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Fatigue failure behavior Analysis of Fiber Reinforced Composite Laminates

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ABSTRACT
Now a day, the conventional materials are replaced by composites in a majority of applications. Composites have high specific strength, stiffness, better fatigue life, wear resistance and corrosion resistance. The properties of laminated composite poses a challenge in getting optimal design solutions. The flexural fatigue failure is a common problem in rotating and cyclic loading components such as wind turbine rotors, leaf springs, and air plane wing structures. Our focuses on critical analysis of various properties with the help of experimental test results to understand the influence of frequency on the fatigue failure behavior. This is due to cyclic fluctuating loads that are present on the composite laminates. The aim of our work is to develop experimental procedure for loading criteria in flexural fatigue analysis of composite laminate. Several tests are conducted including tensile test and performance of flexural fatigue was evaluated.
Keywords: *Tensile test, Fiber Reinforced Composite Laminates, Glass-reinforced polymer, Ultimate Tensile strength, Flexural fatigue.*

I. INTRODUCTION

The mechanical performance, lifetime service and manufacturing costs incurred in the process were found to be significant factors that need to be considered in numerous applications. In the applications as mentioned above, it was observed that exposure of these composite materials to a long-term repeated loading and unloading conditions known as fatigue were likely to fail after a certain number of cycles in most industrial and structural applications. In addition, the fatigue was generally defined as the process involved in the architectural destruction of the material on exposure to variable stresses and strains (Arif et al., 2014). Moreover, in several applications, the excessive fatigue loading was found to damage the material leading to an extreme deformation and fracture in numerous parts such that it causes the restriction in sustaining the load. Fatigue was also defined as the number of cycles the material will undergo stress before the damage is caused concerning service and life of the material (Bijelic-Donova et al., 2016).

Presently, Glass fiber-reinforced polymeric (GFRP) composites were found to be a significant factor in the manufacturing of composite materials. The properties and behavior of the fiber-reinforced composite were found to depend on numerous factors such as the fiber strength, the chemical stability, matrix strength and the bonding between the fiber and matrix in order to allow the stress transfer. The mechanical properties of the composites were found to be enhanced by the use of various GF reinforcements like long longitudinal, woven mat, chopped fiber, and chopped mat (Sathish kumar et al., 2014). Furthermore, the properties of composites were observed to be depended on the fibers laminated in the matrix while preparing the composites. The major limitation of the polymers in numerous commercial applications was concerned with the high cost. Besides, composite materials were noticed to have a wide range of industrial applications, and in addition, glass fiber reinforced composite materials were found to have an excellent resistance towards the environmental, higher tolerance level for impact loading, high specific strength, and stiffness (Raja et al., 2014). Polymeric composites were found to be utilized in several applications reductions of higher fatigue resistance in the fasteners and number of components such as aircraft industries, elevator, and landing gear doors. Thus, it is necessary to have a better understanding of the material's behavior under fatigue loading while considering the structural design.

II. LITERATUREREVIEW

D'Amore and Grassia, (2017) developed phenomenological models as an approach to determine the fatigue damage, residual strength, residual stiffness and predicting the service life. However, it was observed that the residual strength of the materials was found to drastically reduce as they reach the final cycles of failure and was modeled with impulsive death residual strength model. Bajpai, (2016) ascertained that a high cycle fatigue is modeled with wear-out models and it was observed in this study that the changes in the residual strength of the composite were found to reduce gradually. The significant limitation of this research was that it was not practical to measure the strength of the composites during the damage development. Furthermore, it was noticed that the changes in the stiffness were found to be regulated without causing damage to the sample. On the other hand, residual stiffness models are based on the changes in elastic properties of the material under fatigue loading. Abd El-baky et al., (2017) established an entirely reversed bending set-up to determine fatigue behavior of unidirectional carbon fiber/epoxy composites strands. This research indicates that the bending moment caused by reversible bending was observed to follow an exponential decay. In addition, it was noted that the heterogeneous and anisotropic nature of composite materials were found to generate distinct stress levels within the material. Moreover, the research indicates that a variety of failure modes are present within the composite materials such as cracking in matrix, breakage of fiber, and delaminating. Caprino et al., (2015) imply that the reduction in the strength, as well as the loss in elastic modulus, was observed as the composites are subjected to fatigue loadings. This research suggests the degradation of the performance of the composites and reduction in the stiffness of the materials during cyclic loading. In addition, several studies have focused on flexural fatigue testing of hybrid composites. Furthermore, Glass–carbon hybrid fibers/epoxy composite is utilized by Beyene et al., (2016) to determine the flexural fatigue behavior. From this research, it was observed that a number of loading cycles were found to cause degradation in the stiffness of the material with the process of cycling.

