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"BREAKING PATTERN ANALYSIS OF ADHESIVELY BONDED SINGLE LAP JOINT USING FINITE ELEMENT APPROACH"

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Abstract— In the case of composite materials a smoother load transfer between the connecting members helps in lowering the localized stress concentrations as compared to mechanical fasteners . Single lap joint is a frequently used joint configuration at many places in industries. Keeping in view this importance of lap joint in composite materials it becomes imperative to get a more precise picture of the pattern of failure which requires micro approach to analyze the exact pattern of failure. In the present work it is tried to get a real time picture of failure pattern using finite element approach .Different orientation of plywood with different types of epoxy adhesive is considered for the analysis. Variation of normal stress and shear stress are also determined in this work.

Index Terms—Adhesive bonding, Single lap joint, Finite Element ,Epoxy Adhesive ,Normal Stress ,Shear Stress ,Composite Material

1 INTRODUCTION

Adhesive bonding has been one of the most important and evolving technologies for many structural applications in a great variety of industries over the past few decades. Compared to other joining methods like mechanical fastening, welding, brazing and soldering, adhesive bonding can offer improved performance and substantial economic advantages. The ability to join dissimilar materials (like laminated composites), joining of thin sheets and joining of materials with complex geometrical configurations has made the adhesive bonding more attractive over other methods of joining. A smoother load transfer between the connecting members helps in lowering the localized stress concentrations as compared to mechanical fasteners. The increasing use of adhesive bonding methods in many applications such as space, aircraft and automobile industries etc has placed considerable demand for more accurate analyses and design methods keeping in mind the field conditions.

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Failure analyses and appropriate design recommendations would always make these joints worthy of acceptance in such important applications. Besides typical failures like interlaminar or interply delaminations in the adherends, an adhesively bonded joint can fail by different modes as listed as below:

(1). Adhesion failure at the adherend-adhesive interface caused by excessive peel and shear stresses at critical locations.

(2). Cohesion failure within the adhesive layer

(3). Out-of-plane adherend failure in laminated FRP composite adherends caused by interlaminar stresses.

The failure of both isotropic and anisotropic adherends due to bending, tension or compression can be predicted using the standard stress based mechanics of materials approach as well as the Tsai-Wu coupled failure criterion. Cohesion and out-of-plane adherend failure modes pertaining specifically to the failure of the adhesively bonded joints are discussed in detail by some researchers. However there has been practically very little effort to analyze the adherend-adhesive interface failure which is known as adhesion failure or delamination/debonding damages caused by interfacial peel and shear stresses. Such damages occur at the bi-material interfaces i.e. at the interface of the adherend and adhesive in case of bonded joints. Adhesion failures are expected to initiate from the edges of the stress singularity points and would propagate along the adherend-adhesive interfaces.

2 Three-dimensional Finite Element Analyses of adhesively bonded single lap joints in laminated FRP composite

2.1 Geometry

The geometry of the single lap joint used for the problem modeling is shown in the figure 1. The identical top and the bottom adherends are 100mm long, 25mm wide and 0.5mm thick. The overlap length or the contact length of the joint is 12.5 mm. The adhesive is modeled in the overlap region with a thickness of 0.1mm.

2.2 Finite Element Modeling

The finite element mesh is generated using the three dimensional brick element 'SOLID 45' and three dimensional layered volume element 'SOLID 46' of the FEA commercial software ANSYS12.0. The SOLID 45 element is used for the adhesive modeling whereas the SOLID 46 element is used for modeling of adherends. These elements are structural solid elements designed based on three dimensional elasticity theory and is used to model orthotropic solids.

