poisson Ratio                                    |        |

1. Introduction
Numerous situations utilized composite pipes and vessels because of their unique properties, for example, high solidity to weight proportion, composites pipes have gotten alluring for many applications [1]. Due to their low density, good thermal, low cost, ecologically friendly, mechanical and resistivity hardness, the interest in natural fibers has increased worldwide [2].

Ahmed, 2004 [3] Investigated the mechanical properties of additional unsaturated resins supported by husk rice. The composite materials from rice husk has The results better properties compared to the composite prepared from polyester resin without filler. S.B. Hassan, et al (2012) [4], Developed Eggshell/ polyester particulate composites ,carbonized, and un carbonized eggshell powder were utilized as enforcement in polyester matrix with weight fraction (10% to 50%). The results illustrated that, the hardness and density magnitudes of the (eggshell - polyester) composite increased and maximum value at 40% while non-carbonized eggshell; yet it increased to same maximum value at 20% carbonized eggshell. Compressive strength steadily increased to same maximum value at 50% non-carbonized eggshell, and at 50% carbonized eggshell. 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. W.J. Habubi and Hamdi N.F. (2017) [6] investigated the composite preparation of epoxy /eggshell as an insulation. The results showed a good thermal (stability and
conductivity) for 4 percent eggshell / epoxy composite, and can be used as insulation. 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. Reddy, M. I, et al; and it (2018) [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

The egg shell and Ash of firewood natural fibers with polyester were used in this work.

2.2 Sample Fabrication

The eggshell was washed by water, left to dry at room temperature and finally eggshell was grinded by a domestic grinder machine figure (1) a, while ash of fire wood was collected after burning firewood and cleaned from impurities by using affine sieve figure (1) b.

![Figure (1): a- eggshell after Grinding, b- wood fire after](image)

The samples were prepared by mixing (40%) volume fraction powders with polyester. mixed eggshell powder with polyester using ultara –sonication process homogeneously [9]. The mixture was poured into the rectangular mold of glass by method of resin casting. The glass mold dimensions are (30cm*30cm*0.5cm).Then the mixture was poured in mold see figure (2).

Figure (3) show the final shape of composite samples. The rectangular samples was cut utilizing a CNC cutting machine into two kind samples according to test ( tensile and Thermo Mechanical Analyzer Tests)[10][11]. Table (1) show the dimensions, and shape of test samples.
2.3 Mechanical Tests

The mechanical properties have been found using ASTM D 638 standard [12]. A composite plate (20cm*30cm*0.5cm) was casted using resin casting method. The CNC cutting machine was used to desired the sample of tensile test (see figure 4). Thermo Mechanical Analyzer (TMA) is the tool used to determine the thermal expansion coefficient, as shown in figure (5). The required TMA unit sample measurements are (2cm*0.5cm *0.4cm).

![Figure 2](image1.png)

**Figure (2)** a- ultara –sonication mixing process; b- Glass Mold; d- Mixture poured in the Mold

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![Figure 3](image2.png)

**Figure (3):** Rectangular Shapes of a- Eggshell sample ; b- Ash of fire wood

| The test                                    | Sample shape |
|---------------------------------------------|--------------|
| tensile Test                                | ![tensile Test](image3.png) |
| Thermo Mechanical Analyzer Test (TMA)       | ![TMA](image4.png) |

**Table (1):** Dimensions and shapes of samples
3. Analytical Solution

The displacement field, based on classical deformation theory for two dimensions, is given by [13],[14]:

\[ \begin{align*}
  u &= u^* (x, \theta) - z \frac{\partial w^* (x, \theta)}{\partial x} \\
  v &= (1 - 2 z \frac{1}{R}) v^* (x, \theta) - z \frac{1}{R} \frac{\partial W^* (x, \theta)}{\partial \theta} \\
  w &= w^* (x, \theta) - z \frac{1}{R} \frac{\partial v^*}{\partial \theta}
\end{align*} \]  

\( \ldots (1) \)

in which \((^*)\) represents the components of displacement \((u, v, w)\) at the mid-surface position, while \((u^*, v^*, w^*)\) would be corresponding function of \((x, \theta)\) only [15].

