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Fatigue Behavior of Epoxy Bonded Composite Lap Joints.

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Abstract**: *Laminated composites are rapidly finding uses in different engineering applications like Aviation, Sports equipment, Marine technology, Aerospace and Electronics. This is due to their versatile engineering properties. Bolting and Bonding are the widely used joining techniques in composites. However bonding has added advantages over bolting in terms of weight reduction and strength .This paper explores the fatigue strength of single lap epoxy bonded joint between composite laminates. The experimental results are compared with FEA (Finite Element Analysis) results.***

Keywords**: *Adhesive, Composite, Epoxy adhesive, Fatigue, FEA***

I. INTRODUCTION

A composite material is made of a matrix and reinforcing phases. Their widespread application in varied domains of engineering has led to an increased interest in the joining process. Currently the mechanical joining techniques like fastening, riveting and bolting are primarily used. However these mechanical techniques invariably lead to cutting and distortion of fibers leading to decreased strength and increased stress concentrations. Adhesive Bonding provides an alternative to overcome these shortcomings of mechanical techniques. The adhesive bonding technique reduces the stress concentrations by even load distribution along the area and without any need for cutting through the fibers to provide for fastener holes. Rivet and bolt free joining significantly contributes to weight reduction.Adhesive Bonding is a process of placing an adhesive between the bonding surfaces which solidifies to form an adhesive bond. It provides for lower weight, decreased manufacturing cost and ease of repair. A well designed adhesive bond can be much stronger than the base laminate. On the other hand a well-designed fastened joint will be only about 50% stronger than the base laminate[1]. Adhesive joints are preferable when thin composite profiles need to be mounted, when the stresses on the bolted joints are too high or when the weight for mechanical fasteners is too high. In general, thin structures with well-defined load paths are good candidates for adhesive bonding, whereas thicker structures with complex load paths are good candidates for mechanical bolting. Adhesively Bonded Joints (ABJs) provide additional advantages over traditional methods like welding, bolting and riveting.[2] These include excellent resistance to mechanical vibrations and sealing ability.

Epoxy polymers are widely used as matrix for composites and as well adhesives for joining of composites. This owes to their better modulus and temperature resistant properties.[3] Cohesive Zone Modeling (CZM) is used to study the cohesive and adhesive failure in debonding and delamination respectively.[4] CZM relates the relative displacement of two opposing points in a finite region to the force per unit of area, also known as traction. In cohesive elements, the relative displacement is often expressed as changes in surface normal and the traction as a function of the displacement with a stiffness tensor. [5]

II. MATERIALS AND METHODS

A. Materials

A lap shear joint is made up 500 gsm E-glass fibres and Epoxy Resin (Epofine 740) as resin. Epoxy Resin (Epofine 740) is used as an adhesive to bond the joint.

B. Methods

The E-glass specimen are prepared as per ASTM 5868 using the hand lay-up process. The orientation of the fibres is $[0/45/-45/90]_s$. This configuration has equal load bearing capacity in all directions. 8-Laminas are stacked in the said orientation and Epoxy resin is applied to form a laminate. The epoxy is mixed with a hardener and an accelerator in proportion of 100:90:3.The laminates are cured at room temperature for a period of 24 hours. After pressing the laminates they are cured at 150 degrees Celsius for a period of 4 hours in an oven. Finally the specimen of required dimensions (100mm x25mmx3mm) are cut from the plates.

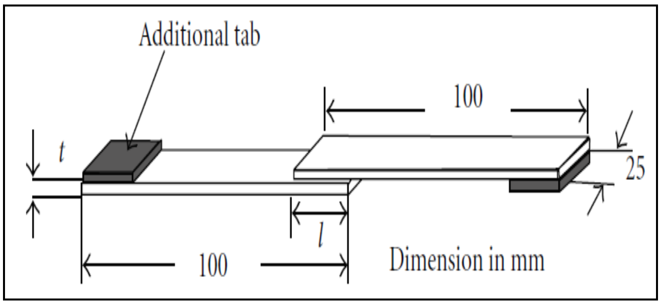

Fig. i Lap Joint Specimen Dimensions

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III. EXPERIMENTATION

Specimens are tested for static strength of bond between composite laminates on UTM of 100 kN capacity.
Load displacement curves are plotted by software. Ultimate strength is taken as average of all five tests.

The specimen is holding between the grips as shown in Figure 1. One end is fixed and does not move. The displacement on other end is given with rate of 3 mm/min.

