



Macro-mechanical analysis of a Bio sandwich application for cylinder under pressure

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ABSTRACT

Before focusing on the design of eco-sandwich pipes under hydrogen pressure, the current study centered on analyzing a structural component using the macromechanical approach. This approach is rooted in sandwich laminated theory, taking into account transverse shear considerations. The major purpose of this paper is to assess the possible uses of bio-fibers to replace glass synthetic fibers that are commonly used in sandwich pipes under pressure. A stress comparison is developed through the thickness of stacking sequence of sandwich element $[-\emptyset / +\emptyset / \text{core} / +\emptyset / -\emptyset]$ between four biocomposite materials based on PALF, Alfa, Jute, and Palm natural fibers and a synthetic composite based on Glass fibers. A failure analysis based on the TSAI-WU criterion is presented, and it is as a function of the increment in internal pressure. The mechanical properties have an influence on the behavior of composite sandwiches based on synthetic or natural fibers. The macromechanical analysis is a good tool to locate the layer of the lower or upper skin that is most stressed, enabling a failure analysis and suggesting reinforcement solutions.

1. INTRODUCTION

Sandwich structures are light, multifunctional composite structures, Sandwich structures are constructed of three layers [1]. The core attached to two identifiable stiff and strong skins; the core distributes the load from one skin to another. The adhesive that transports the shear and axial stresses to the core material is employed as a bonding agent, while the skins contribute to bending and turgidity [2]–[4]. Sandwich structures exhibit lightweight properties, high rigidity, and exceptional energy absorption capabilities, rendering them highly suitable for various structural applications [5]. Because the entire performance of sandwich structures is dependent on the properties of the components, a sandwich structure will have varying mechanical properties depending on the materials used [6].

Sandwich tubes are a subset of sandwich panels. Several studies on the design and performance of sandwich cylinders have been conducted in recent years [7]–[10]. Xiong et al. developed sandwich cylindrical shells with corrugated cores and investigated their failure behaviour in a range of geometrical configurations [11]. Yang et al.

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studied the modal vibration responses of composite pyramidal truss-like core sandwich tubular panels in terms of manufacturing fault sensitivity [12].

Numerous research endeavours are underway to substitute synthetic skins with composites crafted from natural fibres. [13]–[17]. The availability and low cost of these items justify the interest. Bio-based composites hold great potential as a viable alternative to traditional composites since they have lower densities and, as a result, property-density ratios that are comparable to glass fibres [18], [19].

For predicting the mechanical behaviour of sandwich structure, the literature show that the classical laminated plate theory (CLPT) and the elastic solution are the most theories used. Xia et al. [7], [8], [20] introduced analytical solutions based on CLPT to analyse stresses and deformations in thick FW sandwich pipes under various loading conditions. Bakaiyan and Ameri [21] presented an elastic solution for the case of internal pressure combined with through-thickness thermal gradient based on 3D anisotropic elasticity considering shear-extension coupling in FW skins.

It is important to note that composites are known by their multiscale architecture, namely: microscopic (components: fibre and matrix), mesoscopic (composite layer or plie), macroscopic (stratified or stack of layers), and finally structural (structure tubular). Any development of a deterministic or reliable sizing model for multilayer or sandwich-type composites must take this particular configuration into account.

Following the micromechanical analysis, which involves predicting the thermomechanical properties of composites, a number of studies have focused on the macroscopic analysis of the elements of composite structures, represented by laminates. The literature indicates that the sandwich laminated plate theory (SLPT) and the elastic solution are the most commonly used theories for predicting the mechanical behaviour of sandwich structures at the macroscopic level.

Avinash et al. [22] employed elasticity theory to ascertain the stress distribution throughout each layer of the laminate element. This enabled them to conduct failure analysis using the Tsai-Wu criterion.

While the composite tubular structures are being used, damage like matrix cracking, fibre/matrix deboning, delamination between plies and fibre rupture will happen before the material finally breaks. Hence the interest in analysing damage on a macroscopic scale.

Laminate damage analysis has been the subject of numerical model development based on rupture limit thresholds. Ludovic [23] has developed a fatigue damage model for laminates based on Degriek and Van Paepegem's (damage/failure limit) relationship, using Tsai Wu's failure criterion.

For delamination-type damage, several works have been devoted to the experimental investigation of delamination propagation criteria using tests on specimens with different types of loading (Benzeggagh et al. [24], Lachaud [25]). The work of Yong [26] and Xiaolin [27] showed a significant influence of fibre orientation on the propagation of delamination in laminates.

Macroscopically, the effect of temperature and humidity variation on laminated elements has been reported in several research works and has shown their great influence on the diffusion of water within composite materials at the macroscopic scale [28]. Padmavathi et al. [29] showed the dependence between the mass of water absorbed and the temperature variation.

The presence of humidity can have a detrimental effect on the behaviour of composite materials. For this, the work of Castaing [30], Shen and Springer [31], and Weitsman [32] focused on the hygroscopic aging of laminates, which induces a decrease in stiffness and stress at rupture on a macroscopic scale.

This study focuses on the development of analytical model for the analysis of the behaviour of a sandwich element with natural skins. The item in question has a stacking sequence $[-\emptyset / +\emptyset / \text{core} / +\emptyset / -\emptyset]$. The analytical model is based on the sandwich laminated plate theory (SLPT).

2. Materials and properties

2.1. Skin materials

Through this macromechanical analysis, different biomaterials were used for the skin part, based on PALF, Alfa, Jute and Palm natural fibres. Glass/epoxy is chosen for the traditional sandwich. All the material properties cited before are presented in in Table 1.

2.2. Core material

The APC-2 PEEK was selected as the core for the eco-sandwich composite based on the literature. These composites, manufactured by Cytec Engineered Materials, feature a thermoplastic polymer matrix referred to as PEEK. Characterized by a glass transition temperature of 143°C, this polymer exhibits a semi-crystalline nature. Owing to this semi-crystalline structure, the composites find suitability for applications with light loads, even at temperatures reaching up to 260°C. [33]. Table 1 presents the material properties of the APC-2 PEEK.

We note that: E , G and ν are the usual elastic modulus, shear modulus, Poisson's ratio; X , Y are tensile or compressive strengths (subscripts 't' and 'c').

Table 1 - Mechanical properties of the constituents [34].

Properties	E_x [MPa]	E_y [MPa]	ν_{xy}	G_{xy} [MPa]	X_t [MPa]	X_c [MPa]	Y_t [MPa]	Y_c [MPa]	SI [MPa]
Glass/Epoxy	40000	10000	0.32	4950	2000	750	60	160	200
Jute/Epoxy [35]	1250	5633	0.3395	7240	55	55	62	62	27.5
Palm/Epoxy	4153.6	4080.7	0.322	1351.6	—				
Alfa/Epoxy	5993	4721.4	0.348	1682.7					
PALF/Epoxy	7327	4888.7	0.343	1729.7					
Core APC-2 PEEK [33]	4100		0.41	2252.7					

3. Approach analysis

The macro-mechanical analysis examines how a section of the tubular sandwich structure behaves when subjected to biaxial loading, which simulates the internal pressure it encounters. Fig. 1 shows the stresses due to internal pressure in a cylindrical structure.

