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Hybrid Double Lap Joint in Laminated FRP Composites Analysis

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Abstract:

The present investigation deals with the static analysis of adhesively bonded inner tapered double lap joint in laminated FRP composites subjected to transverse loading using three-dimensional theory of elasticity based finite element method. Many researchers studied the influences of various parameters on the failure behaviour on the composites. In those studies, the typical bonding parameters are surface conditions, fillet, bond line thickness, and environmental conditions. In the present study the stresses and deformation characteristics of adhesively bonded inner tapered double lap joint made of generally and especially orthotropic laminates (FRP) subjected to transverse loading for the three different adhesive angles, three different adhesive thicknesses with different fibre angle orientations, i.e. the adhesive angles from 35^0 to 45^0 increased in steps of 5^0. The variation in stresses and deflection are studied when the fibre angle orientation is varied from 0^0 to 90^0 in steps of 15^0. The adhesive thickness varies from 0.05 to 0.15 insteps of 0.05mm. In all the above cases stresses and displacements at various locations are evaluated for the static boundary conditions.

Keywords — **Inner tapered double lap joint (ITDLJ), Finite element method (FEM), Fibre reinforced plastic (FRP), Boundary conditions (C-F), Double lap joint (DLJ).**

Notations:

σ_{xx}	Normal Stress in X – direction
σ_{yy}	Normal Stress in Y – direction
σ_{zz}	Normal Stress in Z – direction
τ_{xy}	Shear stress in – XY
τ_{yz}	Shear stress in –YZ
τ_{xz}	Shear stress in –XZ

INTRODUCTION

Fibre reinforced plastic (FRP) materials have proven to be very successful in structural applications. They are widely used in the aerospace, automotive and marine industries. FRP materials or composites behave differently than typical metals such as steel or aluminium. A typical composite contains layers of aligned fibres oriented at different angles held together by a resin matrix, giving high strength and stiffness in different directions. This anisotropy can cause difficulties when joining two parts together, especially if the two pieces have different stiffness and strength characteristics. The joint can potentially become the weakest link in the structure due to the large amount of load it must transfer. There are wide varieties of ways to join different parts together. Two major methods include mechanical fastening and adhesive bonding. Adhesive bonding of structures has significant advantages over conventional fastening systems. Bonded joints are considerably more fatigue resistant than mechanically fastened structures because of the absence of stress concentrations that occur at fasteners. Joints may be lighter due to the absence of fastener hardware. A major advantage of adhesive bonds is that adhesive bonds may be designed and made in such a way that they can be stronger than the ultimate strength of many metals in common use for aircraft construction.

The stresses induced at the interfaces of the adherends and adhesive play an important role in the design of adhesively bonded joints in FRP composites.

M.A. McCarthy et.al [1], investigated on issues in modelling the contact between the joint parts, which affect the accuracy and efficiency of the model are presented. Experimental measurements of surface strains and joint stiffness are compared with results from a finite element parameter study involving variations in mesh density, element order, boundary conditions, analysis type and material mode issues in modelling the contact between the joint parts, which affect the accuracy and efficiency of the model, are presented. Experimental measurements of surface strains and joint stiffness are compared with results from a finite element parameter study involving variations in mesh density, element order, boundary conditions, analysis type and modelling. The ability of the models to capture three-dimensional effects such as secondary bending and through-thickness variations in stress and strain is evaluated, and the presence of mathematical singularities in such models is highlighted.

K.Mohamed Bak [2], investigated on the, effect of adhesive thickness area of single lap joints in composite laminate and found that increasing the overlap adhesive thickness area results in significant reduction in the stress distribution throughout the joint.

T. Subramani[3] found that, the shear stress with hybrid joint has less value of stress and also the carbon fibre reinforced plastic is more strength than any other composite material. The stress induced by using ANSYS is less than the material ultimate stress and ultimate limit. The total deformation for both the materials in hybrid joint is less. It was found that a well designed hybrid joint is very efficient when compared.