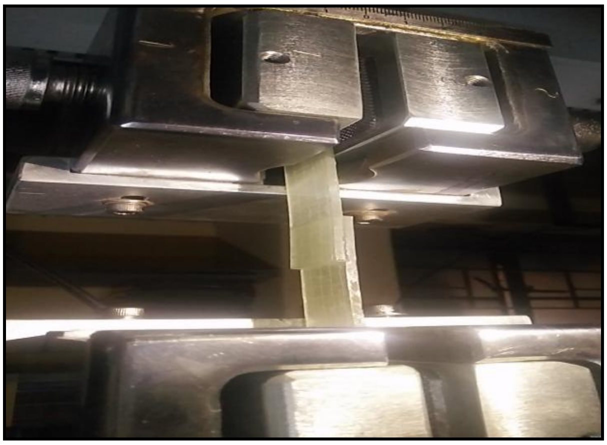

Fig. 1 Fatigue test of bonded joint.

Then specimen are tested for fatigue under Tension-Tension for R-ratio = 0.1 which the ratio for minimum to maximum load. Frequency is kept at 3Hz for all tests to avoid any temperature effects at higher frequencies. The setup is shown in Fig.1. Load applied while testing are 90 %, 80 %, 75%, 70 %, and 60 % of the ultimate load.
The static test results are tabulated in Table 1.

Table 1. Static test results.

Specimen	Max Load (KN)	Elongation at Max Load (mm)	Load at Break (KN)	Elongation at Break (mm)
1	3.56	2.42	3.34	2.44
2	3.11	1.66	3.11	1.63
3	3.64	2.03	3.64	2.03
4	3.80	2.63	3.80	2.62
Average	3.53	2.17	3.47	2.17

The fatigue test results are tabulated in Table 2.

Table 2. Load Vs Cycles.

Specimen	% Load Value	Load Value (KN)	Cycles
1	90	3.12	3797
2	80	2.77	7678
3	75	2.64	31470
4	70	2.24	48875
5	60	2.08	99990

IV. VALIDATION OF FEA MODELS

In Load- Displacement curve by FEA, the maximum load is 3605.24 N at 1.98 mm displacement. Whereas from experimental results average maximum load is 3528.5 N at 2.17275 mm displacement (Table3). The error in maximum load from FEA and experimentation is 2.1 % and error in displacement from FEA and experimentation is 8 %. While complete debonding in FEA occurs at 2.132 mm and experimental value is 2.1 mm, so the error is 1.5 %. Table 5.8 is showing comparison result for load – displacement curve we get form experimentation and FEA.

Table 3. Experimental Vs FEA

Sr No	Parameters	Experimental Result	FEA Result	Error %
1	Max Load (KN)	3.52	3.60	2.1
2	Displacement at Max Load (mm)	2.17	1.98	8
3	Displacement at Failure	2.17	2.13	1.5

Maximum Stress in Composite laminate is found to be 141 MPa in ABAQUS model (Figure 2) at load value of 3605.24 N. To check stresses in each ply ANASYS is the better option because it has dedicated module for composites. Therefore the stress analysis is carried out in ANSYS ACP by applying maximum load extracted from ABAQUS results which is 3605.24.

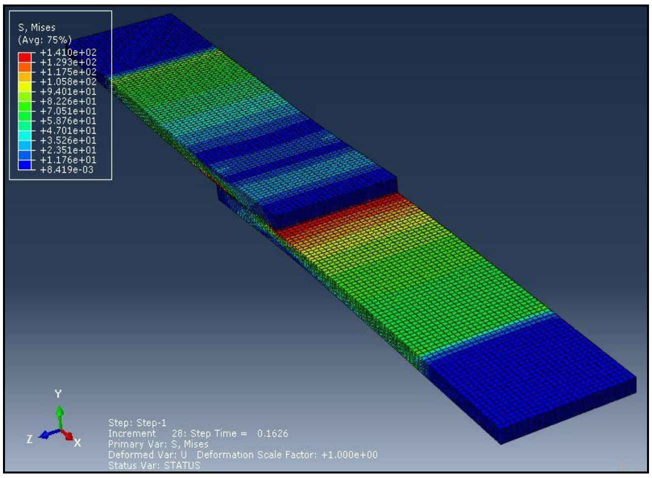

Fig. 2 ABAQUS Model

Figure 3 shows the results from ANSYS model. Maximum stress of 156.54 MPa is occurring at edges of bond. The error in maximum stress value obtained by ABAQUS model and by ANSYS model is found to be
9 %.