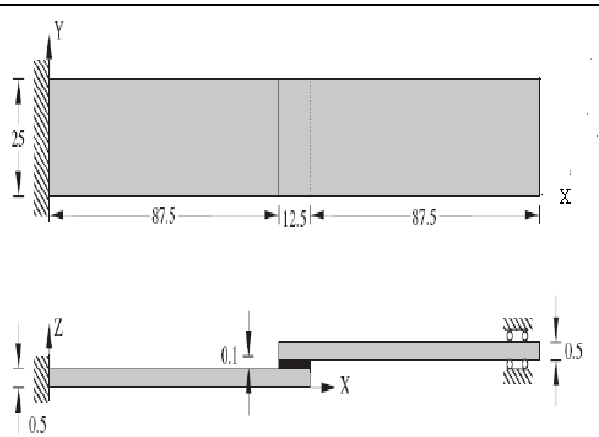
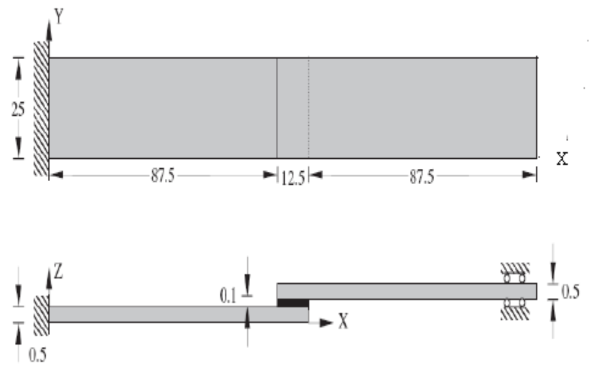


Figure.1 Finite Element Mesh at the overlap region



2.3 Loading

A uniform axial load of 1 MPa is applied at the free end of the top adherend for prediction of the response of the structure.4

2.4 Boundary Conditions

For the present case one end of the joint is clamped and the other end is restricted to move in the transverse direction, i.e. u, v, w = 0 at x = 0 and w = 0 at x = L,

where u, v and w are the displacements in the x, y and z directions and L is the overall length of the single lap joint .

2.5 Laminate Sequence

Two $0^0/\theta^0/\theta^0/0^0$ laminated FRP composite plates are used as adherends for the present analysis where θ is varied in steps of 0^0, 30^0, 45^0, 60^0 and 90^0

3 Material Properties

The following mechanical properties are taken from the reference [22, 34]

TABLE 1

FRP composite Graphite/Epoxy adherendproperties

Material	Material constants	Strengths

Graphite/Epoxy FRP composite adherend	Ex = 127.5 Gpa, Ey = 9 Gpa, Ez = 4.8 Gpa, vxy = 0.28 vxz =0.28, vyz = 0.41, Gxy = 4.8 GPa Gxz = 4.8 GPa Gyz = 2.55 GPa	XT = 1586 MPa, XC = 1517 MPa YT = 80 MPa YC = 80 MPa, Z = 49 MPa S = 2.55 MPa

TABLE 2
FRP COMPOSITE GLASS/EPOXY MATERIAL PROPERTIES

Material	Material constants	Strengths
Graphite/Epoxy FRP composite adherend	Ex = 17 GPa Ey = 17 GPa , Ez = 15 GPa , vxy = 0.24 vyz = 0.4 vxz 0.4, Gxy = 5 GPa Gxz = 5 GPa Gyz = 5 GPa	XT = 360MPa, XC = 240 MPa YT = 360 MPa YC = 205 MPa, Z = 40 MPa S = 98MPa

TABLE 3
FRP COMPOSITE GLASS/EPOXY MATERIAL PROPERTIES

Material	Material constants	Strengths
Carbon/Epoxy FRP Composite adherend	Ex = 126 GPa Ey = 11 GPa Ez = 11 GPa vxy = 0.28 vxz =0.4, vyz = 0.4 Gxy = 6.6 GPa Gxz = 6.6 GPa Gyz = 6.6 GPa	XT = 1950 MPa, XC = 1480 MPa YT = 48 MPa YC = 200 MPa, Z = 48 MPa S = 79 MPa

TABLE 4
FRP composite Epoxy adhesive Isotropicproperties

Material	Material constants	Strengths
Epoxy adhesive Isotropic	E = 2.8 GPa v = 0.4	YT = 65 MPa YC = 84.5 MPa

4 ANALYSIS

Fig. 1 shows the finite element mesh on the overlap region of the single lap joint. One of the major concerns in the analysis of laminated FRP composite single lap joint is the prediction of the location of damage initiation due to prevailing tri-axial states of stresses which have to be evaluated by the three dimensional FEA. As the joints are considered as the weakest point of any structure its proper design and analysis is necessary to predict the strength and life of the entire structure.

