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Analysis of Double Riveted Single Lap Joint in Laminated FRP Composites Subjected to Transverse Loading

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Abstract—*The present investigation deals with the static analysis of Double riveted single lap joint in laminated FRP composites using three-dimensional theory of elasticity based finite element method. The finite element model is validated for the longitudinal loading and is extended for the analysis of a Double riveted single lap joint made of generally and specially orthotropic laminates subjected to Transverse loads for different fiber materials. Maximum stresses in the structure are computed and the effect of fiber angle on these stresses is studied. The results of the present analysis reveals that the three-dimensional stress analysis is required for the analysis of Double riveted lap joint in laminated FRP composites.*

1. INTRODUCTION

Fiber 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 aluminum. A typical composite contains layers of aligned fibers 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.

Delale et.al (1) developed a closed form solution for lap-shear joints with orthotropic adherend using classical plate theory. Suyogkumar W. Balbudhe, S. R. Zaveri (2) have carried out stress analysis of riveted lap joint. Stress and fracture analysis are done by them for both the residual stress field and external tensile loading using finite element method. S.Venkateswarlu**,** K.Rajasekhar (3) has developed analysis of single lap joint subjected to tensile load and the stress distribution in the members under various design conditions. They have found vonmises stress, shear stress, and normal stress for stress distribution. Ch. Aswini Kumar, G.Pattabhi, S.Santosh, I.Bhanu Latha (4) have carried out the Analysis of Adhesively Bonded Double Lap Joint in Laminated FRP Composites Subjected To Longitudinal Loading. They have found normal and shear stresses in the structure for different adhesive thicknesses.The displacements in laminates and as well as adhesive are also computed.

Adams (5) predicted strength for lap joints especially with composite adherends by classical linear elastic solution. He also introduced Volkerson's shear lag equation that calculates shear stress in the adhesive.

Panigrahi and Pradhan (6) has developed a three dimensional finite element analysis to compute the out-of-plane normal and shear stresses in an adhesive bonded single lap joint made of specially orthotropic laminates subjected to longitudinal loading. They proved that the three dimensional effects exists in the joint. They also found that the peel stresses are extremely sensitive to the three dimensional effect, but the shear stresses are not. Tong (7) investigated the strength of adhesive bonded composite double-lap joints. Due to the fact that failure often occurs at the resin-fiber interface adjacent to the adhesive. Tong used a simplified I D model as well as a finite element model in conjunction with several existing and new inter-laminar failure criteria to predict the strength of joints. Huang et.al (8) has developed an analytical model to determine the stress and strain distributions of single lap adhesive bonded composite joints under tension. They have used laminated plate theory in defining the mechanical behavior of the composite adherends.

Li et.al (9) considered the geometrical non-linear effects on the adhesive stress and strain distribution across the adhesive thickness in a composite single-lap joint. They showed that the tensile peel and shear stresses at the bond–free edges changed significantly across the adhesive thickness and became increasingly higher with distance from the center line and the peak near, but not along, the adherend-adhesive interface.

Tsai (10) and Morton analyzed a single-lap joint with laminated polymeric composite adherends and with a spew fillet, subjected to tensile loading. They used finite element analysis for this problem to address the mechanics and deformation of such a material and bonding configuration.

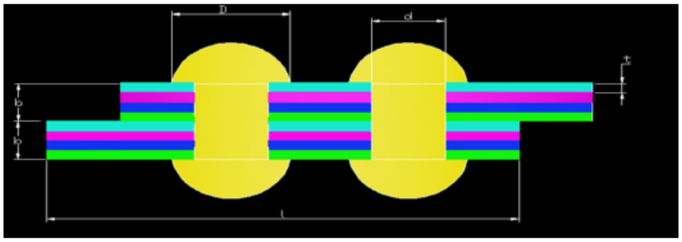
Very few works appear to have been made on the performance of Double riveted single lap joint in isotropic materials. No significant work has been reported for the analysis of Double riveted single lap joint in Laminated FRP composites. In this paper, attempts are made to study the stresses and deformation characteristics of Double riveted single lap joint made of generally and specially orthotropic laminates (FRP) subjected to Transverse loading with C-C end conditions. The analysis includes the evaluation of normal stresses, shear stresses and deformations in the structure.

2. PROBLEM MODELING

2.1 Geometry

The geometry of the Double riveted lap joint used is as shown in Fig. 1.

Thickness of the each layer (t) = 4 mm,
Thickness of the plate (b) = 16 mm,
Rivet head diameter (D) = 38.4 mm,
Length of each plate (l) = 153.6 mm and
Diameter of rivet hole (d) = 24 mm.



All dimensions are in mm

Fig. 1: Geometry of Double riveted single lap joint

2.2 Finite Element Model

The finite element mesh is generated using a three-dimensional brick element 'SOLID 45' of ANSYS [14]. This element (Fig. 2) is a structural solid element designed based on three-dimensional elasticity theory and is used to model thick orthotropic solids. The element is defined by 8 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions.

