FATIGUE LIFE PREDICTION OF E-GLASS CHOPPED STRAND MAT/EPOXY COMPOSITE LAMINATES

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Abstract The tension-tension fatigue behaviour of newly developed E-glass chopped strand mat/ Epoxy composite was characterized experimentally. The researchers as examine an improved model for fatigue life prediction including the effects of stress ratio, frequency and mean stress as the testing parameters. The fatigue test data of E-glass chopped strand mat/Epoxy composites are validated using the ANSYS software, and they are compared with other common E-glass fiber reinforced plastic composites. It inFdicates that other fiber reinforced plastic composites are more fatigue sensitive comparable to other fiber –reinforced plastic composites in their fatigue behaviour. The effect of stress ratio, frequency, and mean stress on fatigue life of E-glass chopped strand mat/Epoxy composites are studied and discussed. The present fatigue test can be useful to characterize the effect of various parameters on the fatigue behaviour of fiber reinforced plastic composites.

Key words: *polymer matrix composites, fatigue, stress ratio, frequency, S-N curve, fiber reinforced plastic.*

I. INTRODUCTION

The majority of engineering composite materials in service consist of continuous fibres of glass, or carbon, reinforcing an epoxy polymeric matrix. Due to their high specific strength and stiffness, Fibre Reinforced Polymer (FRP) composites are widely used in ship hull, airframe, and wind –turbine structural applications. The components in such structure invariably experience various types of constant and variable amplitude fatigue loads in service. Thus, safe operation of the structure for the required technical life time demands that such composite materials, in addition to their good static mechanical properties, need to possess relatively high fatigue durability and fracture toughness. The epoxy, when polymerized, is an amorphous and a highly cross-linked material. This microstructure of the epoxy polymer results in many useful properties such as high modulus and failure strength, low creep, etc., but also leads to an undesirable property in that it is relatively brittle and has a relatively poor resistance to crack initiation and growth. These adverse fracture properties may obviously also affect the overall fatigue and fracture performance of the FRP composites.

Fatigue strength of FRP composites is an important factor in the design of structures frequently subjected to random or constant cyclic loadings. The fatigue characteristics of common FRP composites with unidirectional/epoxy, carbon fiber/epoxy, E-glass/polyurethane materials are available in the literature, there is rarely available for fatigue behaviour of newly developed E-glass Chopped strand mat /Epoxy composites. Therefore, a need exists to investigate the behaviour of E-glass chopped strand mat/Epoxy composites under cyclic loading and develop fatigue life diagrams for such advanced FRP products.

The characterization of the fatigue behaviour is a relatively complicated process, particularly for composite materials. Several studies in the literature addressed the characterization and modelling of fatigue process. Manjunatha and Tailor [1] studied the fatigue behaviour of particle filled Epoxy materials and they concluded that the particle cavitations and the plastic deformation of the surrounding material appear to contribute towards enhanced fatigue life in modified epoxy. Pizhongqiao et al. [2] investigated the stress strain range of fatigue life E-glass/polyurethane composite. Papanikos et al. [3] developed modelling of progressive fatigue damage of Carbon Fiber Reinforced Polymer composite. Agarwal and James [4] studied the effect of stress ratio R on the fatigue life of composite and it was shown that the stress ratio had a strong influence on the fatigue life composites. More recently, fibrous fillers such as carbon nano fibers [5], nano tubes [6] and layered fillers such as silicate-clay [7] have also been used to try to improve the composite properties. Piggot [8] also reported that the fatigue life of FRP composites was insensitive to the temperature increase at frequencies below 30 Hz. The effect of rubber particles on the mechanical properties of epoxy polymer and FRP composites has been extensively investigated.

Although, in this study the tension – tension uniaxial fatigue behaviour of newly developed E-glass chopped strand mat/Epoxy composites was characterized. A combined analytical and experimental approach to characterize the fatigue of FRP composites was developed, and the factors considered the stress ratio, stress level, and frequency. First, experimental tests of E-glass chopped strand mat/ Epoxy composites under cyclic loading are conducted and then the testing results was validated with ANSYS software.