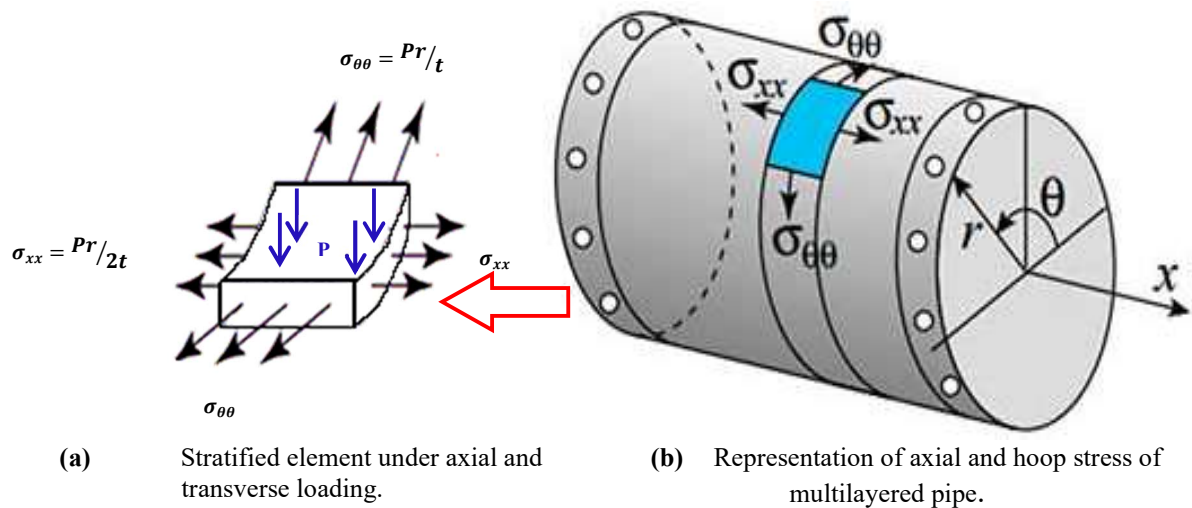


Fig. 1 - Macromechanical approach of multilayered tubular structure under pressure.

The geometric model used under Matlab software contained three main elements: the two skins (upper and lower skins) and the core as shown in schematic view (Fig. 2).

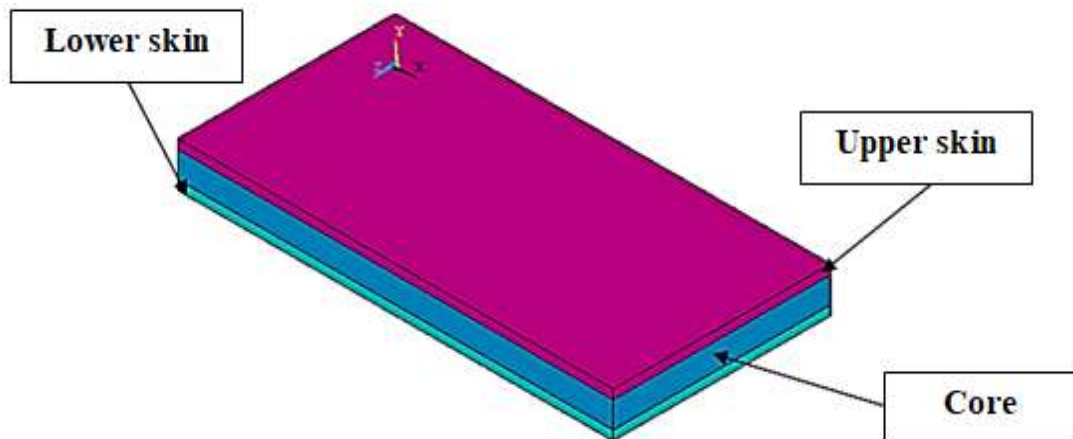


Fig. 2 - Geometrical model.

4. Macro scale analytical model

The theory of sandwich plates, with a focus on the elasticity of micro deformations, serves as the theoretical underpinning for the model developed in this investigation. This theory substantiates the following fundamental theories:

- The core's thickness significantly exceeds that of the skins: $h \gg h_1, h_2$, and it exclusively transmits transverse shear stresses σ_{xz} and σ_{yz} . And σ_{xz} and σ_{yz} .
- The skins neglect transverse shear stresses σ_{xx} , σ_{yy} , σ_{xy} and σ_{zz} .
- The displacements of the core, u_a and v_a , along the x and y directions respectively, are linear functions of the coordinate z .
- The displacements u and v along the x and y directions respectively are uniform throughout the thickness of the skins.

- The transverse displacement w is independent of the variable z the strain ε_{zz} is neglected.
- Lastly, the theory addresses elasticity problems under conditions of small deformations.

Fig. 3 gives an example of a Sandwich sample evaluations used in this study.

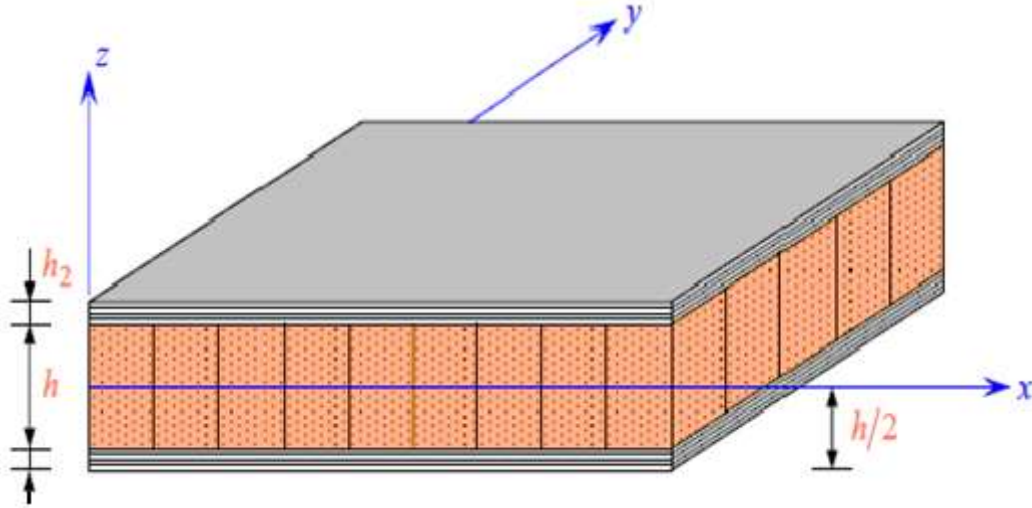


Fig. 3 - Sandwich sample evaluations [36].