The common failure modes in the adhesively bonded joints are:

1) Adhesion failure
2) Cohesion failure
3) Out of plane adherend failure

The adhesion failure occurs at the adhesive adherend interface. The excessive peel and shear stresses at critical locations are responsible for the initiation and propagation of the adhesion failure. The out of plane stress distributions at adhesive adherend interface of the single lap joint is an important factor in the joint analysis due to the reason that the adhesive layer is comparatively of lower strength then the adherends.

ISSN 2229-5518

4.1 Variation of Stresses for different ply orientations

Generally the interlaminar or out-of-plane stresses are ... tion ... and ... are ... f the ... rface ... oxy, ... ding

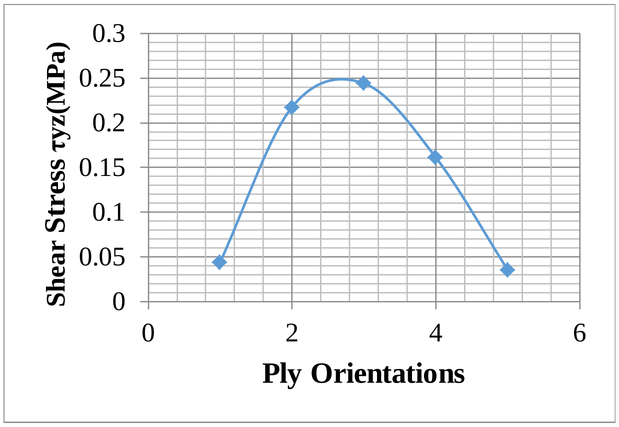


Fig. 3Variation of shear stress τ_{yz}

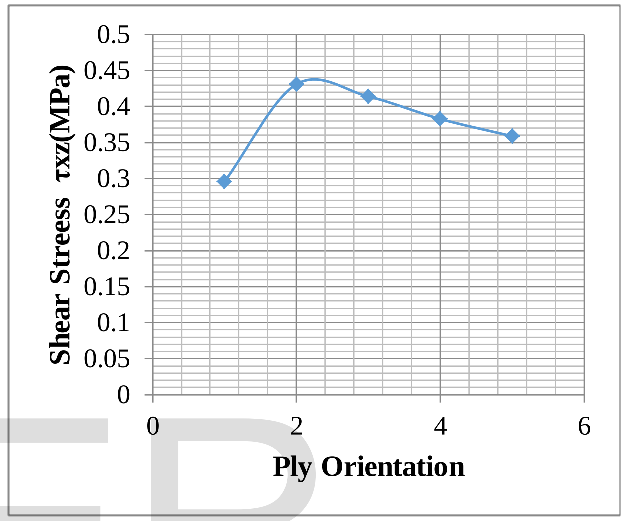


Fig. 4. Variation of shear stress τ_{XZ}

TABLE 5

Comparison of the various stresses for different ply orientations (Graphite/epoxy)

S.No	Stresses (Mpa)	Ply Orientations				
		0/0/0/0 (1)	0/30/30/0 (2)	0/45/45/0 (3)	0/60/60/0 (4)	0/90/90/0 (5)
1	σ_z	0.504336	0.810096	0.754059	0.654355	0.596865
2	τ_{yz}	0.044311	0.217562	0.244068	0.161183	0.035441
3	τ_{xz}	0.295883	0.4309	0.413981	0.382775	0.358827

Maximum variation in the values of normal stress and the shear stresses can be seen in between the first and the second orientation i.e. for the orientation [0/0/0/0] and [0/30/30/0] stresses vary considerably.

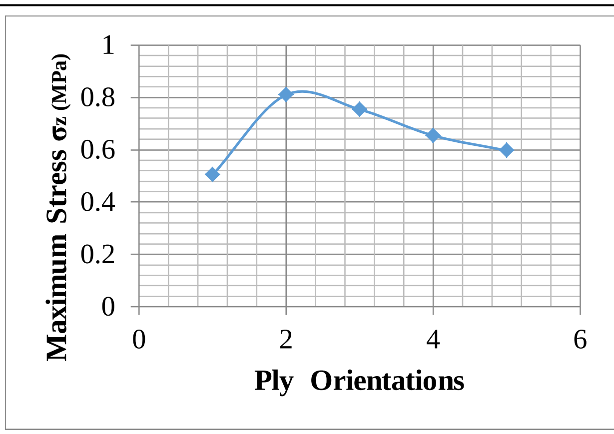


Fig. 2. Variation of normal stress σ_z

Material 2: Glass/epoxy

TABLE 6

COMPARISON OF THE VARIOUS STRESSES FOR DIFFERENT PLY ORIENTATIONS (GLASS/EPOXY)