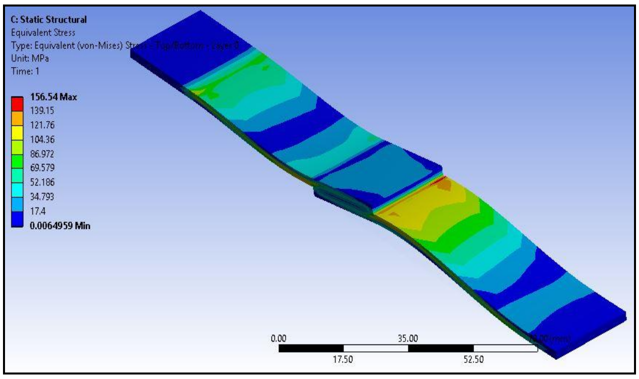

Fig 3. ANSYS Model

V. RESULTS AND DISCUSSION

Experimental load displacement curves for Composite-Composite joint are shown in Figure 4. Graph of load verses displacement is found to be linear till failure and even after failure.

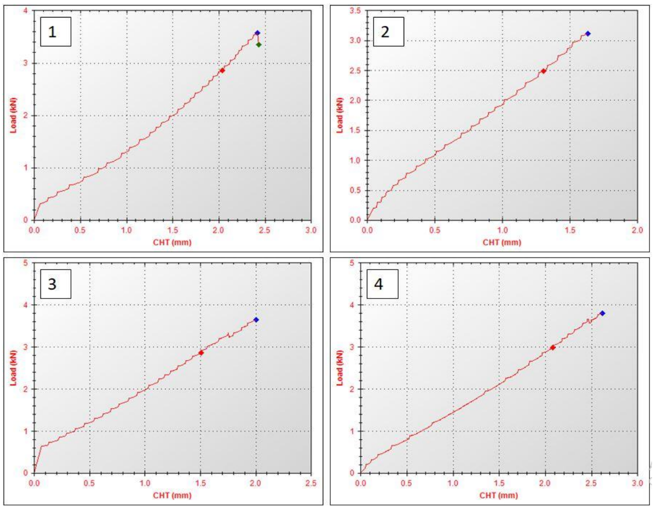

Fig 4. Load Displacement Curves for the Composite Joint.

The S-N Daigram for the composite joint is shown in figure 5

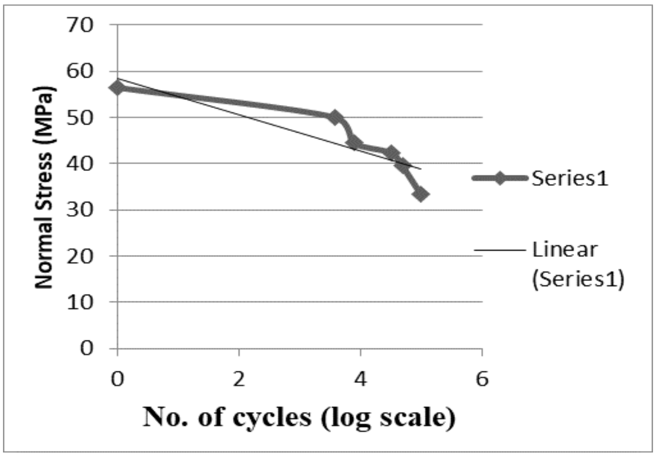

Fig 5. S-N Curve for Composite Joint

On x-axis number of cycles in $\log_{10}$ scale is shown and on y-axis normal stress i.e. Force per unit cross sectional area of the laminate is shown. Here maximum stresses are shown. As R = 0.1, To calculate minimum stresses we can use the formula mentioned above. The thick line is showing experimental S-N curve named as ‘Series 1’ and the thin line is linear line drawn from same data named as ‘Linear (Series1)’.

Debonding is observed from the edges where stress concentration is high. Crack is generated and propagates gradually with increase in number of cycles.

Due to uniformly distributed stress over bond area causing the less stress concentration with maximum stress of 156.64 MPa. The savoir local failure is not observed compared to conventional joining methods as in case of bolted joint. Lateral bending is observed around bond when loaded in tension due to offset. This bending will increase as the thickness of base laminates will decrease which can affect the joint as well as laminates. Also, minimal degradation of laminates after joint failure is observed in the laminates. These laminates can be reused.

The results from cohesive zone model we get the maximum load value as 3605.24 N with error of 2.1 % and displacement at maximum load is 1.98 mm with error of 8 % when compared with experimental results.

When loaded at 90%, 80%, 75%, 70%, and 60% of ultimate load carrying capacity the fatigue life found to be 3797, 7678, 31470, 48875, and 99990 number of cycles at frequency of 3 Hz and stress ratio is 0.1. At 60% of ultimate load carrying capacity the endurance limit occurred.

VI. CONCLUSION

The number of cycles to failure increased drastically with respect to reduction in percentage of loading stress. The experimental results are conforming with FEA analysis within the acceptable error range.

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