P K SahooL et.al [4] investigated on geometrically non-linear analysis of adhesively bonded lap joints is presented using both linear and non linear material properties of the adhesive. The numerical results show beneficial effects of material non linear behaviour of the adhesive which decrease the stress concentration at the ends of the lap length

SolymanSharifi&NaghdaliChoupani[5] Presents the behavior of adhesively bonded joints subjected to combined thermal loadings, using the numerical methods.The joint configuration considers aluminum as central adherend with six different outer adherends including aluminum, steel, titanium, boronepoxy, unidirectional graphite-epoxy and cross-ply graphite-epoxy and epoxy-based adhesives. Free expansion of the joint in x direction was permitted and stresses in adhesive layer and interfaces calculated for different adherends.

M.Y.Tsai&J.Morton[6], Studies the mechanics of double-lap joints with unidirectional and quasi-isotropic composite adherends under tensile loading are investigated experimentally using moiré interferometry, numerically with a finite element method and analytically through a one-dimensional closed-form solution. A linear-elastic two-dimensional finite element model was developed for comparison with the experimental results and to provide deformation and stress distributions for the joints

Julia de Castro San Román[7]had done quasi-static tensile experiments on adhesively double-lap joint with different adhesive were performed in order to quantify the adhesive behaviour effect. The conclusions from the adhesive double-lap joint are:1) Adhesively-bonded joint efficiency using a highly nonlinear adhesive was greater than mechanical joint efficiency (50% according to Matthews (1987)) and thus adhesive-bonding is more appropriate to the anisotropic character and brittle behaviour of FRP materials. 2) The strain distribution across the joint width indicated higher strains at the edge than in the middle. The deviations reached 20% when assuming a transversal uniform distribution. Thus, a uniform approximation is assumed for numerical and analytical analyses leading to 2-D rather than 3-D models.

Ali Kaya[8], made research on Stress and strain distributions in the adhesive bonded joints subjected to distributed forces are investigated using finite element method. Two different cases are considered, the bonded materials are the same, and the bonded materials are different. The investigations are conducted on a three dimensional model. The finite element model of the joint is obtained using isoparametric three dimensional elements having eight nodes with three degrees of freedom each. The stress components and their distributions both on adhesive surface and on metallic elements are given in dimensionless form using three dimensional graphics.

O. ESSERSI et.al [9], investigates on the composite assembly's dynamic behaviour. In his investigation on the structural rate dependent behaviour of adhesively bounded double lap joints. High rate tests showed ringing in the force/displacement curves. An attempt was made to determine the origins of this phenomenon.

C. Pickthall, M. Heller &L.R.F. Rose[10], Characterisation of the stress reduction compared to the(non-yielding)elastic case, was sought by examining the influences of configurational parameters including plate,adhesive and reinforcement moduli, and adhesive yield stress. Finite element (FE) analyses were conducted for a two-dimensional section through a double-sided (symmetric) lap joint, representative of a typical repair. Stress reductions in the reinforcement of the order of 25% were found. The adhesive yield was shown to be dominated by shear stress, and thus the adhesive behaved essentially one dimensionally. The linear increase in plastic zone length with applied load, as predicted by the Hart-Smith one-dimensional theory, was in good agreement with the FE results. However the observed load transfer length was 6-18% longer than predicted.

N. States and K. L. DeVries[11],In his study the experimental and computational research exploring the means of enhancing the engineering design process for adhesive lap joints to include such effects. It clearly demonstrated that both the cleavage stresses and the shear stresses, near the bond termini, play important roles in lap 'shear' joint failure. Lap joints with similar geometries to those analyzed were designed, fabricated and tested. In a separate set of experiments the bond termini were constrained in the direction normal to the uniaxial loading. If the strength of lap shear joints is dominated by the adhesive shear strength, then constraining the lateral motion of the bond termini should have little or no effect on the overall shear strength of the adhesive joint.

Hart-Smith [12] in his extensive work on bonded joints has outlined various aspects of efficient bonded joint design in composite structures that an airframe designer should consider while designing bonded joints between components. He has also made many useful studies to analyze the load transfer mechanism in the adhesive bonded joints and outlined some practical ways to minimize the transverse shear and peel stresses in the adhesive layer.