S.No	Stresses (Mpa)	Ply Orientations				
		0/0/0/0 (1)	0/30/30/0 (2)	0/45/45/0 (3)	0/60/60/0 (4)	0/90/90/0 (5)
1	σz	1.341	1.387	1.395	1.387	1.341
2	τyz	0.4732	0.57030	0.60158	0.56954	0.47329

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		9	7	6		
3	τxz	0.678127	0.697961	0.701746	0.697961	0.678127

For glass/epoxy adherend very less variation in the values of normal stress σz and the shear stresses τyz and τxz is observed.

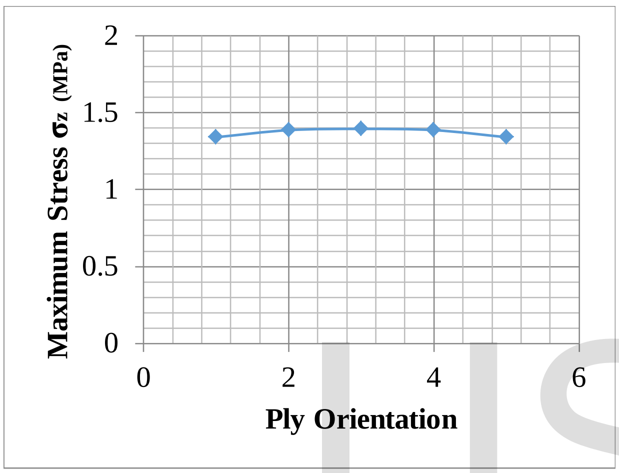


Fig. 5. Variation of normal stress σz

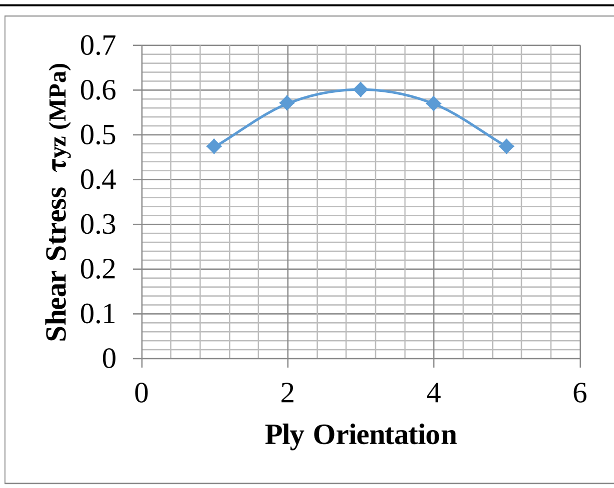
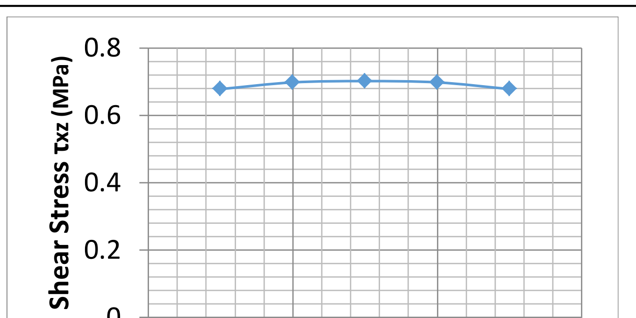


Fig. 5. Variation of normal stress σz



Material 3: Carbon/epoxy

Material 3: Carbon/epoxy

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Material 3:Carbon /Epoxy

Material 3: Carbon/Epoxy

TABLE 6

COMPARISON OF THE VARIOUS STRESSES FOR DIFFERENT PLY ORIENTATIONS (GLASS/EPOXY)

S.No	Stresses (Mpa)	Ply Orientations				
		0/0/0/0 (1)	0/30/30/0 (2)	0/45/45/0 (3)	0/60/60/0 (4)	0/90/90/0 (5)
1	σ_z	0.544038	0.854665	0.812061	0.717315	0.661758
2	τ_{yz}	0.060463	0.205044	0.237787	0.163395	0.04981
3	τ_{xz}	0.29748	0.420333	0.411182	0.385062	0.362676