In the classical theory of linear elasticity, the tensor representation of the generalized Hooke's law is given by the equation:

$$\sigma_{ij} = C_{ijkl} \cdot \varepsilon_{kl} \quad i, j, k, l=1,2,3 \quad (1)$$

The inverse form of this law can be expressed as follows:

$$\varepsilon_{ij} = S_{ijkl} \cdot \sigma_{kl} \quad i, j, k, l=1,2,3 \quad (2)$$

4.1. Expression of the strain field

The field of deformation in the upper and lower skins is written as:

$$\begin{bmatrix} \varepsilon_{xx}^1 \\ \varepsilon_{yy}^1 \\ \gamma_{xy}^1 \end{bmatrix} = \begin{bmatrix} \varepsilon_{xx}^0 \\ \varepsilon_{xy}^0 \\ \gamma_{xy}^0 \end{bmatrix} - \frac{h}{2} \begin{bmatrix} k_x \\ k_y \\ k_{xy} \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} \varepsilon_{xx}^2 \\ \varepsilon_{yy}^2 \\ \gamma_{xy}^2 \end{bmatrix} = \begin{bmatrix} \varepsilon_{xx}^0 \\ \varepsilon_{xy}^0 \\ \gamma_{xy}^0 \end{bmatrix} + \frac{h}{2} \begin{bmatrix} k_x \\ k_y \\ k_{xy} \end{bmatrix} \quad (4)$$

The strain field has the same writing as the strain field of the laminate theory with transverse shear. It is the superposition of two strain fields:

The field of strains in membrane-bending:

$$\begin{bmatrix} \varepsilon_{xx}^a \\ \varepsilon_{yy}^a \\ \gamma_{xy}^a \end{bmatrix} = \begin{bmatrix} \varepsilon_{xx}^0 \\ \varepsilon_{xy}^0 \\ \gamma_{xy}^0 \end{bmatrix} + z \begin{bmatrix} k_x \\ k_y \\ k_{xy} \end{bmatrix} \quad (5)$$

- The transverse shear deformation field :

$$\begin{bmatrix} \gamma_{yz}^a \\ \gamma_{xz}^a \end{bmatrix} = \begin{bmatrix} \frac{\partial \omega_0}{\partial y} + \varphi_y \\ \frac{\partial \omega_0}{\partial x} + \varphi_x \end{bmatrix} \quad (6)$$

4.2. Expression of the constraint field

The field of constraints within the core is derived from the hypothesis [36] :

$$\sigma_{xx}^a = \sigma_{yy}^a = \sigma_{xy}^a = \sigma_{zz}^a = 0 \quad (7)$$

Only shear stresses are transmitted via the core:

$$\begin{bmatrix} \sigma_{yz}^a \\ \sigma_{xz}^a \end{bmatrix} = \begin{bmatrix} C_{44}' & C_{45}' \\ C_{45}' & C_{55}' \end{bmatrix} \begin{bmatrix} \gamma_{yz}^a \\ \gamma_{xz}^a \end{bmatrix} \quad (8)$$

The following relationships are employed to derive the remaining stresses from the deformations of the skin:

$$\begin{bmatrix} \sigma_{xx}^K \\ \sigma_{yy}^K \\ \sigma_{xy}^K \end{bmatrix} = \begin{bmatrix} Q_{11}' & Q_{12}' & Q_{16}' \\ Q_{21}' & Q_{22}' & Q_{26}' \\ Q_{16}' & Q_{26}' & Q_{66}' \end{bmatrix} \begin{bmatrix} \varepsilon_{xx}^i \\ \varepsilon_{yy}^i \\ \varepsilon_{xy}^i \end{bmatrix}, i = 1, 2 \quad (9)$$

For the k-layer of the lower skin ($i=1$) or the upper skin ($i=2$).

4.3. Constitutive equation

The constituent equation of sandwich plates involves the results and moments already introduced in the stratified theory:

- membrane results:

$$\begin{bmatrix} N_x \\ N_y \\ N_{xy} \end{bmatrix} = \int_{-(h/2+h_1)}^{-h/2} \begin{bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{xy} \end{bmatrix} dz + \int_{h/2}^{-h/2+h_2} \begin{bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{xy} \end{bmatrix} dz \quad (10)$$

N_x, N_y, N_{xy} are the results per unit length, respectively, of the normal stresses according to x, y and of the shear stresses in the plane (x, y).

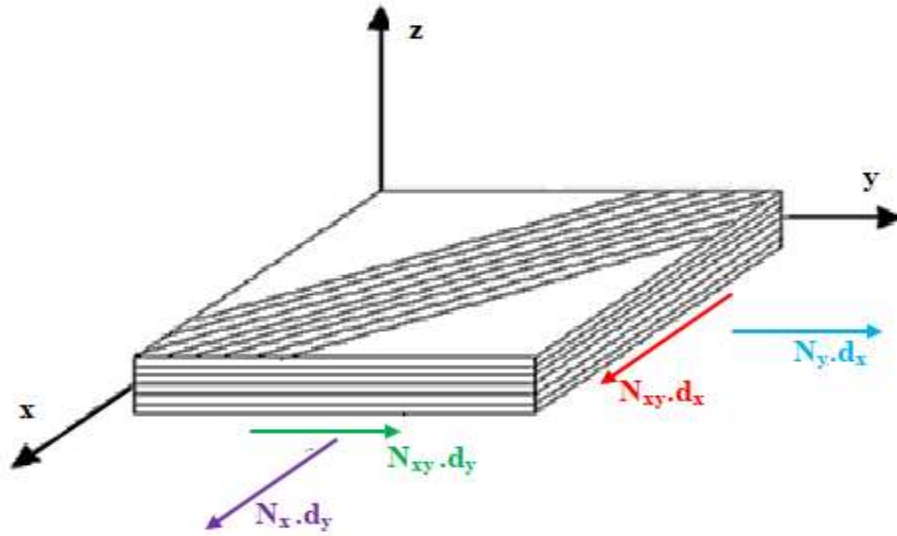


Fig. 4 - Membrane loading mode [37].