The strains are [16]

\[ \begin{align*}
  \varepsilon_x &= \varepsilon_x^* + z k_x \\
  \varepsilon_\theta &= \varepsilon_\theta^* + z k_\theta \\
  \gamma_{x\theta} &= \gamma_{x\theta}^* + z k_{x\theta}
\end{align*} \]  

\( \ldots (2) \)

Where the \((\varepsilon^*)\) is the middle-surface strains:
\[ ε_x^0 = \frac{∂u_0}{∂x} \quad ε_θ^0 = \frac{1}{R} \frac{∂v_0}{∂θ} + \frac{w_0}{R} \quad γ_{xy}^0 = \frac{∂v_0}{∂x} + \frac{1}{R} \frac{∂u_0}{∂θ} \]  \quad \ldots (3)

and (k) is the middle surface curvatures:

\[ k_X = -\frac{∂^2w_0}{∂x^2} \quad k_Y = \frac{1}{R} \frac{∂v_0}{∂θ} - \frac{∂^2w_0}{∂θ^2} \quad k_{xy} = \frac{1}{R} \frac{∂v_0}{∂x} - 2 \frac{∂^2w_0}{∂x∂θ} \]  \quad \ldots (4)

While \( z \) is the thickness of layer. The main three thermal stresses in each layer can be expressed as \[ (17) \]:

\[ \sigma_i = Q^s_{ij}(ε_i - α_jΔT) \quad i,j = 1,2,\ldots 6 \]  \quad \ldots (5)

it can be write equation (5) as:

\[ \sigma_x^s = Q_{11}^s \frac{∂u_0}{∂x} + Q_{12}^s \left( \frac{1}{R} \frac{∂v_0}{∂θ} - \frac{w_0}{R} \right) - Z[Q_{11}^s \frac{∂^2w_0}{∂x^2} + Q_{12}^s \frac{1}{R^2} \left( \frac{∂^2w_0}{∂θ^2} + \frac{∂v_0}{∂θ} \right) - (Q_{11}^s α_x + Q_{12}^s α_θ)T_0 - (Q_{11}^s α_x + Q_{12}^s α_θ)T_1 - Q_{12}^s α_x + Q_{22}^s α_θ] ] \]  \quad \ldots (6)

\[ \sigma_θ^s = Q_{12}^s \frac{∂u_0}{∂x} + Q_{22}^s \left( \frac{1}{R} \frac{∂v_0}{∂θ} - \frac{w_0}{R} \right) - Z[Q_{12}^s \frac{∂^2w_0}{∂x^2} + Q_{22}^s \frac{1}{R^2} \left( \frac{∂^2w_0}{∂θ^2} + \frac{∂v_0}{∂θ} \right) - (Q_{12}^s α_x + Q_{22}^s α_θ)T_0 - (Q_{12}^s α_x + Q_{22}^s α_θ)T_1 ] \]  \quad \ldots (7)

\[ τ_{xθ}^s = [Q_{66}^s \frac{∂^2w_0}{∂x^2} + \frac{1}{R} \frac{∂u_0}{∂θ}] - Z[\frac{2}{R} Q_{66}^s \left( \frac{∂^2w_0}{∂x∂θ} + \frac{∂v_0}{∂θ} \right) ] \]  \quad \ldots (8)

Where:

\( Q_n^s \) are the transformed reduced stiffness are given in terms of reduced stiffnesses given by \[ (18) \].

\( α_j \) coefficient of thermal deformation

\( S \) number of layers

\( ΔT \) temperature difference

The resultant thermal loads and moments are \[ (19) \].

\[ N_x = A_{11} \frac{∂u_0}{∂x} + A_{12} \left( \frac{1}{R} \frac{∂v_0}{∂θ} - \frac{w_0}{R} \right) - B_{11} \frac{∂^2w_0}{∂x^2} - B_{12} \frac{1}{R^2} \left( \frac{∂^2w_0}{∂θ^2} + \frac{∂v_0}{∂θ} \right) - (A_{11} α_x + A_{12} α_θ)T_0 - (B_{11} α_x + B_{12} α_θ)T_1 \]

\[ N_θ = A_{12} \frac{∂u_0}{∂x} + A_{22} \left( \frac{1}{R} \frac{∂v_0}{∂θ} - \frac{w_0}{R} \right) - B_{12} \frac{∂^2w_0}{∂x^2} - B_{22} \frac{1}{R^2} \left( \frac{∂^2w_0}{∂θ^2} + \frac{∂v_0}{∂θ} \right) - (A_{12} α_x + A_{22} α_θ)T_0 - (B_{12} α_x + B_{22} α_θ)T_1 \]

\[ N_{θθ} = A_{44} \left( \frac{∂^2w_0}{∂x^2} + \frac{1}{R} \frac{∂u_0}{∂θ} \right) - B_{44} \frac{2}{R} \left( \frac{∂^2w_0}{∂x^2} + \frac{∂v_0}{∂θ} \right) \]
\[ M_x = B_{11} \frac{\partial u^0}{\partial x} + B_{12} \left( \frac{1}{R} \frac{\partial \theta^0}{\partial x} - \frac{w^0}{R} \right) - D_{11} \frac{\partial^2 w^0}{\partial x^2} - D_{12} \frac{1}{R^2} \left( \frac{\partial^2 w^0}{\partial \theta^2} + \frac{\partial v^0}{\partial \theta} \right) - (B_{11} \alpha_x + B_{12} \alpha_\theta) T_0 - (D_{11} \alpha_x + D_{12} \alpha_\theta) T_0 \]