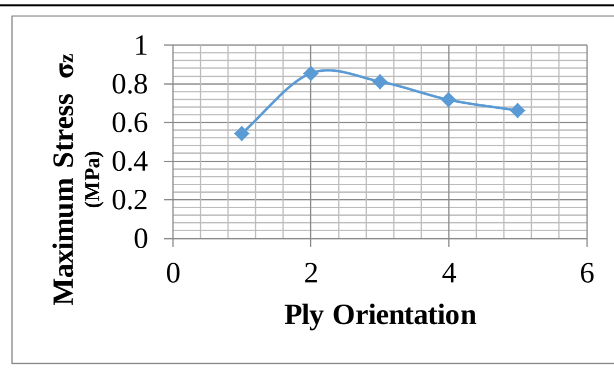
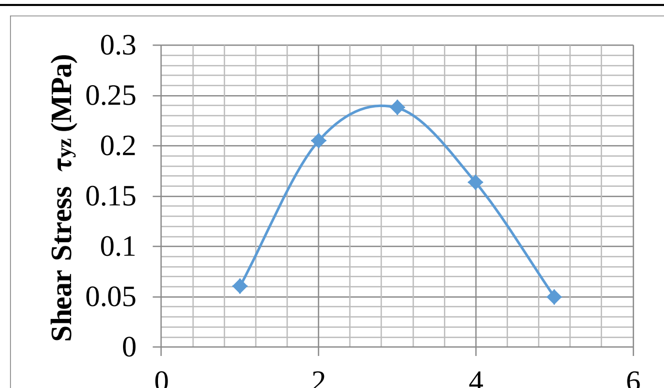


Fig. 5. Variation of normal stress σz



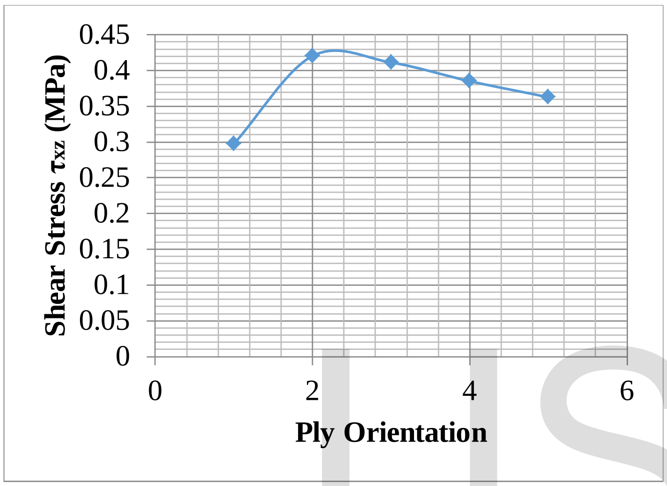


Fig. 5. Variation of normal stress σ_z

5 Results

One of the reasons for variation of stresses across the width of the laminate for different ply orientation adherends is due to the non uniform distribution of the fibers in the width direction. Another reason is the interlaminar effect at the free edges of the structure. Interlaminar stresses in the form of out of plane stresses are induced in the vicinity or at the free edges of the adhesive adherend interface, in case of bonded joints. These stresses can cause damages such as adhesion failure, cohesive failure and delamination damages or combination of these failures. The adhesion failure initiates from the stress singularity region and propagates along the bondline interface due to peeling or shearing. This failure occurs on a macro scale when surface preparations or material qualities are poor. Cohesive failure occurs in the adhesive layer due to shear yielding of adhesive and such failures mostly generated by the properties of the resin.

6 Conclusion

Failure due to delamination induced damages occurs in the laminated FRP composite adherend by the transverse or interlaminar stresses. This is so because the interlaminar strength of FRP composites is of the same order or lower than that of the matrix. As the bonded joints experience peel loading so the FRP composite adherends may fail due to delamination induced damages before the adhesive fails. Also laminated FRP composite adherend will fail by interlaminar tension for a given load level at which the adhesive peel stresses exceeds the interlaminar strength. So the failure due to delamination will initiate at the overlap end of the joint.

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