Simulation of CoFRP analytical and computational model for various fiber volume fraction and Investigation of the local stresses for different fiber orientation angle

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Abstract. Present work provides a numerical tool for analyzing the variation of failure strength of Coir Fiber Reinforced Polymer (CoFRP) with respect to Fiber Volume Fraction (FVF) and Fiber Orientation Angle (FOA). A model has been developed for analyzing the failure strength of CoFRP. It is analyzed for various fiber orientation angle and fiber volume fraction. Failure strength of the CoFRP depends upon both FVF and FOA. In this analysis, it has been investigated that the analytical results for CoFRP lamina are very close to computational results. Finite element analysis scores over the experimental tests as it is more convenient and economical method of analysis. Therefore, this method is more suitable for future work.

1. Introduction

Nowadays, Natural Fiber Reinforced Polymers are extensively used in structures in engineering and industrial applications which are subjected to loads. Natural Fiber Reinforced Polymer consists of two phases i.e. natural fiber and epoxy. In this investigation process, coir fiber is used as a reinforcement phase and epoxy as a protection and binding phase. Coir fiber and epoxy phase are not soluble in each other. All the CoFRP have behavior like orthotropic materials and have nine independent elastic constants i.e. three modulus of elasticity, three modulus of rigidity and three Poisson's ratio. Orthotropic materials have the maximum and minimum load carrying capacity in the longitudinal and transverse direction respectively [1]. The variation of failure strength has been determined through coding in both, MATLAB and ANSYS.

Mathematical equations and their curve are solved by generating a code with the help of MATLAB numerical tool. In current analysis micro-mechanics of lamina is used for computing the failure strength of CoFRP.

Different types of modelling and thermal analysis on the basis of their dimensions and boundary conditions are done by ANSYS which works on finite elements method [3].

The macro-mechanical analysis of fiber oriented lamina, independent from separate properties of fiber and matrix, is performed by considering lamina as a homogeneous and orthotropic composite material [4, 5].
2. Material and Model

The elastic constants and failure strength of Coir Fiber and Epoxy are shown in Table 1.

**Table 1. Material properties of natural fiber and epoxy**

|          | Coir | Epoxy |
|----------|------|-------|
| E(GPa)   | 5.00 | 3.45  |
| Nu       | 0.30 | 0.35  |
| Sy(MPa)  | 16.00|       |
| Su(MPa)  | 175.0| 24.00 |
| ET(GPa)  | 0.28 |       |
| G(GPa)   | 1.92 | 1.28  |

In the present simulation a model has been developed for the CoFRP. For the analysis of failure strength, the fiber volume fraction and the fiber orientation of lamina are taken from 30% to 70% and from 0° to 90° respectively. Lamina is fixed at the center. All degrees of freedom are zero at the center. Pressure is applied at the edge of the Natural Fiber Reinforced Polymer.

3. Previous Works

Nirbhay et al. (2014) determined the failure load for laminated composite under tensile loading. In this simulation the analysis of failure stresses of laminated composite has been carried out using ABAQUS [6].

Rahmani et al. (2015) developed a mathematical technique to investigate the elastic constants of carbon fiber reinforced polymer laminates. For this purpose, a mathematical code was developed in MATLAB i.e. MATLAB calculation code (MCC). This code provides sufficient compatibility to analyze mechanical behavior of the composite material. The code in MATLAB uses various orientation angles of the fiber which makes it possible to analyze the volume fraction for a wide variety of fibers under mechanical load [7].

Maheshwari et al. (2018) also predicted the variation of elastic constants and stress of JFRP with fiber volume fraction and fiber orientation angle [8].

4. Methods

4.1. Macromechanical analysis for a lamina

A unidirectional lamina can be analyzed as an orthotropic material. It has nine independent constants.