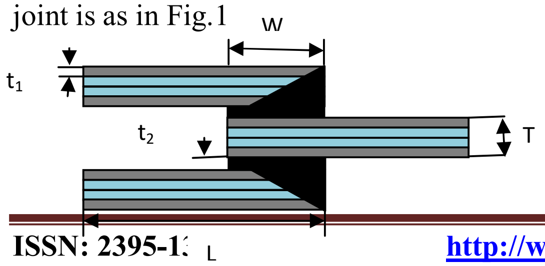
Yehia A. Bahei-El-Din et.al [13], Investigated on composite laminates to reduce or eliminate the failure modes associated with delamination and tensile and/or shear failure of the surface plies that are often observed in lap joints, and provide for a better stress distribution in the adhesive. In contrast to lap-joint designs, which transfer in-plane tensile stresses and other loads from the adherends to doubler plates by out-of-plane shearing of the surface plies, the new joint configurations transfer most of the load by in-plane shear and normal stresses, through bonded inserts or interlocking interfaces which have the same thickness as the laminate adherends. The stress concentrations often found in conventional designs, in the adherend surface plies and the adhesive layer at the leading edges of the doublers, are substantially reduced.

So far, the analysis of lap joints was done by others using isotropic materials, the current investigation deals with analysis of adhesively bonded inner tapered double lap joint in laminated FRP composites specially and generally orthotropic materials, subjected to loading as specified.

The objective of the present paper is to study the three-dimensional stress analysis of adhesively bonded inner tapered double lap joint subjected to transverse loading with boundary conditions. The analysis includes the evaluation of i) Inter-laminar normal stresses, ii) Inter-laminar shear stresses and deformation of the structures in x, y and z directions in laminates and adhesive.

PROBLEM MODELING:

The geometry of inner taper double lap joint is as in Fig.1



All dimensions are in mm.
Fig. 1Geometry of adhesively bonded inner tapered double lap joint

Table.1 shows the values of the stresses at the free surfaces where the stresses should be zero.

Node no:	Co-ordinate position in mm (x,y,z)	Stress in MPa		
		σ_{YY} in MPa	τ_{XY} in MPa	τ_{YZ} in MPa
1972	X=106.30 Y=16.05 Z=16.68	2.0274	-11.585	-12.243
1998	X=139.41 Y=16.05 Z=16.69	-1.1735	-4.4244	-3.0236
2008	X=117.06 Y=16.05 Z=10.43	1.3143	-9.6075	-9.7917
2011	X=152.11 Y=16.05 Z=14.98	-0.28585	-2.1480	-1.4248
2016	X=125.44 Y=16.05 Z=15.00	2.0638	-5.3229	-5.7281
3176	X=98.41 Y=24.1 Z=11.70	0.42735	-0.39895	0.82462E-01
3189	X=23.46 Y=24.1 Z=18.79	0.98400E-03	0.30369E-02	-0.39003E-02
3211	X=10.71 Y=24.1 Z=15.39	0.10875E-03	0.23612E-03	-0.76366E-03
3217	X=26.76 Y=24.1 Z=12.61	-0.18030E-02	0.55568E-02	-0.51859E-02
3221	X=53.33 Y=24.1 Z=12.71	0.26089E-03	0.22839E-01	-0.14398E-01

- T = Thickness of the Laminate = 8mm.
- t_1 = Thickness of each lamina = 2mm.
- t_2 = Thickness of Adhesive in between the two laminates = insteps of 0.05 up to 0.15
- L = Length of each laminate in X-direction= 100mm.
- W = Length of Adhesive in X-direction =20mm.
- α = Adhesive angle in degrees.

The width of the Laminate in Z-direction=25mm

FINITE ELEMENT MODEL

The finite element mesh is generated using a three-dimensional brick element'SOLID185' of ANSYS. It is used for 3-D modelling of solid structures. It is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, hyper elasticity, stress stiffening, creep, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyper elastic materials.

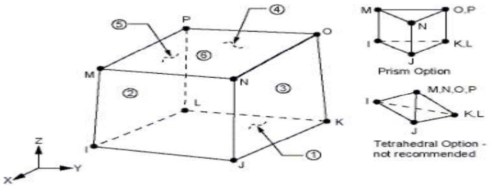


Fig.2 SOLID 185˚element

Loading

A uniform transverse load of 10 KN is applied.