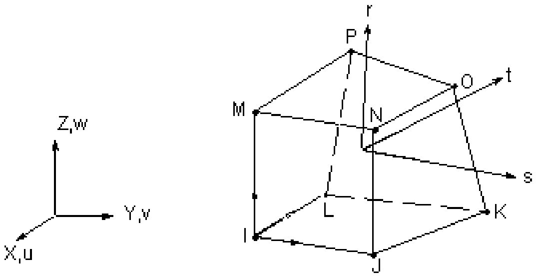


Fig. 2: SOLID 45 Element

2.3 Loading

The following types of loads are applied for validation and prediction of the response of the structure for the present analysis.

i) A force of 69120 N in transverse direction is applied for the prediction of the response of the structure for the present analysis.

2.4 Boundary Conditions

In this case, Both the ends are fixed and a load of 69120 N is applied at the top surface.

2.5 Material Properties

The following mechanical properties are used for the validation purpose.

Graphite/epoxy FRP (adherend):

$E_X = 127.5$ GPa;$E_Y = 9.0$ GPa;$E_Z = 4.8$ GPa;

$\nu_{XY} = \nu_{XZ} = 0.28$; $\nu_{YZ} = 0.41$;

$G_{XY} = G_{XZ} = 4.8$ GPa;$G_{YZ} = 2.55$ GPa

Glass FRP (adherend):

$E_X = 41$ GPa; $E_Y = E_Z = 10.4$ GPa;

$\nu_{XY} = \nu zx = 0.28$; $\nu_{YZ} = 0.50$;

$G_{XY} = Gxz = 4.3$ GPa;$G_{YZ} = 3.5$ GPa

kevalar FRP (adherend):

$E_X = 80$ GPa; $E_Y = E_Z = 5.5$ GPa;

$\nu_{XY} = \nu zx = 0.34$;$\nu_{YZ} = 0.40$;

$G_{XY} = Gxz = 2.2$ GPa;$G_{YZ} = 1.8$ GPa

Steel :

Young's Modulus = 210 GPa ;

Poisson's Ratio=0.27

Epoxy (adhesive)

Young's Modulus = 5.171 GPa ;

Poisson's Ratio=0.35

2.6 Laminate sequence

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

3. RESULTS

3.1 Finite element Mesh

Fig.3and Fig.4 shows the finite element mesh of Double riveted single lap joint and rivets.

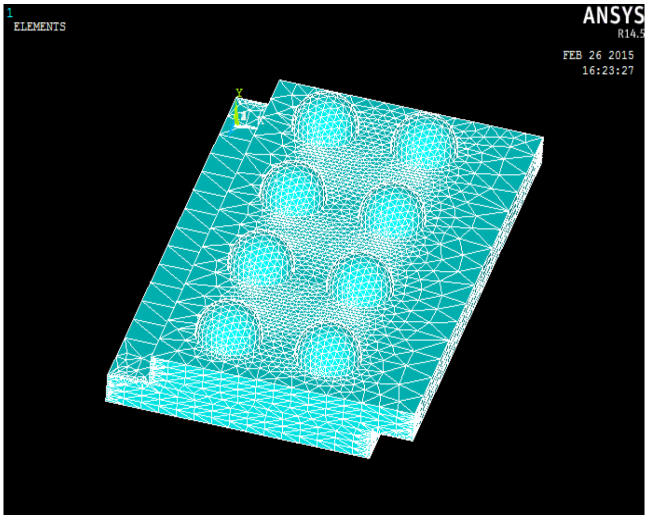


Fig. 3: Finite element mesh of Double riveted single lap joint

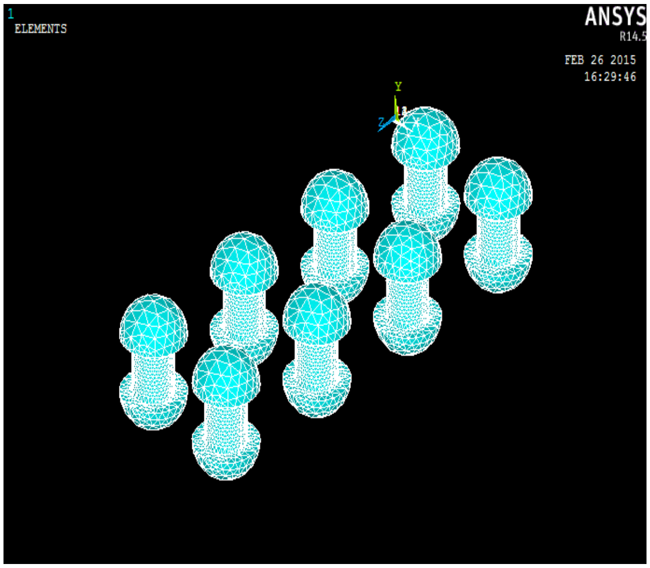


Fig. 4: Finite element mesh of rivets

3.2 Variation of the maximum stresses in the laminates with respect to the fiber angle θ

One of the reasons for the variation of the stresses across the width of the laminate is due to the non-uniform arrangement of the fibers in the width direction except at $\theta=0^0$ and 90^0. The second reason is due to the coupling between bending, shear, and extensions in the deformations of the laminates. Another reason is due to the inter-laminar effect at the free edges of the structure.