- Bending-torsional moments:

$$\begin{bmatrix} M_x \\ M_y \\ M_{xy} \end{bmatrix} = \int_{-(h/2+h_1)}^{-h/2} \begin{bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{xy} \end{bmatrix} z dz + \int_{h/2}^{h/2+h_2} \begin{bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{xy} \end{bmatrix} z dz \quad (11)$$

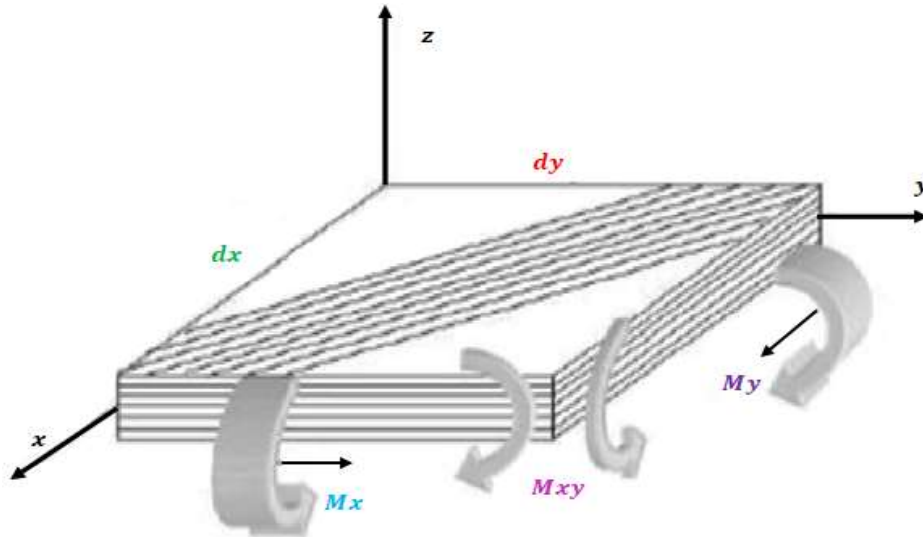


Fig.5 - Torsional bending loading mode [37].

- The shear results:

$$\begin{bmatrix} Q_y \\ Q_x \end{bmatrix} = \int_{-h/2}^{h/2} \begin{bmatrix} \sigma_{yz} \\ \sigma_{xz} \end{bmatrix} dz \quad (12)$$

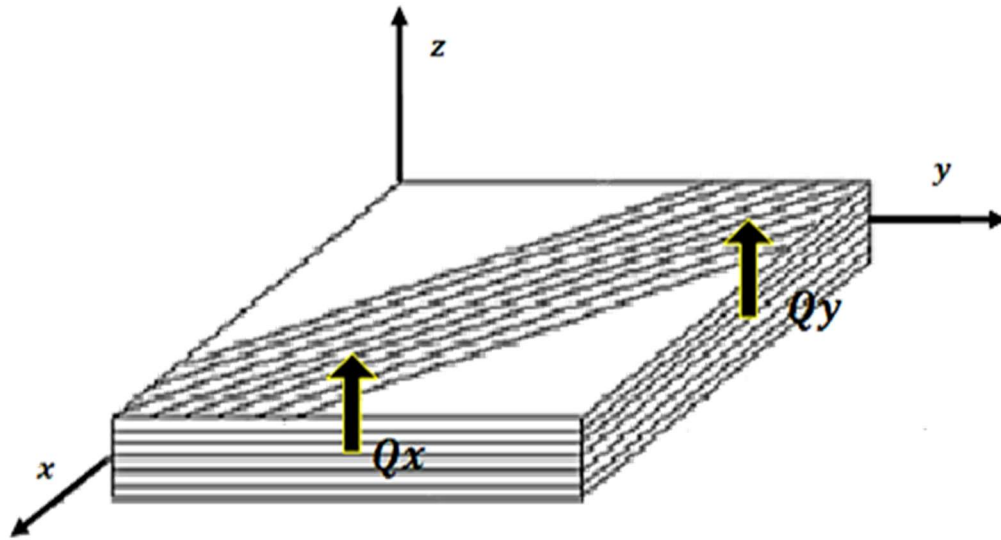


Fig.6 - Shear loading mode [37].

By substituting the expressions of the constraints (6) for (7) in the previous expressions of the resultants and moments, we obtain the constitutive equation:

$$\begin{bmatrix} N_x \\ N_y \\ N_{xy} \\ M_x \\ M_y \\ M_{xy} \\ Q_y \\ Q_x \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{16} & B_{11} & B_{12} & B_{16} & 0 & 0 \\ A_{21} & A_{22} & A_{26} & B_{21} & B_{22} & B_{26} & 0 & 0 \\ A_{61} & A_{62} & A_{66} & B_{61} & B_{62} & B_{66} & 0 & 0 \\ G_{11} & G_{12} & G_{16} & D_{11} & D_{12} & D_{16} & 0 & 0 \\ G_{21} & G_{22} & G_{26} & D_{21} & D_{22} & D_{26} & 0 & 0 \\ G_{61} & G_{62} & G_{66} & D_{61} & D_{62} & D_{66} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & F_{44} & F_{45} \\ 0 & 0 & 0 & 0 & 0 & 0 & F_{45} & F_{55} \end{bmatrix} \begin{bmatrix} \varepsilon_{xx}^0 \\ \varepsilon_{yy}^0 \\ \varepsilon_{xy}^0 \\ K_x \\ K_y \\ K_{xy} \\ \gamma_{yz}^0 \\ \gamma_{xz}^0 \end{bmatrix} \quad (13)$$

$$\begin{aligned} A_{ij} &= A_{ij}^1 + A_{ij}^2 \\ B_{ij} &= \frac{h}{2} (A_{ij}^2 + A_{ij}^1) \\ G_{ij} &= G_{ij}^1 + G_{ij}^2 \\ D_{ij} &= \frac{h}{2} (G_{ij}^2 - G_{ij}^1) \end{aligned} \quad (14)$$

Where:

$$\begin{aligned} A_{ij}^1 &= \int_{-(h/2+h_1)}^{-h/2} (Q'_{ij})_k dz = \sum_{K=1}^{n_1} \int_{h_{k-1}}^{h_1} (Q'_{ij})_k dz = \sum_{K=1}^{n_1} (Q'_{ij})_k e_k \\ G_{ij}^1 &= \int_{-(h/2+h_1)}^{-h/2} Z(Q'_{ij})_k dz = \sum_{k=1}^{n_1} \int_{h_{k-1}}^{h_1} Z(Q'_{ij})_k dz = \sum_{k=1}^{n_2} (Q'_{ij})_k e_k Z_k \end{aligned} \quad (15)$$

$$\begin{aligned}
 A_{ij}^2 &= \int_{h/2}^{h/2+h_2} (Q'_{ij})_k dz = \sum_{k=1}^{n_2} \int_{h_{k-1}}^{h_1} (Q'_{ij})_k dz = \sum_{k=1}^{n_2} (Q'_{ij})_k e_k \\
 G_{ij}^2 &= \int_{h/2}^{h/2+h_2} Z(Q'_{ij})_k dz = \sum_{k=1}^{n_2} \int_{h_{k-1}}^{h_1} Z(Q'_{ij})_k dz = \sum_{k=1}^{n_2} (Q'_{ij})_k e_k Z_k \\
 F_{ij}^2 &= h.C_{ij}'^a
 \end{aligned}$$

In the preceding expressions of the stiffness coefficients: n_1 and n_2 represent the numbers of layers in the lower skin and the upper skin respectively, while $C_{ij}'^a$ are the coefficients related to the transverse shear of the core.

