Fatigue Analysis of Composite Material Component Using Fem

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Abstract—**Composite materials are widely used in aerospace, automotive, and structural engineering applications because of their high strength-to-weight ratio and durability. However, understanding their fatigue behavior under repeated cyclic loading is essential for ensuring structural reliability and safety. This study investigates the fatigue performance of composite material components using Computer-Aided Design (CAD), Finite Element Method (FEM), and Artificial Intelligence (AI)-based predictive techniques. Finite element analysis is performed in ANSYS to evaluate stress distribution, deformation characteristics, and fatigue life under varying loading conditions. Fatigue assessment is carried out using S-N curve analysis, while AI models are employed to enhance prediction accuracy and reduce computational effort. The results indicate that composite materials exhibit superior fatigue resistance compared to conventional materials, although failure mechanisms vary with stress levels and loading conditions. The integration of FEM and AI improves the efficiency of fatigue life prediction and supports the optimization of composite component design. The study contributes to the development of reliable, lightweight, and high-performance composite structures for advanced engineering applications.**

Index Terms—**Composite Materials, Fatigue Analysis, Finite Element Method (FEM), ANSYS, Artificial Intelligence (AI), S-N Curve, CAD/CAM.**

I. INTRODUCTION

Composite materials have become increasingly important in modern engineering due to their excellent strength-to-weight ratio, corrosion resistance, and durability [1]. These materials are widely utilized in aerospace, automotive, marine, and structural applications where lightweight and high-performance components are required. Despite their advantages, composite structures are often subjected to repeated loading conditions that can lead to fatigue damage over time [3]. Understanding fatigue behavior is therefore essential for improving structural safety and service life. Advanced technologies such as Computer-Aided Design (CAD), Finite Element Method (FEM), and Artificial Intelligence (AI) provide effective tools for analyzing fatigue performance, predicting failures, and optimizing composite material designs for enhanced reliability and efficiency [8].

II. LITERATURE REVIEW

Kumar and Sharma (2021) investigated the fatigue performance of Carbon Fiber Reinforced Polymer (CFRP) composites under cyclic loading conditions. The study employed finite element analysis and experimental testing to evaluate stress distribution and fatigue life. The findings revealed that CFRP composites exhibit superior fatigue resistance compared to conventional metallic materials due to their high stiffness and lightweight characteristics.

Patel et al. (2022) examined the application of Finite Element Method (FEM) in predicting the fatigue behavior of composite structures used in aerospace and automotive industries. Using ANSYS software, the researchers analyzed deformation patterns, stress concentrations, and fatigue damage under varying load conditions. The results demonstrated that FEM is an

effective and economical tool for evaluating structural performance without extensive physical testing.
Reddy and Rao (2023) explored the integration of Artificial Intelligence (AI) techniques with finite element simulation data for fatigue life prediction of composite materials. Machine learning models, including Random Forest and Artificial Neural Networks, were trained using stress and fatigue datasets generated through simulations.

III. METHODOLOGY

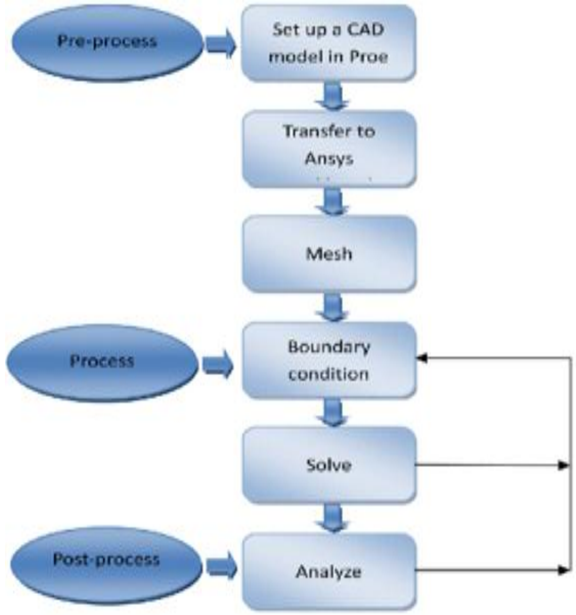
3.1 CAD modeling
This chapter delves into the materials, design methodology, and simulation methodologies that were used to conduct fatigue study of composite material components using the Finite Element Method (FEM). In order to accurately anticipate the fatigue life, this study integrates computer-aided design (CAD) modeling, finite element method (FEM) simulation, and artificial intelligence (AI). Selection of materials, production of geometries, meshing, description of boundary conditions, study of fatigue, and prediction based on artificial intelligence forms the process.

3.2 Material Selection

Table 3.1 Properties of Carbon Fiber Composite

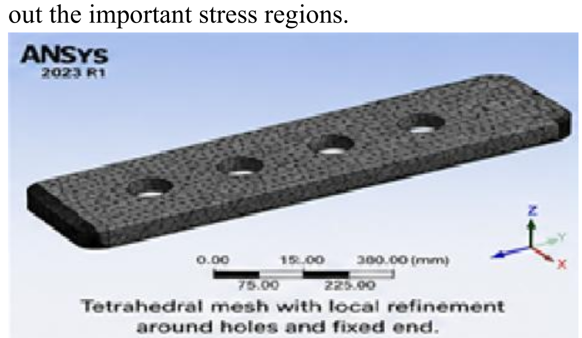
Property	Value	Unit
Density	1600	kg/m³
Young's Modulus (E_1)	135	GPa
Young's Modulus (E_2)	10	GPa
Poisson's Ratio	0.3	–
Tensile Strength	1500	MPa

3.3 FEM Methodology
Figure 3.1: Flow Chart of Finite Element Methodology for Fatigue Analysis of Composite Material Component



IV. FINITE ELEMENT MODELING AND ANALYSIS

This chapter describes the fatigue analysis and finite element modeling of composite material component using ANSYS software. The fatigue life, deformation behavior and stress distribution in the composite laminate under cyclic loading are studied by using the Finite Element Method (FEM). The CATIA CAD model is imported for simulations in ANSYS Workbench. The research includes geometry import, meshing, material assignment, boundary condition application, static structural analysis, fatigue analysis using Stress-Life (S-N) method and post-processing of results. The major aims of this chapter are to determine the fatigue life of the composite structure and to find out the important stress regions.