4.1.1 Hook’s law for 2-D lamina

A local co-ordinate system is used for generating stress-strain relationship. Two different axes of lamina, one along the direction of fibers and second perpendicular to the fibers are known as local longitudinal and local transverse axes respectively. In Figure 1, global axes and local axes or material axes are shown by X-Y and 1-2 respectively [3].

4.1.2 Simulation of CoFRP lamina

Many FEM software are available for analysis such as ANSYS, ABAQUS, NASTRAN, FORTRAN etc. The simulation of CoFRP lamina has been done through ANSYS finite element analysis [5,8].

Finite element analysis requires these basic steps: pre-processing, processing and post-processing. In the first step the elastic properties, strength properties, lamina properties, geometry of lamina, meshing, boundary and loading conditions are defined. In processing step, ANSYS analyzes...
the conditions and solves the problem whereas results in terms of stress-strain distribution and failure strength or load are rendered in the post-processing step [2].

Figure 1. Local and global axes

5. Results and Discussion

In the current macro-mechanical analysis of lamina, failure strengths of CoFRP are determined through two ways. Firstly, writing code in MATLAB and secondly computed using ANSYS software, then compared both results.

Figure 2 shows the variation of stresses in X, Y-direction (tensile) and XY plane (shear) with fiber volume fraction. The stress in longitudinal direction has higher value as compared to that in the transverse direction of lamina. Both, stress and shear strength, have linear variation with the fiber volume fraction and increase in stresses and shear strength is detected with the increment in fiber volume fraction.

Figure 2. Plot of Stresses vs FVF

5.1 Macro-mechanical Analysis of CoFRP

When orientation of fibers and loading direction was different, then CoFRP strength known as off-axis strength has been calculated.
Computational method, analytical method, theories of failure based on ANSYS, stress-strain relationship and MATLAB respectively have been used for calculated off-axis strength value of lamina and after that both the results are compared with each other.

5.2 Analysis of CoFRP at 50% fiber volume fraction

MATLAB program and ANSYS analysis has been used to calculate the failure strength and local stress value of lamina [8].

5.2.1 Comparison of computational (ANSYS) results and analytical (MATLAB) results

The comparison between failure strength values for lamina obtained from computational and analytical analysis presented in Figure 3 and are found to be in very good agreement with each other.

Figure 3 shows the best optimum failure strength comparison results which obtained from lamina analysis by ANSYS.

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**Figure 3.** Comparison of computational (ANSYS) and analytical (MATLAB) results

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**Figure 4.** Plot of local stress vs FOA
Figure 4 shows local stress variation with FOA. Increment of FOA in positive or negative direction decreased the value of failure strength in 1-direction. At ± 90° stress has been shown minimum value i.e. zero. Where as in 2-direction, Increment of FOA increased failure strength. It has maximum value at ±90°. Shear failure strength in plane12 has minimum value at 0° and ±90°. The value of shear failure strength in plane12 increases up to -45° and after that decreases. Shear failure strength in plane12 has maximum value at -45°.

Figure 5 shows local strain variation with FOA. Increment of FOA in positive or negative direction decreased the value of strain in 1-direction. At ± 90° strain has been shown minimum value i.e. zero. Where as in 2-direction, Increment of FOA increased strain. It has maximum value at ±90°. Strain in plane12 has minimum value at 0° and ±90°. The value of strain in plane12 increases up to -45° and after that decreases. Strain in plane1-2 has maximum value at -45°.

![Figure 5. Plot of local strain vs FOA](image)

6. Conclusion

In this study, the variation of stresses with fiber volume fraction has been determined. CoFRP has maximum longitudinal failure strength and lesser transverse failure strength. The determination of CoFRP is simulated using finite element analysis software ANSYS. Shell model was developed and analysis of the model was carried out as per given boundary conditions. Shell model was examined and the obtained results through ANSYS were in good agreement with the analytic results. Local stress and strain variation has been analyzed for CoFRP. Therefore analysis of the composite structure can be conveniently done with finite element method.

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