Boundary Conditions

For the purpose of validation, one of the joint is clamped and the other end is restricted to move in the transverse direction.

Mechanical properties

The following mechanical properties are considered

1. T300/934Graphite/epoxy FRP (adherent)

Ex = 127.5 GPa,
Ey = 9.0 GPa, Ez = 4.8GPa.
υxy= υxz= 0.28, υyz= 0.41.
Gxy=Gxz= 4.8 GPa, Gyx=2.55 GPa

2. Epoxy (adhesive)

Young's Modulus = 2.8 GPa.
Poisson's Ratio= 0.4.

Laminate sequence

Three $+\theta^0/-\theta^0/-\theta^0/+\theta^0$ laminated FRP composite plates are used as adherends for the present analysis. The value of θ is measured from the transverse direction of the structure (x-axis) and varied from 0^0 to 90^0 in steps of 15^0 is considered.

Laminated joint design & meshing:

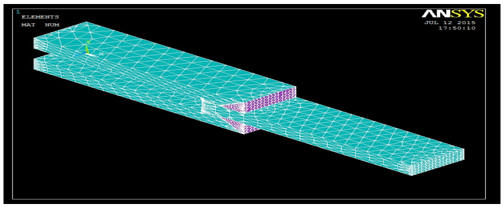


Fig.3. Loading of Inner taper double lap joint in laminated FRP

Loading of Inner taper double lap joint in laminated FRP

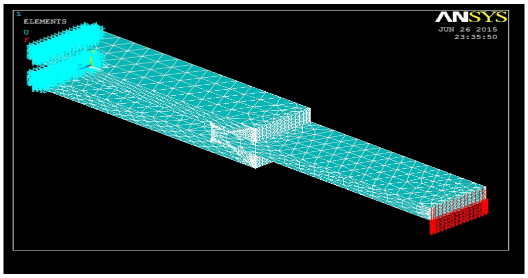


Figure.3.1 shows transverse loading of a Inner taper double lap joint in laminated FRP

RESULTS:

I.)Variations of maximum stresses in the joint with respect to fibre angle θ

For adhesive angle α=45⁰

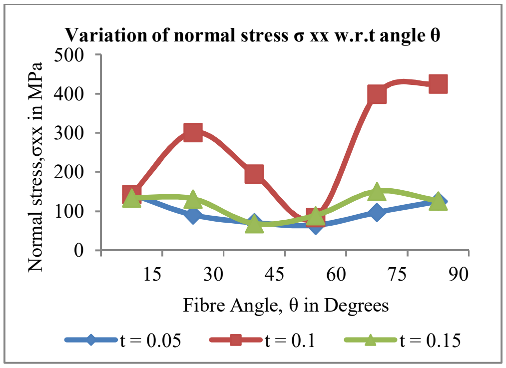


Fig-4: Variation of normal stress σ xx w.r.t angle θ.

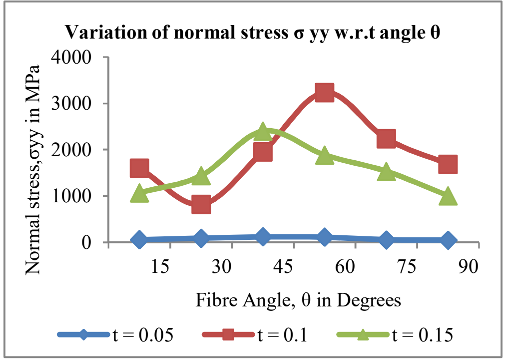


Fig-5: Variation of normal stress σ yy w.r.t angle θ.

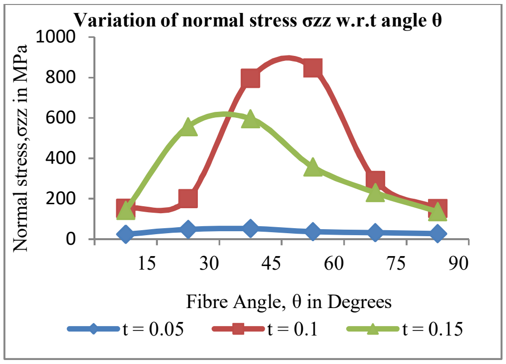


Fig-6: Variation of normal stress σzz w.r.t angle θ.

