Prediction of Stress-Strain Field and Safety Factor of a Hybrid Composite Material

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Abstract. In this work, the stress-strain field is estimated through the application of classical laminate theory. The composite material studied is a hybrid composite made from plant fibers and synthetic fibers. The law of mixtures was used, to identify, the elastic properties of the studied hybrid composite materials. The effect of fiber orientation on the mechanical behavior of the composite material is analyzed. It should be noted that the orientation is a significant parameter affecting the amplification of the stress and strain field in the material and consequently on the safety and integrity of the structure.

1. Introduction

The use of composite materials in the manufacture of components or systems, whether in the high-tech or leisure sector, has become the main concern of manufacturers. These materials can be used in several fields such as aeronautics and military applications, civil engineering, textile industry, chemical industry, and even medicine [1, 2]. In addition, it is very interesting to know that for example with using composite materials to repairs of steel corroded structure such as water network piping, and hydrocarbon pipelines, is quick and effective [3-5], because this big threats of corrosion decrease the remaining strength and the reliability of steel structures, and the routine maintenance using composite materials will help to preserve their remaining life [6-13]. This particular interest to the composites materials is mainly due to the lower manufacturing cost of the products without at the expense of the desired quality, following their excellent stiffness-to-weight ratio accompanied by good corrosion resistance and good resistance to fatigue. The combination of mechanical properties superior to that of conventional composite materials is ensured by the use of hybrid composites materials. This type of composites offers a combination of properties such as tensile modulus, compressive strength and impact resistance, which are beyond the reach. The fibers used as reinforcement in a composite material will withstand the various stresses that the structure will undergo, while the matrix will ensure the transfer of these loads. The use of natural fibers, for the development of hybrid composite materials as an alternative to glass fibers, has become the concern of industrialists, because their production is based on local resources, and in most cases abundant with combined advantages, economic and ecological [14-21].
2. Stress-Strain filed

The geometric model used is a hybrid composite material composed of 20 layers, and the thickness of each layer is 1 mm. The three geometric configurations are chosen as follows: (0° / 0°)_10, (-45° / 45°)_10, and (60° / 60°)_10. The composite material plate used is subjected to a load equal to 1000 N, in the x direction and the y direction. A MATLAB script has been developed to estimate the stresses and strains developed in the xx and yy directions, and in the plane xy of the composite plate, and these are illustrated in Figures 1, 2, 3, 4, 5, and 6.

![Figure 1. Stress evolving in a hybrid composite of 20 plies for the first configuration.](image-url)
Figure 2. Strain evolving in a hybrid composite of 20 plies for the first configuration.

Figure 3. Stress evolving in a hybrid composite of 20 plies for the second configuration.
Figure 4. Strain evolving in a hybrid composite of 20 plies for the second configuration.

Figure 5. Stress evolving in a hybrid composite of 20 plies for the third configuration.
Figure 6. Strain evolving in a hybrid composite of 20 plies for the third configuration.

3. **Stiffness matrix**

For the three configuration, the reduced stiffness matrix NM are assessed based on the classical laminate theory.

3.1. **Configuration (-0\(^\circ/0\)^\(_\circ\))**

NM =

\[
\begin{bmatrix}
0.1126 & 0.0092 & 0 & 0 & 0 & 0 \\
0.0092 & 0.0327 & 0 & 0 & 0 & 0 \\
0 & 0 & 0.0152 & 0 & 0 & 0 \\
0 & 0 & 0 & 3.7522 & 0.3056 & 0 \\
0 & 0 & 0 & 0.3056 & 1.0916 & 0 \\
0 & 0 & 0 & 0 & 0.5067 & 0
\end{bmatrix}
\]

3.2. **Configuration (-45\(^\circ/45\)^\(_\circ\))**

NM =

\[
\begin{bmatrix}
0.0561 & 0.0257 & 0 & 0 & 0 & 0.0100 \\
0.0257 & 0.0561 & 0 & 0 & 0 & 0.0100 \\
0 & 0 & 0.0317 & 0.0100 & 0.0100 & 0.0000 \\
0 & 0 & 0.0100 & 1.8704 & 0.8571 & 0 \\
0 & 0 & 0.0100 & 0.8571 & 1.8704 & 0 \\
0.0100 & 0.0100 & 0 & 0 & 0 & 1.0581
\end{bmatrix}
\]
3.3. Configuration (-60°/60°)_{10}

NM = 

\[
\begin{array}{cccccc}
0.0403 & 0.0216 & 0 & 0 & 0 & 0.0051 \\
0.0216 & 0.0802 & 0 & 0 & 0 & 0.0122 \\
0 & 0 & 0.0276 & 0.0051 & 0.0122 & 0.0000 \\
0 & 0 & 0.0051 & 1.3431 & 0.7192 & 0 \\
0 & 0 & 0.0122 & 0.7192 & 2.6735 & 0 \\
0.0051 & 0.0122 & 0 & 0 & 0 & 0.9203 \\
\end{array}
\]

4. Security factor assessment

In this section, the security factor estimation is based on the Tsai-Wu failure criterion. When the composite structure of each configuration is loaded to a fixed tensile load in the axial, and the transverse directions, the integrity of the composite is affected. For example, if the material is loaded only in the axial direction with the same force (1000 N); the security factor is equal to 30. If the material is loaded in the axial and the transverse directions, the security factor is fell to 0.807, Figure 7.

Figure 7, 8, and 9 illustrates the evolving of the security factor estimation on the top and bottom of each layer of the hybrid composite, for the three configurations (0° / 0°)_{10}, (-45° / +45°)_{10} and (-60° / +60°)_{10}.

![Figure 7](image)

**Figure 7.** Security factor evolving in a hybrid composite of 20 plies for the first configuration.
Figure 8. Security factor evolving in a hybrid composite of 20 plies for the Second configuration.

Figure 9. Security factor evolving in a hybrid composite of 20 plies for the Third configuration.
5. Conclusion

- For the loading along the x-axis and the y-axis, the longitudinal and transverse stresses are equivalent for the configuration $(0^\circ / 0^\circ)_{10}$, and the shear stresses are zero.
- For the second configuration, the maximum longitudinal stress is 80 MPa, while the weakest stress in this direction is 69 MPa.
- In the transverse direction, the developed stresses are in the range of 24-27 MPa. In this direction, the shear stresses are negligible.
- For the third configuration, the maximum longitudinal stress is worth varies between 62 MPa and 71 MPa.
- The configuration: $(0^\circ / 0^\circ)_{10}$, represents the worst case, with the lowest safety coefficient, equal to 0.8. While the second configuration $(45^\circ / 45^\circ)_{10}$, is the most secure structure with a safety coefficient varying from 1.51 - 1.67. For configuration $(60^\circ / 60^\circ)_{10}$, the safety factor is within the range of 1.14 - 1.21.

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