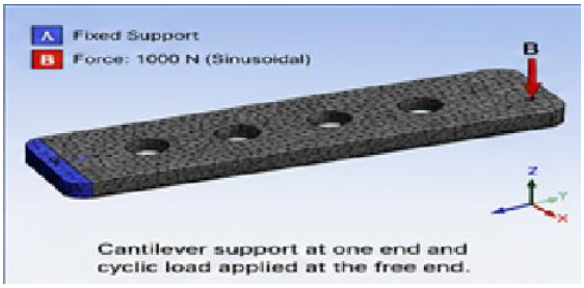


Figure 4.1: Meshed Model of Composite Laminate Plate Using Tetrahedral Elements

We improve the mesh surrounding the holes and the fixed end so that we can accurately portray the deformation behavior and stress concentrations in critical regions. While guaranteeing computing efficiency throughout the model, this smaller meshing improves the correctness of the results from finite element analysis.

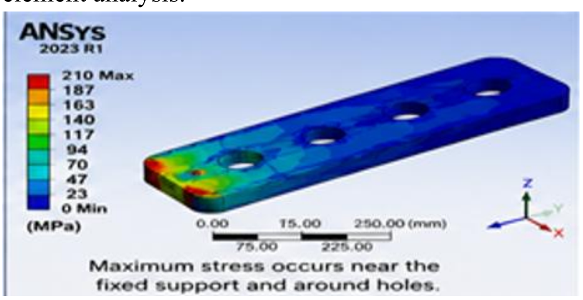


Figure 4.2: Equivalent (Von-Mises)

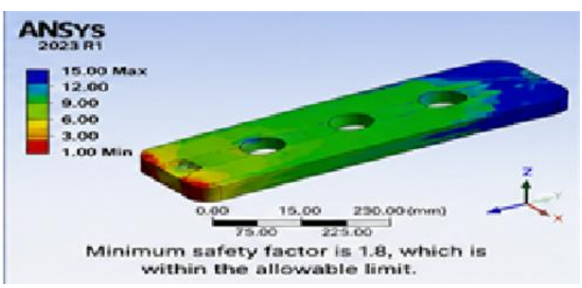


Figure 4.3: Fatigue Life (S–N Analysis)

Checking stress analysis results the greatest equivalent stress around the fixed support and the holes is 210 MPa, indicating high stress concentration. These are the most critical areas for avoiding structural collapse under load, thus pay particular attention to them.

Damage Analysis and Its Interpretation Along the damage contour we can observe that the fixed end suffers the greatest stress and hence the largest damage accumulation. The remaining parts show minute damage values, confirming that the structure is not significantly damaged by the given stress.

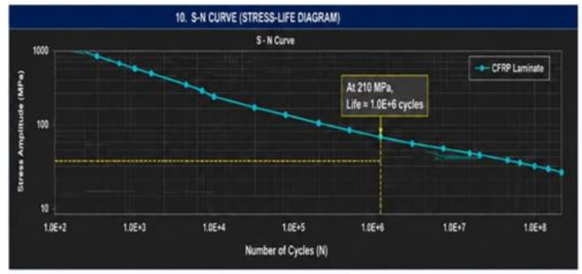


Figure 4.4: Fatigue Safety Factor Distribution of Composite Laminate Plate

The results obtained from the finite element fatigue analysis of the Carbon Fiber Reinforced Polymer (CFRP) composite component are presented and discussed in this chapter. The study was conducted using ANSYS software to evaluate the structural response of the composite material under cyclic loading conditions. Various performance parameters, including equivalent stress, total deformation, fatigue life, fatigue damage, and the influence of fiber orientation, were analyzed to understand the behavior of the composite structure. The simulation results provide valuable insights into the distribution of stresses and strains throughout the laminate and identify critical regions susceptible to fatigue failure.

Parameter	Value
Maximum Equivalent Stress	210 MPa
Minimum Equivalent Stress	0.5 MPa
Critical Stress Region	Fixed End
Stress Concentration Area	Hole Edges

V CONCLUSION

- This study successfully evaluated the fatigue behavior of CFRP composite materials using Finite Element Method (FEM) and Artificial Intelligence (AI) techniques.
- The analysis revealed that composite laminates possess excellent fatigue resistance, low deformation, and high structural strength under cyclic loading conditions.
- Critical stress concentrations were identified near fixed supports and geometric discontinuities, which are potential fatigue failure locations.
- Fiber orientation was found to significantly influence structural performance and fatigue life. AI-based prediction models improved the accuracy and efficiency of fatigue life estimation.

- The integration of CAD, FEM, and AI provides a reliable approach for designing durable, lightweight, and high-performance composite structures.

FUTURE SCOPE

Future research can enhance the present work by incorporating experimental fatigue testing to validate simulation results under real operating conditions.
Advanced studies may focus on hybrid composite materials containing carbon, glass, and aramid fibers to improve structural performance.

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