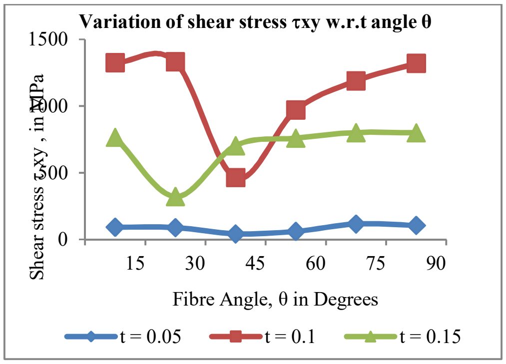


Fig-7: Variation of shear stress τxy w.r.t angle θ .

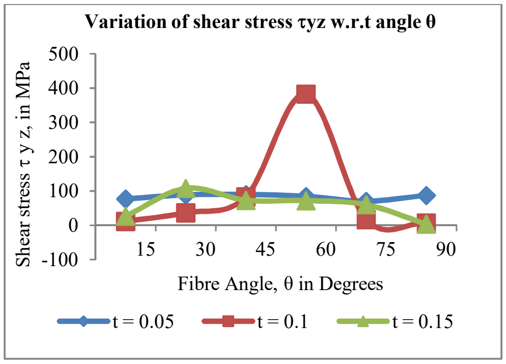


Fig-8: Variation of shear stress τyz w.r.t angle θ.

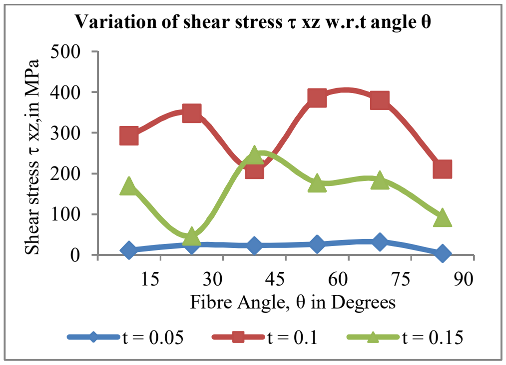


Fig-9: Variation of shear stress τyz w.r.t angle θ .

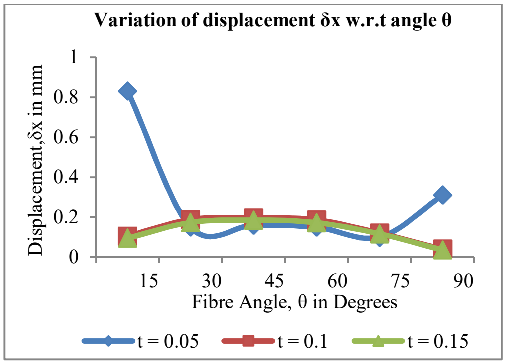


Fig-10: Variation of displacement δx w.r.t angle θ .

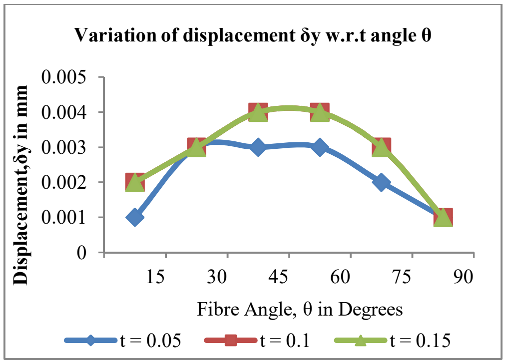


Fig-11: Variation of displacement δy w.r.t angle θ .