II. EXPERIMENTAL ANALYSIS

2.1 Materials

The type of epoxy resin used in this investigation is LY556 and hardener HY951 supplied by Ram Composites of India Limited, Hyderabad. E-glass chopped strand mat fibers of 350 GSM were obtained from the GVR Enterprises, Madurai, Tamilnadu.

2.2 Fabrication Process

The Glass Fiber Reinforced Polymer (GFRP) composites materials were manufactured by the Hand Layup Technique. Thin plastic sheets are used at the top and bottom of the mould plate to get good surface finish of the product. Reinforcement in the form of chopped strand mats (350 GSM) are cut as per the 200×150 size and placed at the surface of mould after Plastic sheet. Then thermosetting polymer (EPOXY LY556) in liquid form is mixed thoroughly in 10:1 proportion with a prescribed hardener HY951 (curing agent) and poured onto the surface of mat already placed in the mould. The polymer is uniformly spread with the help of brush. Second layer of mat is then placed on the polymer surface and a roller is moved with a mild pressure on the mat-polymer layer to remove any air trapped as well as the excess polymer present. The process is repeated for each layer of polymer and mat, till the required thickness as per standard. After placing the plastic sheet the pressure is applied. The time of curing is 24 hours.

A layer is finally placed on top of the laminates and squeezed properly with roller so as to remove the entrapped air and obtain the void free and smooth surface. The composite laminateis allowed to cure at room temperature for twenty four hours. After curing Plastic sheet is removed from both sides of the laminate. Specimens are cut from the fabricated laminates to over dimension (about 3-5 mm on each side) using abrasive cut-off wheel mounted with water cooled cutting saw. Specimens are placed in between the wooden backing plates of same dimension and then machined together to the required dimension by a cutting machine. Backing plates are used to avoid edge delamination. The fabricated specimens are shown in Figure1.

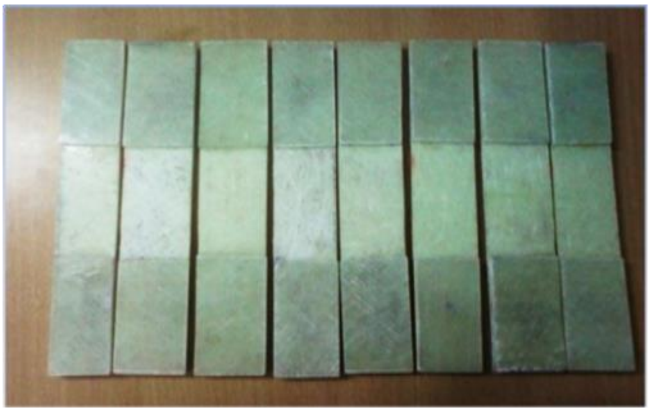

Figure.1: E-glass Chopped Strand mat/ Epoxy Fabricated Specimen

2.3 Tensile Properties

The tensile properties of the GFRP composites were determined according to ASTM- D3039 test standard specifications. The ASTM-D3039 specimen is shown in Figure2.

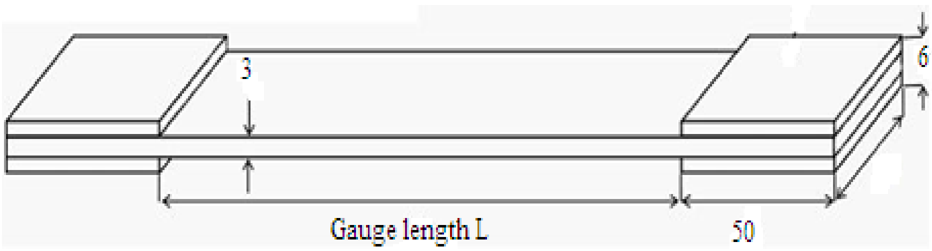

Figure.*2: Schematic diagram showing dimensions of the tensile test specimen*

GFRP composite test specimens were end-tabbed, using GFRP composites (about 1.5 mm in thickness) to prevent the damage to the specimen due to the grips during testing. All the tests were performed using 100 KN computer controlled universal testing machine. Five replicated tests were conducted for each specimen and the average tensile properties are shown in Table 1.and tested specimens are shown in Figure.3.