The constitutive equation has a similar form to the equation obtained in the case of laminated theory with transverse shear. However, it differs by the inclusion of the terms G_{ij} , which introduce an asymmetry in the stiffness matrix.

4.4. Failure criteria

In this part, we investigate skin failure using the Tsai-Wu failure criterion and isotropic core failure using the von Mises yield criterion. They are linked to Cartesian coordinates through the transformation matrix:

$$\begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \tau_{23} \\ \tau_{13} \\ \tau_{12} \end{bmatrix} = \begin{bmatrix} m^2 & n^2 & 0 & 0 & 0 & 2mn \\ n^2 & m^2 & 0 & 0 & 0 & -2mn \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & m & -n & 0 \\ 0 & 0 & 0 & n & m & 0 \\ -mn & mn & 0 & 0 & 0 & m^2 - n^2 \end{bmatrix} \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \\ \tau_{yz} \\ \tau_{xz} \\ \tau_{xy} \end{Bmatrix} \quad (16)$$

Where: $m = \cos \emptyset$ and $n = \sin \emptyset$; $\emptyset$ is the fiber angle with respect to the cylindrical axial direction.

The criterion of Tsai-Wu [38] in plane stresses is written as:

$$\left(\frac{1}{X_t} - \frac{1}{X_c} \right) \times \sigma_L + \left(\frac{1}{Y_t} - \frac{1}{Y_c} \right) \times \sigma_T + \frac{\sigma_L^2}{X_t X_c} + \frac{\sigma_T^2}{Y_t Y_c} + \frac{\sigma_{LT}^2}{S_{LT}^2} - \frac{\sigma_L \times \sigma_T}{X_t X_c} \quad (17)$$

Circumferential stress:

$$\sigma_\theta = pr/t \quad (18)$$

Axial stress:

$$\sigma_x = pr/2t \quad (19)$$

With:

$$\sigma_\theta = 2\sigma_x \quad (20)$$

5. Results and discussions

In this section, the results of the analytical models developed are presented and thoroughly discussed.

The symmetrical configuration of the sandwich influenced the magnitude of the stresses and strains, which is similar to that of laminate behavior due to the similarity of the constitutive equations between the two theories for this type of stacking.

5.1. Stress analysis in Plate plan x-y

The distribution of axial σ_{xx} and transversal σ_{yy} stresses across the thickness of the sandwich element for a composite made of Glass/epoxy synthetic fibres and biocomposites is illustrated in Fig. 7 and Fig. 8. Fig. 9 illustrates the symmetrical shear stress σ_{xy} distribution across the thickness of the sandwich elements, with the core part neglected.

As a general remark, material properties play a crucial role in the response of stratified plates to bi-axial loading. The intensity of transverse stress is more significant than axial stress and translates to hoop stress in the case of a tubular pipe.

The results of the axial σ_{xx} and transversal σ_{yy} stresses of the stratified biosandwich reveal a discontinuity of stress between the skins and the core component.

The stress distribution reflects the conditions imposed by the theory of sandwich plates, where the axial, transverse, and shear stresses are zero in the core part. The magnitude of the transverse stresses is twice the magnitude of the axial stresses, aligning perfectly with the distribution of axial and circumferential stresses observed in a pressurized tube.

The primary observations drawn from the stress distributions across the thickness of the sandwich plate can be summarized as follows:

- The stress distribution is nearly symmetrical with respect to the mid-plane.
- The effect of stacking sequence is almost negligible for palm and Alfa fiber-based materials.
- The magnitudes of axial σ_{xx} , transverse σ_{yy} , and shear σ_{xy} stresses are higher for the Jute/epoxy, Glass/epoxy, and PALF/epoxy materials compared to the other two materials, Alfa/epoxy and Palm/epoxy.
- Access to data regarding tensile, compressive, and shear rupture limits is essential for determining the rigidity of each material analyzed during this macromechanical approach.
- Due to the significant magnitude of the shear modulus, the Jute/epoxy material exhibits a different behavior compared to the materials treated during the distribution of axial and shear stresses.
- It is observed that the second layer of the lower skin and the first layer of the upper skin record higher stresses compared to the other layers.
- The increase in pressure within the composite tube can lead to the initiation of micro cracks at the levels of the most stressed layers.

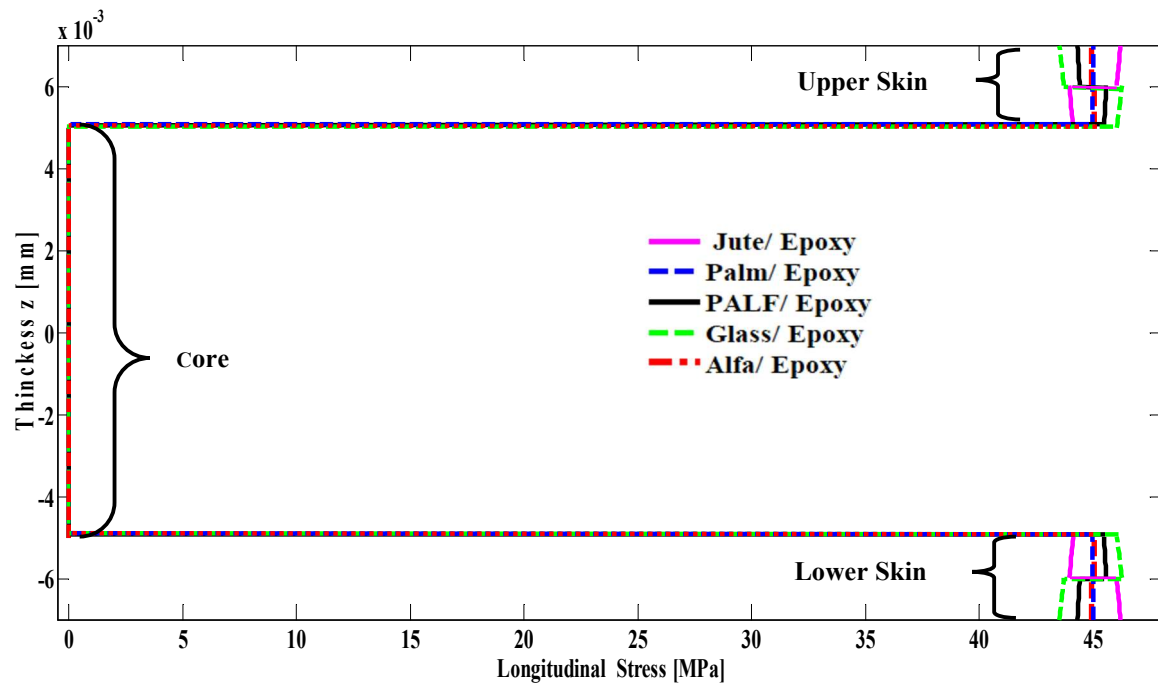


Fig. 7 - Variation of axial stress across the thickness of the sandwich for five bi-directional types of layering materials.