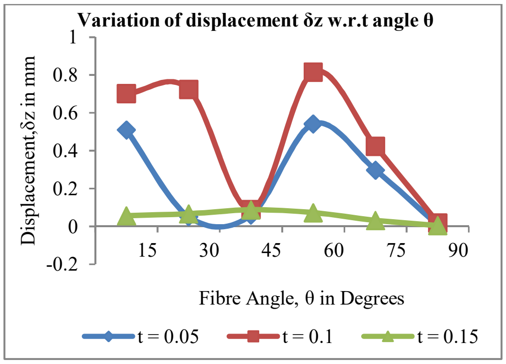


Fig-12: Variation of displacement δz w.r.t angle θ **.**

II.)Variations of maximum stresses in the adhesive of joint with respect to fibre angle θ

For adhesive angle $\alpha=45^0$

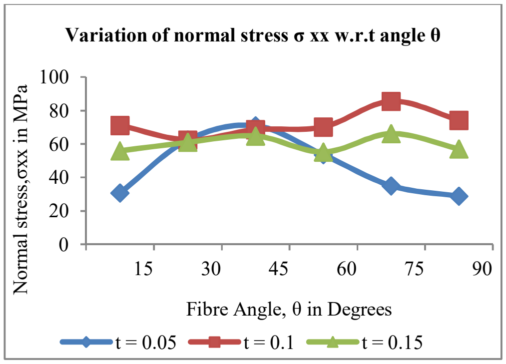


Fig-13: Variation of normal stress σ xx w.r.t angle θ

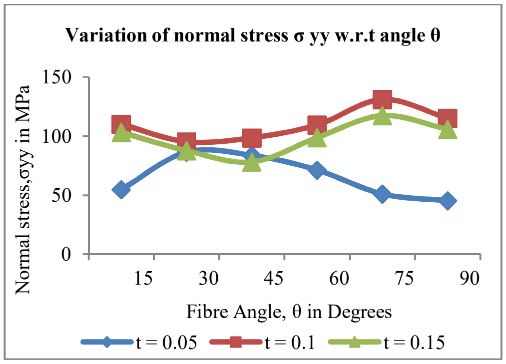


Fig-14:Variation of normal stress σ yy w.r.t angle θ .

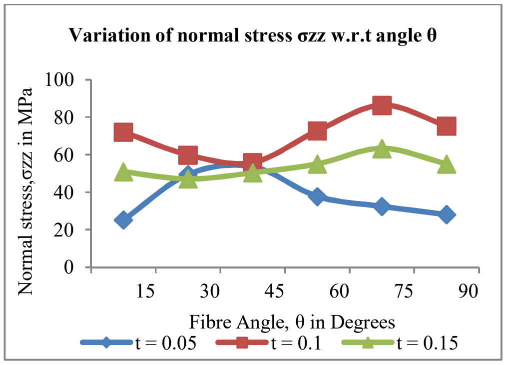


Fig-15:Variation of normal stress σzz w.r.t angle θ .

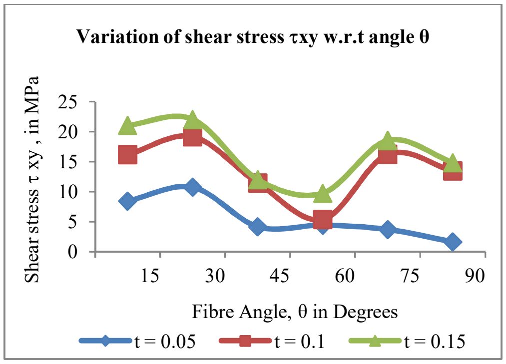


Fig-16: Variation of shear stress τxy w.r.t angle θ .

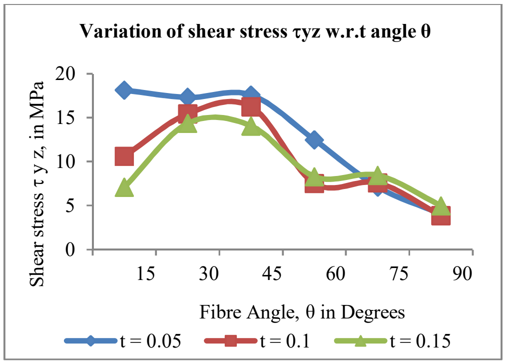


Fig-17: Variation of shear stress τyz w.r.t angle θ .