Table 1 Tensile properties of the E-glass chopped strand mat glass fiber composite obtained from the test

Specimen no.	Tensile strength (MPa)
1	191
2	185
3	180
4	176
5	150
Mean	**177**

Figure.3: E-glass Chopped Strand mat/ Epoxy specimen after the Tensile Test

2.4 Fatigue Testing Procedures

In this study, the effect of stress ratio 0.1, frequency and maximum stress on fatigue life prediction of E-glass chopped strand mat/epoxy composites were investigated. All the fatigue tests were performed according to the ASTM D3470 test standard specifications, using an Instron 25 KN computer controlled servo-hydraulic test machine, is shown in Figure. 4. The following fatigue parameters were employed for the tests: Stress ratio R=0.1; f= 1-3 Hz; and σ_{max}= 0.50, 0.55, 0.60, 0.65, 0.70 and 0.80 σ_u was conducted. The frequency should be noted that it has been shown that higher test frequencies may induce thermal effects, and lead to reduce fatigue lives in composites [1]. Therefore, the test frequency was kept below 3 Hz in the present studies. A load control mode was adopted, and the fatigue failure is defined as the complete breaking/separation of the samples. As per ASTM D3479 requirements, the minimum number of specimens required for each S-N curve is six for preliminary and exploratory study, 12 for research and development testing, and 24 for design allowable and reliability data [2]. For this exploratory study eight samples are tested, all the tests are carried out under same stress ratios and varying loads.

The experimental process: (1) Let the loading be ramped to the mean stress. (2) Let the load run cyclically to the full amplitude and count the transition cycle numbers. (3) Monitor the peak and valley values for the test. A total of eight samples were tested and their fatigue life (N) under a given testing parameter combination was recorded. No significant temperature increase was observed during the fatigue experiments, indicating that the temperature effect on fatigue life could be excluded.

Figure.4: Instron computer controlled servo-hydraulic testing machine

The conducted fatigue test results are shown in Figure. 6. For that test given parameters are followed by, R=0.1; f= 1-3 Hz; and σ_{max}= 0.50, 0.55, 0.60, 0.65, 0.70 and 0.80σ_y.

III. NUMERICAL ANALYSIS OF FATIGUE

The progressive fatigue analysis is carried out in ANSYS 15. In this work, a thin lamina containing randomly oriented discontinuous fibers exhibits planar isotropic behaviour [15]. The properties are ideally the same in all directions in the plane of the lamina. Therefore the taken material properties are given as isotropic material. For this work, the effect of stress ratio 0.1, frequency and maximum stress on fatigue life prediction of E-glass chopped strand mat/epoxy composites were analysed. Three stress ratios (0.1, 0.5, and 0.9) are taken and analysed at different loads. It is observed that when increasing the stress ratio, the material fatigue life (number of cycles) is increased. The specimen meshing model is shown in Figure. 5.