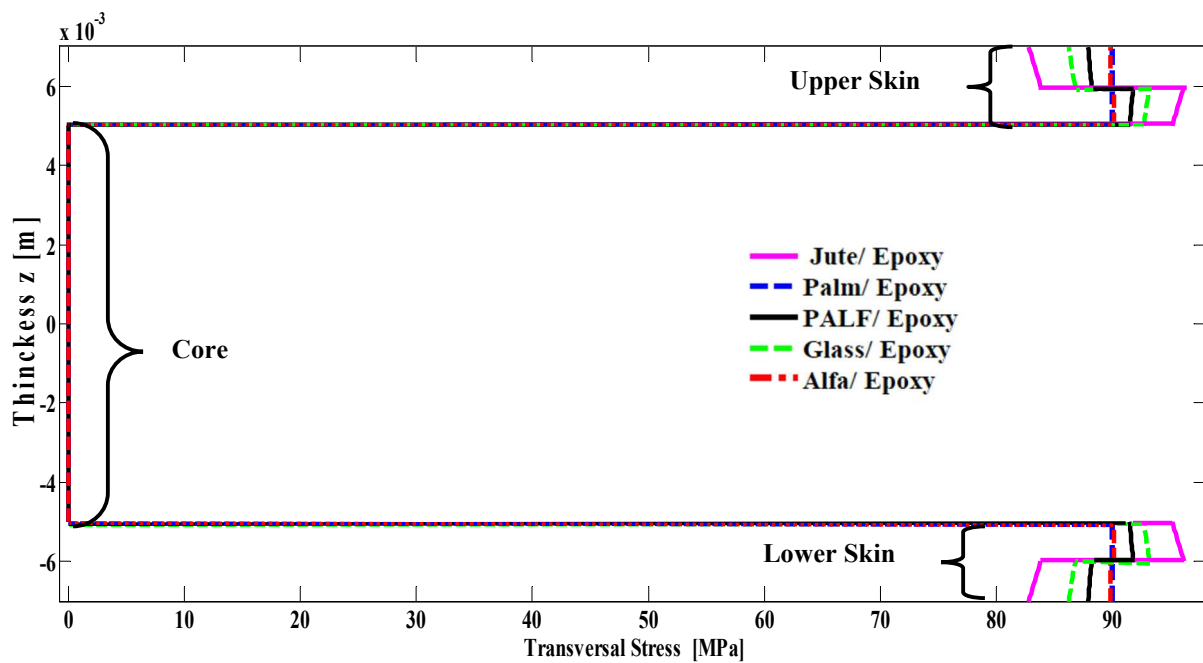


Fig. 8 - Variation of transversal stress across the thickness of the sandwich for five bi-directional types of layering materials.

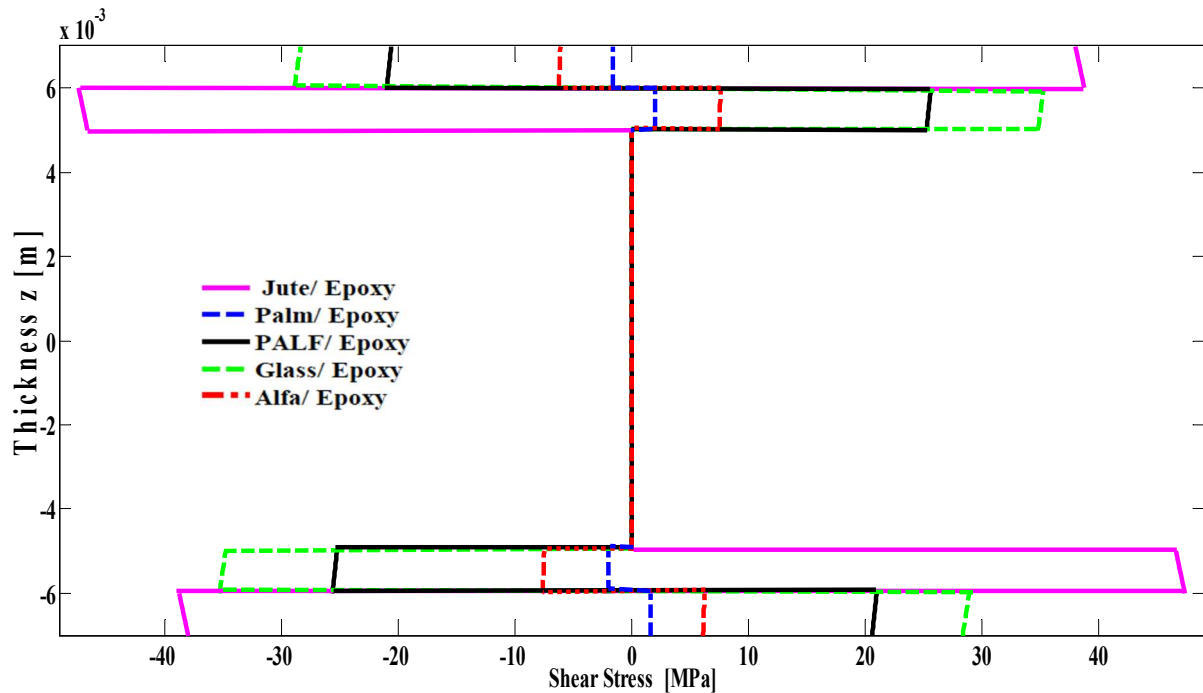


Fig. 9 - Variation of shear stress across sandwich thickness for five bi-directional laminated materials.

5.2. Stress analysis in the fibers plane L-T

The distribution of stresses in the fiber plane through the thickness of the sandwich panel is depicted in Fig. 10, Fig. 11, and Fig. 12 for two materials: synthetic Glass/epoxy and biocomposite Jute/epoxy. The mechanical properties directly influence the magnitude of the longitudinal σ_L , transverse σ_T and shear τ_{LT} stresses.