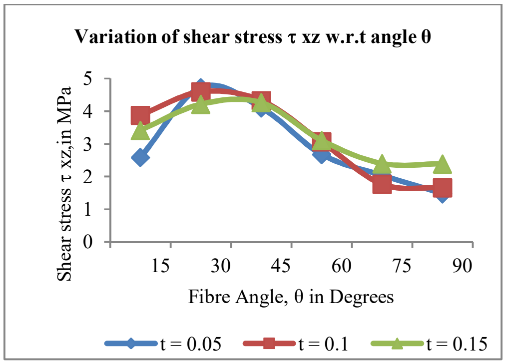


Fig-18: Variation of shear stress τ xz w.r.t angle θ .

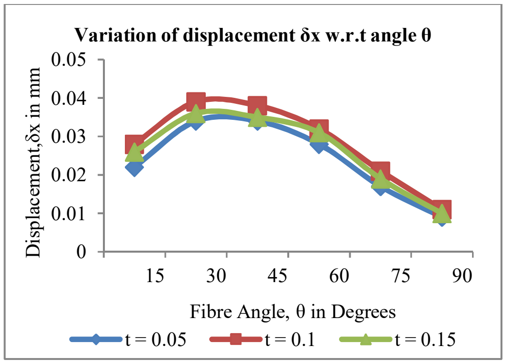


Fig-19: Variation of displacement δx w.r.t angle θ .

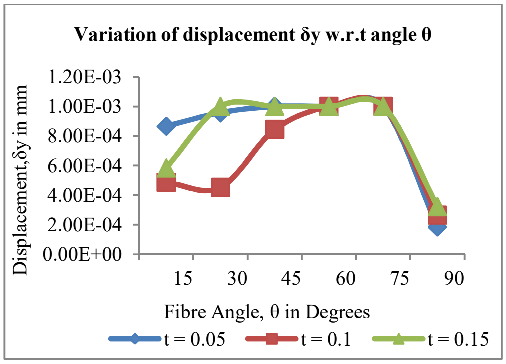


Fig-20: Variation of displacement δy w.r.t angle θ.

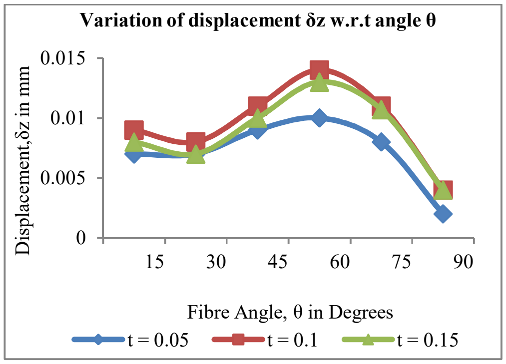


Fig-21: Variation of displacement δz w.r.t angle θ .

DESCRIPTION:

Variation of normal stresses increases with increase in fibre angle, and normal stress is maximum at 60^0,in σyy & σzz.In σxx stress is minimum at 60^0 .In adhesive normal stress is minimum for the thickness 0.05.

Variation of shear stresses increases with increase in fibre angle, stress is minimum for the thickness 0.05 in all the cases. In adhesive shear stress is minimum for the three different thicknesses in τxy, τyz,τxz respectively.

Variation of displacement increases in dy, dz and is maximum at 50^0 ,and in adhesive displacement is minimum for 0.05 thickness.

CONCLUSIONS:

Three-dimensional finite element analysis has been taken up for the evaluation of stresses and deflections of the joint and adhesive in inner tapered double lap joint made of laminated FRP composites of generally and specially orthotropic nature subjected to transverse loading. The following conclusions are drawn.

- The fibres can be oriented at an angle ranging from 0° to 30° and so that the stresses developed in the joint will be minimum
- Displacement is minimum for the thickness 0.05, and it is preferred for applications.
- Stress formed in the adhesive minimum for the thickness 0.05 for the joint without delamination.
- It is also observed that the coupling effect in the laminate influences the deflection and stresses, and causing for the increase in their magnitudes up to some value of fibre angle and then decreasing of the values later.
- The inter-laminar normal stresses σ xx and σ zz are observed to be very high when compared with lower and upper adhesive, results in either light fibre tear failure or stock break failure. This failure can be prevented by using fibre angle orientation 0^0-$15^{0.}$

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