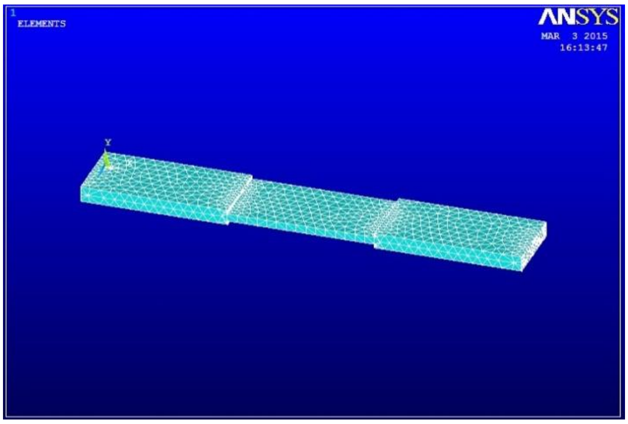

Figure.5: Specimen Meshing Model

The following parameters are taken to analyse the fatigue life of E-glass Chopped Strand mat/ Epoxy composites material and the results are presented in graphical form as shown in Figure. 6, 7 and 8 for the Stress ratio = 0.1, 0.5 and 0.9 respectively. Frequency = 1-3 Hz; Maximum Stress (σ_{max}) = 0.50, 0.55, 0.60, 0.65, 0.70 and 0.80σ_u

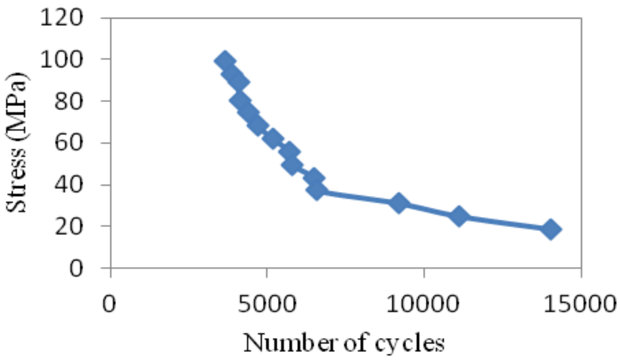

Figure.6: S-N Curve of GFRP Composite Laminate Composite Laminate at Stress ratio 0.1

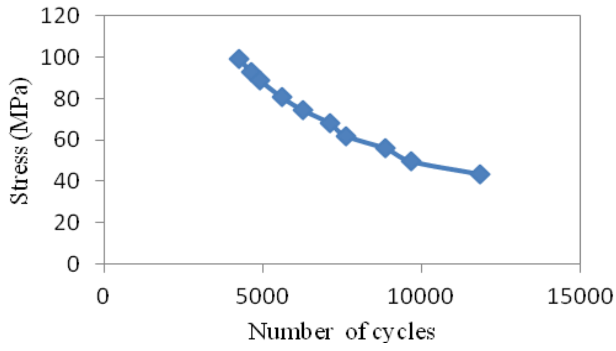

Figure.7: S-N Curve of GFRP at Stress ratio 0.5

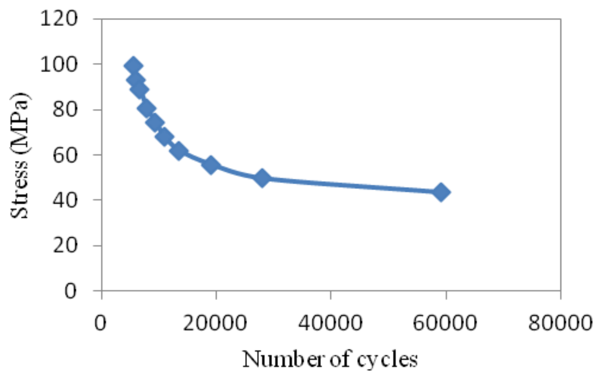

Figure.8 S-N Curve of GFRP Composite Laminate at Stress ratio 0.9

IV. RESULT AND DISCUSSION

In this section, the experimental fatigue testing data of E-glass chopped strand mat/ epoxy composites were validated using the ANSYS software and the effect of stress ratio, on the fatigue life had been analysed using software. The stress controlled, constant- amplitude tensile fatigue test results at a stress ratio, R=0.1 are obtained for the GFRP composites with Epoxy matrices and numerically analysis is carried out for the same parameters and its results are shown in Figure.9. It is observed that, over the entire range of stress level investigated, when stress ratio increase the fatigue lifecycles has been increased.