In the longitudinal direction within the fiber plane, Glass/epoxy is more sensitive to bidirectional loading applied to the sandwich panel compared to Jute/epoxy. It is observed that the ultimate tensile strength in the longitudinal direction is approximately 2000 MPa for Glass/epoxy and 55 MPa for Jute/epoxy (refer to Table 1). The stress magnitudes obtained and depicted in Fig. 10 show that any increase in pressure can be detrimental to Jute/epoxy, based on the maximum stress criterion.

For the distribution of transverse stresses, shown in Fig. 11, Jute/epoxy is characterized by a stress magnitude of around 98 MPa within the surface layers, potentially leading to damage initiation, given that the ultimate tensile strength in the transverse direction Y_t is approximately 62 MPa. On the other hand, Glass/epoxy is found in a safety zone in the transverse direction.

For the distribution of shear stresses, Jute/epoxy records a stress magnitude of around 45 MPa, which exceeds its S_I shear limit estimated at 27.5 MPa, thereby leading to damage. Conversely, the Glass/Epoxy composite provides more security for the plate under such biaxial loading conditions, with a shear rupture limit of 200 MPa.

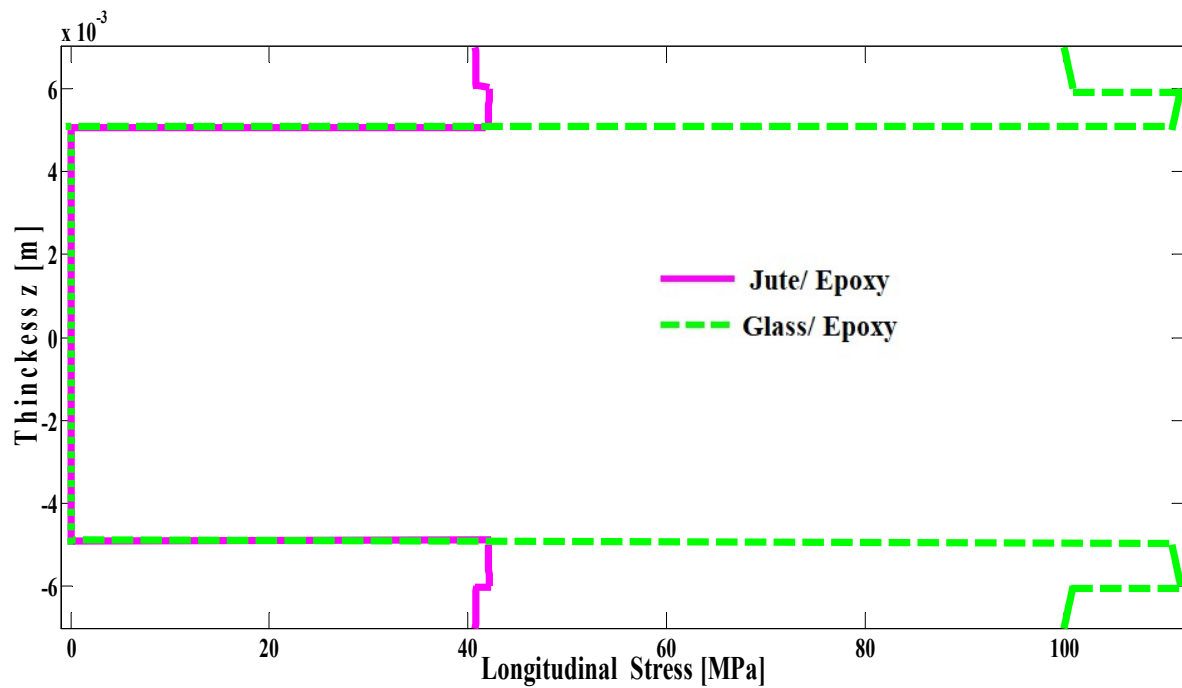


Fig. 10 - Variation of longitudinal stress σ_L within the fiber plane across the thickness of the sandwich.

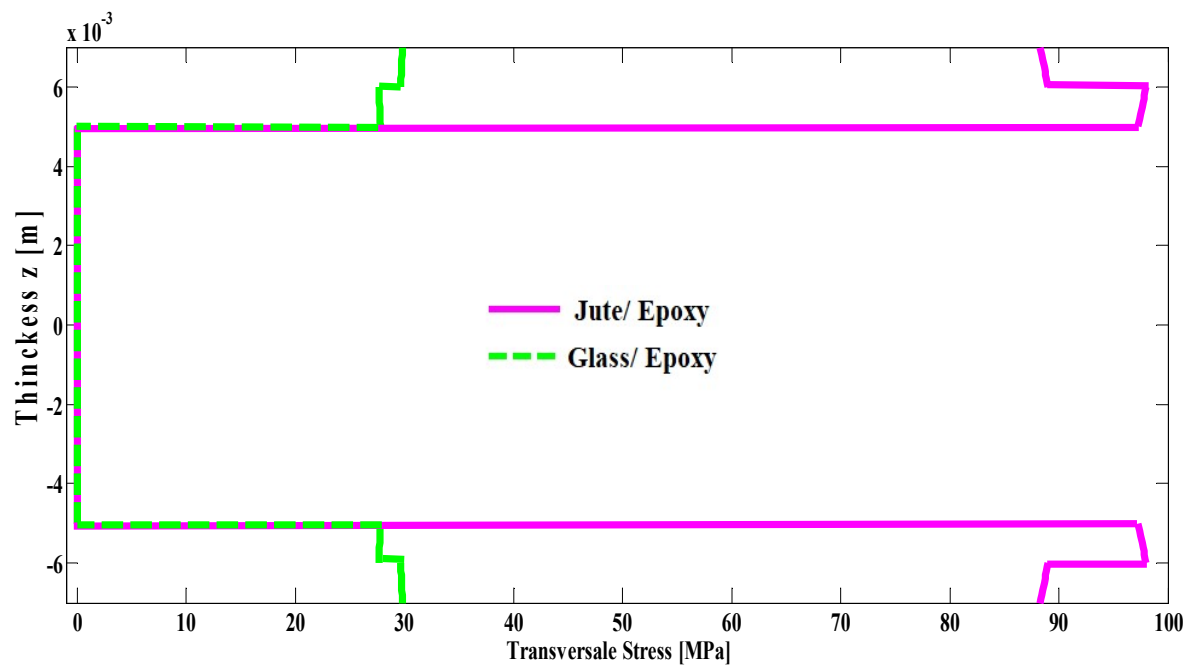


Fig. 11 - Variation of transverse stress σ_T within the fiber plane across the thickness of the sandwich.