III. RESEARCHMETHODOLOGY

The proposed research methodology describes the technique that isused to conduct the experimental and the critical analysis of reinforced composite laminates. The present work will focus on critical analysis of various properties by conducting experimental test to understand the influence of frequency on the fatigue failure behavior due to cyclic flexing loads on the composite laminates. The steps involved in this study are as follows.

3.1 High Cyclic Fatigue

The general definition provided for high cyclic fatigue was given by the stresses which were induced due to cyclic loading and were represented with constraints such that it should be below 50% of the ultimate tensile stresses or strength in the specimen which are subjected to fatigue loading. This research had focused on flexural fatigue analysis of fiber reinforced composites. For the assessment of the simulating stresses and to estimate the bending of loads that need to be simulated on the specimens the following calculations were considered.

Let, B= Bending Moment = D*L (1)

Where, D is the bending load and L is the effective length of the specimen and s is the Bending Stresses. The moment of inertia of the specimen is expressed as,

$$I = \text{Moment of Inertia of the specimen} = \frac{bt^3}{12} \quad (2)$$

Where, b and t are defined as the width and thickness of the specimen. The load to be simulated was estimated from classical bending beam equation which is given by,

$$\frac{B}{I} = \frac{s}{F} \quad (3)$$

Where, s is the bending stresses to be simulated concerning the high cyclic fatigue loading. And Y is defined as half the thickness of the specimen. The balance load was found to estimate by the following equations,

$$D = \frac{fI}{LF}$$

3.2 Testing Methods

In this research it was observed that as a cyclic load is provided to the composite specimen, a fatigue crack was generated which was found to reduce the stiffness of the composite specimen at the fixed end and this was indicated on the voltage output obtained from the strain measuring bridge circuit. The increase in the cyclic loading from 0 cycles to n number of cycles was found to decrease the amplitude of wave as the damage progresses in the due course. This wave form was found to diminish with progress in time and was found to represent the layer of the laminate as the time progresses. The obtained data was recorded for further analysis in order to understand the fatigue failure behavior of the laminate. The primary objective of the test rig observed in this research was in simulating the desired reversed cyclic bending load on the vertically fixed composite laminate. The signals of the load cells were utilized to measure the bending load. Besides, the signal emitting from the load cells were continuously fed into the signal conditioning system to amplify the signal such that the data could be read for further analysis. The signal conditioning system was found to be capable in amplifying and conditioning the signal precisely, as shown in Fig 3&4 Bending stresses induced in the specimens =

1/2(Ultimate Tensile strength of the specimen)
Therefore, from theabove theory the bending load for each specimen is obtained. The study further performs critical analysis of the reinforced composite materials by employing numerous mechanical testing methods that were based on American Standard Testing Methods (ASTM). The Tensile Test (ASTM D638) is further performed. The composite samples as in Fig1and that is after performed the tensile test is shown in Fig2. The tensile test values will be tabulated sample is shown in Table.1. The Bending moment values will be tabulated shown in Table2.