\[ M_\theta = B_{12} \frac{\partial u^0}{\partial x} + B_{22} \left( \frac{1}{R} \frac{\partial v^0}{\partial \theta} - \frac{w^0}{R} \right) - D_{12} \frac{\partial^2 w^0}{\partial x^2} - D_{22} \frac{1}{R^2} \left( \frac{\partial^2 w^0}{\partial \theta^2} + \frac{\partial v^0}{\partial \theta} \right) - (B_{12} \alpha_x + B_{22} \alpha_\theta) T_0 - (D_{12} \alpha_x + D_{22} \alpha_\theta) T_1 \]

\[ M_{X\theta} = B_{66} \left( \frac{\partial u^0}{\partial x} + \frac{1}{R} \frac{\partial u^0}{\partial \theta} \right) - D_{66} \frac{2}{R^2} \left( \frac{\partial^2 w^0}{\partial x \partial \theta} + \frac{\partial v^0}{\partial \theta} \right) \]

\[ \ldots (9) \]

the components of matrix are \[ 20], [21]a

\[ (A_{ij}, B_{ij}, D_{ij}) = \int_{\frac{h}{2}}^{\frac{h}{2}} Q_i^j (1, z, z^2) \, dz = \sum_{c=1}^{N_L} Q_i^j \left( \frac{z^c_s - z^c_{s+1}}{1}, \frac{z^c_s - z^c_{s+1}}{2}, \frac{z^c_s - z^c_{s+1}}{3} \right) \]

\[ \ldots (10) \]

Where:

\[ A_{ij}, B_{ij}, D_{ij} \] are the extensional stiffnesses, bending-extensional coupling stiffnesses, bending stiffnesses respectively

The above equations are solved analytically using matlab software.

**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. Eggshell composite sample illustrates has greater mechanical properties compared with ash of fire wood sample composite.

| Type            | \( \alpha \) (m/mk) | \( E \) (GPa) | \( \nu \) | \( \sigma_y \) (MPa) | \( \sigma_{ult} \) (MPa) |
|-----------------|----------------------|---------------|----------|----------------------|------------------------|
| Eggshell        | 2.796E-6             | 13.35         | 0.38     | 33.1                 | 39.2                   |
| Ash of fire wood| 1.795E-06            | 7.26          | 0.42     | 17                   | 21.7                   |

**4.2 Analytical Result**

Figures (6) and (7) give the relation between the longitudinal and hoop strain respectively and temperature for eggshells, and ash of fire wood. From those figures, it can be showed that, when the temperature increased, the longitudinal and hoop strain increased, also it can be seen from the figures that the ash of fire wood highest withstand temperature up to (259°C) compared with the eggshells that the temperature withstand of (200°C). While the ash of fire wood showed lower hoop and longitudinal strain compared to the eggshell, with (20%) and (10%) difference respectively.

Figures (8) and (9) show the relationship between the longitudinal and hoop stress respectively and temperature for eggshells, and ash of fire wood. From those figures, it can be showed that, when the temperature increased the longitudinal and hoop stress increased.
also it can be seen from the figures that eggshell gives highest longitudinal and hoop stress of 17.59 and 21.96 MPa compared to longitudinal and hoop stress of ash of fire wood 10.98 and 10 MPa. the difference of longitudinal and hoop stress (37.2%) and (8.9%) respectively between eggshell and of ash of fire wood respectively.

Figure (10) show the relationship between the von mises stress and temperature increasing for the egg shell and ash of fire wood. Can be noticed the von mises stress of the egg shell highest stress of (20.13MPa) compared to the (10.52MPa) of ash of fire wood. Figure (11) and (12) give the longitudinal and hoop stress respectively temperature for eggshell and ash of fire wood respectively. It can be seen from figure the eggshell and ash of fire wood have highest longitudinal stress compared with hoop stress [22].

Figure (6) Temperature increase effect on Longitudinal strain

Figure (7) Temperature increase effect on Hoop strain

Figure (8) Temperature increase effect on Longitudinal stress

Figure (9) Temperature increase effect on Hoop stress
5. Conclusions

1- Ash of fire wood natural composite materials can be withstand temperature reach to (259° C) and the eggshell natural composite materials can be withstand temperature reach to (200°C).

2- The eggshell natural composite materials showed the hoop stress, longitudinal stress, longitudinal strain, and hoop strain, greater than ash of fire wood natural composite materials.

3- The eggshell natural composite showed a good mechanical properties compared with fire wood natural composite materials.

4- The eggshell natural composite materials showed the highest value of coefficient of thermal expansion compared with ash of fire wood natural composite materials.

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