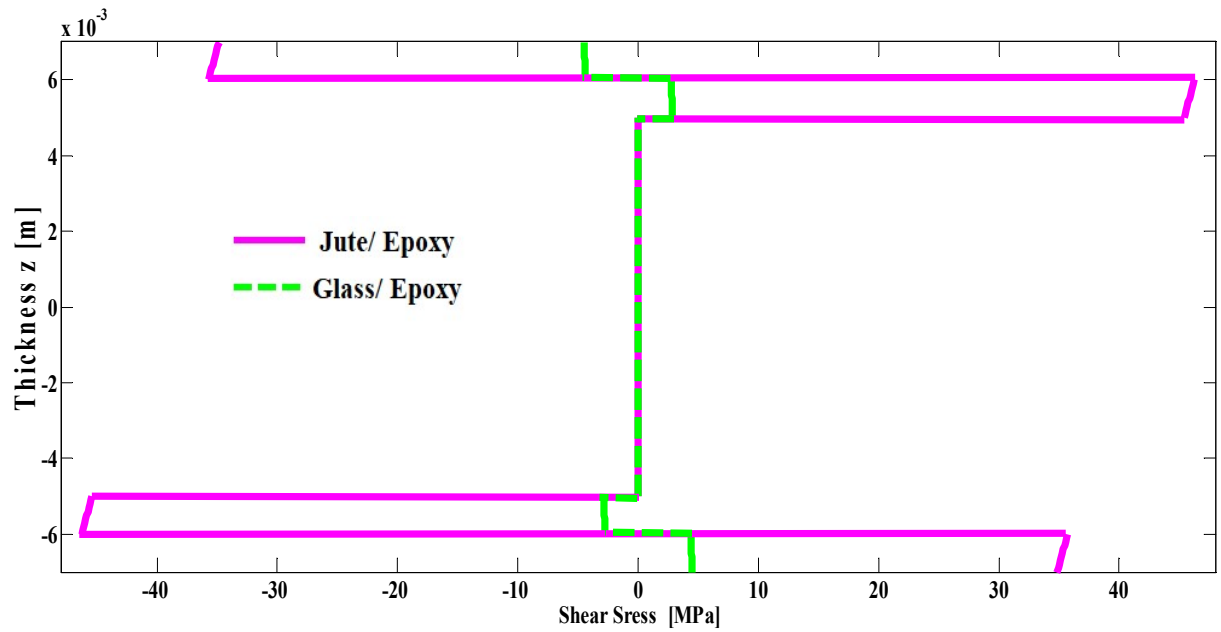


Fig. 12 - Variation of shear stress τ_{LT} within the fiber plane across the thickness of the sandwich.

5.3. Failure analysis

Due to a lack of data, the failure analysis was limited to only two materials: the synthetic Glass/Epoxy and the biocomposite Jute/Epoxy. Fig. 13 presents the variation of the TSAI-WU criterion as a function of the increment of the internal pressure. The latter is represented by the axial and transverse stresses applied to the sandwich plate sample.

Both trends accurately represent the rigidity of each material. To reduce the gap, which is evaluated at 78.87%, and enhance the stiffness of the biocomposite, it is essential to simultaneously increase the number of layers in both the lower and upper skins.

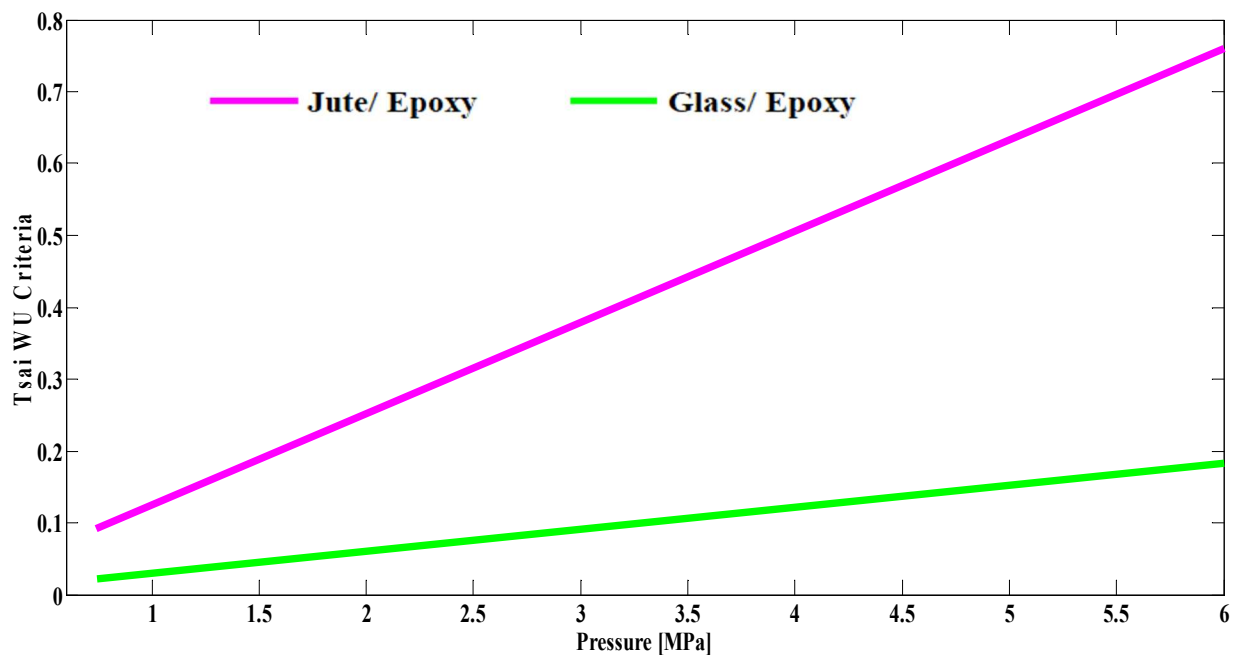


Fig. 13 - Variation of Tsai Wu criteria regarding pressure for skin components.

6. Conclusion

- The aim of the macromechanical analysis is to understand the response of a tubular structure's sandwich element under pressure by developing an analytical model for evaluating the distribution of stress through the thickness of the sandwich plate, considering a stacking sequence configuration of: $[+\emptyset / -\emptyset / \text{core} / +\emptyset / -\emptyset]$.
- This analysis includes a comparison between natural and synthetic fiber composite layers for both inner and outer skins.
- The magnitudes of the forces applied to the sandwich plate reflect the internal pressure loading of the sandwich tubular structure.
- The macromechanical analysis helps locate the layer of the lower or upper skin that is most stressed, enabling a failure analysis and suggesting reinforcement solutions.
- The obtained results have demonstrated the influence of mechanical properties on the behavior of composite sandwiches based on synthetic or natural fibers.
- Limiting the loading pressure is essential in order to avoid any scenario of creating micro cracks, which can lead to the ruin of the sandwich skins.
- Based on failure analysis, it is essential to simultaneously increase the number of layers in both the lower and upper skins to reduce the gap between the synthetic and biocomposite materials, which is evaluated at 78.87%, in order to enhance the stiffness of the biocomposite.

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