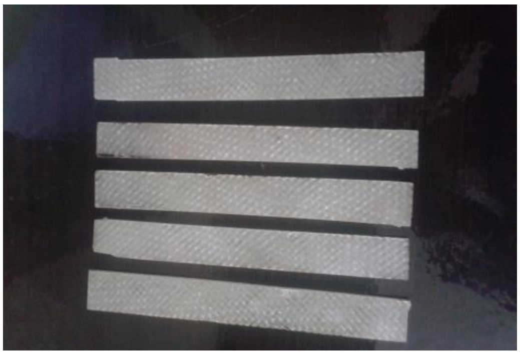

Figure1 The composite samples

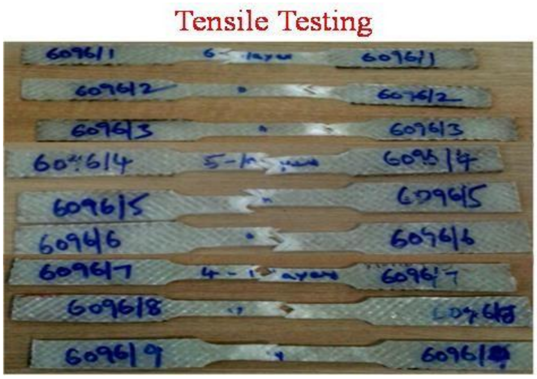

Figure2 Samples that is after performed the tensile test

Table 1 Tensile strength of the composite laminate

Samples	Layers	UltimateLoad(KN)	Ultimate Tensile Strength(N/mm^2)
1	8Layers	5.46	97.79
2	8Layers	5.28	93.96
3	8Layers	5.24	93.48
Average		5.32	95.07

Samples	Layers	UltimateLoad(KN)	Ultimate Tensile Strength(N/mm^2)
1	7Layers	5.52	80.16
2	7Layers	5.82	79.14
3	7Layers	6.12	84.96
Average		5.82	81.42

Samples	Layers	UltimateLoad(KN)	Ultimate Tensile Strength(N/mm^2)
1	6Layer	5.4	75.57
2	6Layer	5.28	75.07

3	6Layer	5.22	72.73
Average		5.30	74.73

Bending stresses induced in the specimens =1/2(Ultimate Tensile strength of the specimen) Bending stresses induced in the 8Layers specimens=1/2×95.07 =47.535N/mm^2
Bending stresses induced in the7 Layers specimens=1/2×81.45= 40.710 N/mm^2 Bending stresses induced in the 6Layers specimens=1/2×74.73=37.365N/mm^2

Table 2 The Bending moment values will be tabulated

Layers	Width(b)mm	Thickness(t)mm	Ultimate Load (KN)	Ultimate Tensile Strength (N/mm^2)	Bending stresses(S) (N/mm^2)	Moment of Inertia	Bending moment B=S*I/(t/2) N-mm
8Layers	12	5.5	5.32	95.07	47.535	166.37	2875.78
7Layers	12	5.0	5.82	81.42	40.710	125.0	2035.50
6Layers	12	4.5	5.30	74.73	37.365	91.12	1513.19

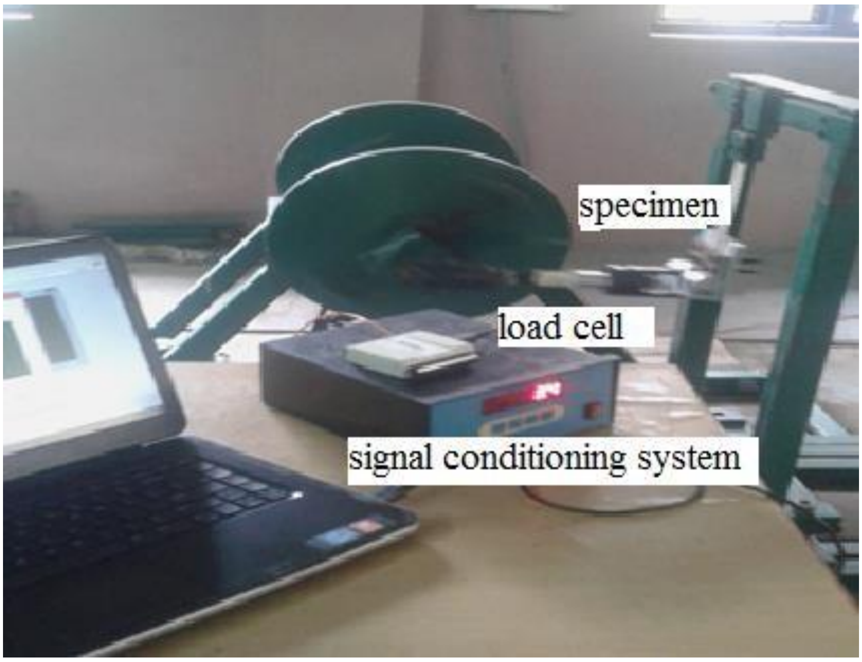

Figure3 Flexural Fatigue Test Machine

Figure4 Amplitude vs samples chart

IV. CONCLUSION

In this paper, an experimental procedure for loading criteria in flexible fatigue analysis of composite laminate is proposed. Also, this paper provides the critical analysis of various properties by experimental test results to understand the influence of frequency on the fatigue failure behaviour on the composite laminates.

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