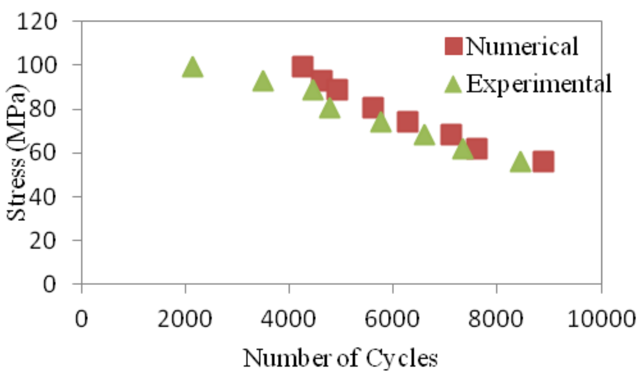

Figure.9: Numerical and Experimental Analysis values in different ratios

The progressive fatigue load is applied on the ASTM D3039 glass/epoxy laminate subjected to tension-tension cyclic loading with load ratio of 0.1. Fatigue life of ASTM D3039 glass/epoxy composite material is predicted and compared with numerical solutions. The triangle dotted line in the plots of Figure. 9 is the experimental results of the composite material and square dotted line in the plots of Figure. 9 is the numerical analysis of the composite materials. Figureure 10 and Figure 11 shows the numerical solutions for the composite materials at stress ratio 0.1, 0.5 and 0.9 with different loads.

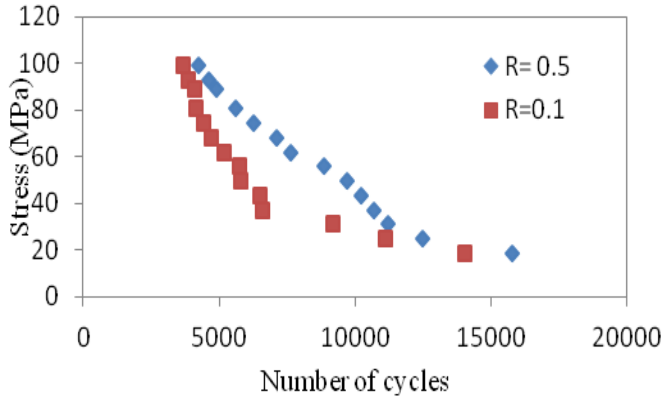

Figure.10:S-N Curve of GFRP Composite Laminate at Stress ratio 0.1 and 0.5

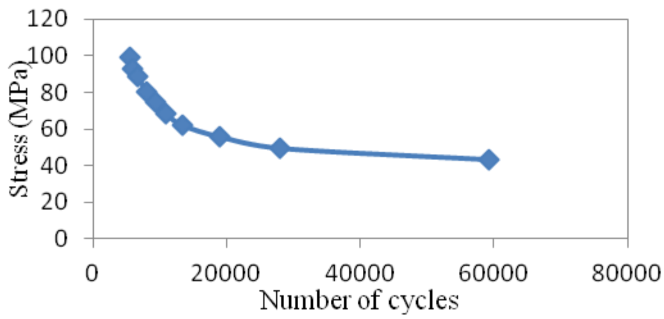

Figure.11: S-N Curve of GFRP Composite Laminate at Stress ratio 0.9

The results of numerical solutions are good agreement with the experimental results. The finite element analysis is leads to few drawbacks because several assumptions (e.g. stress locations and plane stress) need to be made.

V. CONCLUSIONS

Fatigue life of glass fiber chopped strand mat/epoxy composites material is investigated in experimental method and numerical analysis. The numerical analysis is performed by ansys software. The results show the good agreement between predicted fatigue life and experimental fatigue life. In this study, it is seen that when the stress ratio increased the fatigue life of the material was increasedand it was shown that the stress ratio had a strong influence on the fatigue life of composites.

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