The figures 5 to7 shows the variation of normal stresses in the structure for different fiber materials of different fiber angle orientations.

The normal stress σ_{xx} is observed to be very less at Cfrp and Kfrp at fiber angle orientations of 60^0. The normal stress σ_{yy} is observed to be very less at Cfrp and Kfrp at fiber angle orientations of 15^0. The normal stress σ_{zz} is observed to be very less at Cfrp and Gfrp at fiber angle orientations of 15^0.The magnitude of normal stress σ_{zz} is less at all the fiber angles for fiber materials Cfrp and Gfrp.

The figures 8 to10 shows the variation of shear stresses in the structure for different fiber materials at different fiber angle orientations.

The shear stress τ_{xy} is observed to be very less at Gfrp and combination of Gfrp&Kfrp at fiber angle orientation of 0^0. The shear stresses τ_{yz} , τ_{zx} are observed to be very less at Gfrp and combination of Gfrp&Kfrp at fiber angle orientations of 0^0.

The figures 11 to13 shows the variation of displacement in the structure for different fiber materials at different fiber angle orientations. The displacements of structure is less for cfrp material at 15^0 fiber angle orientation.

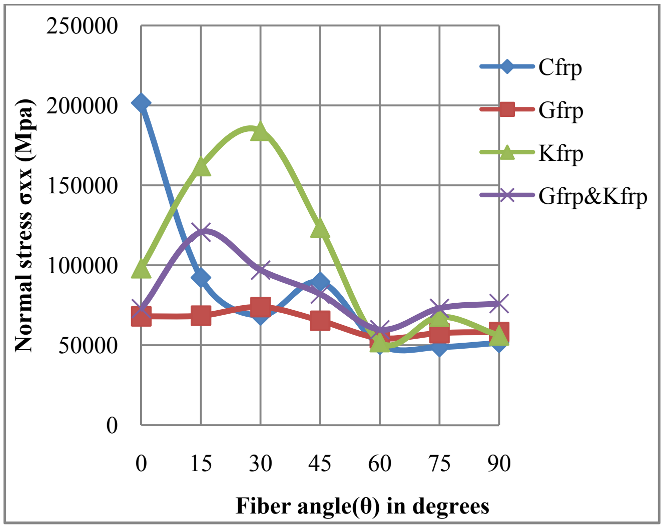


Fig. 5: Variation of σ_{xx} w.r.t θ

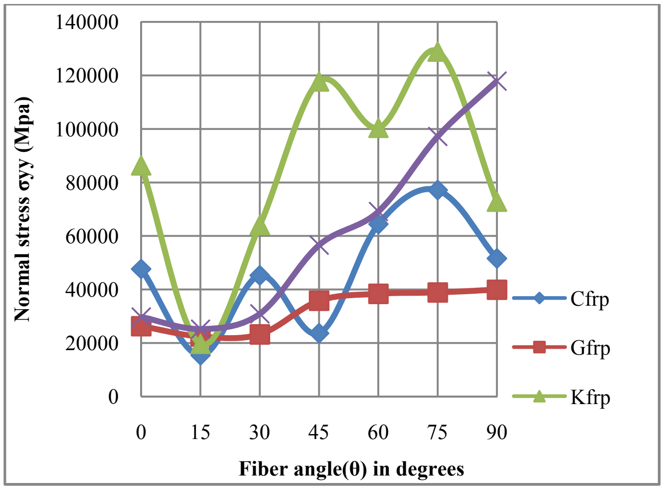


Fig. 6: Variation of σ_{yy} w.r.t θ

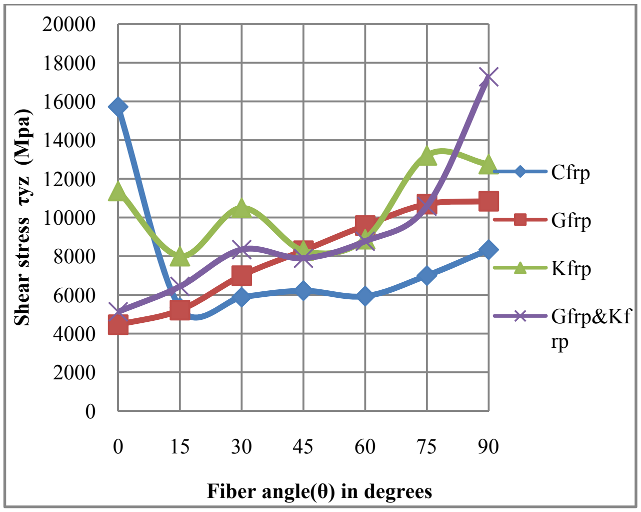


Fig. 9: Variation of τ_{yz} w.r.t θ

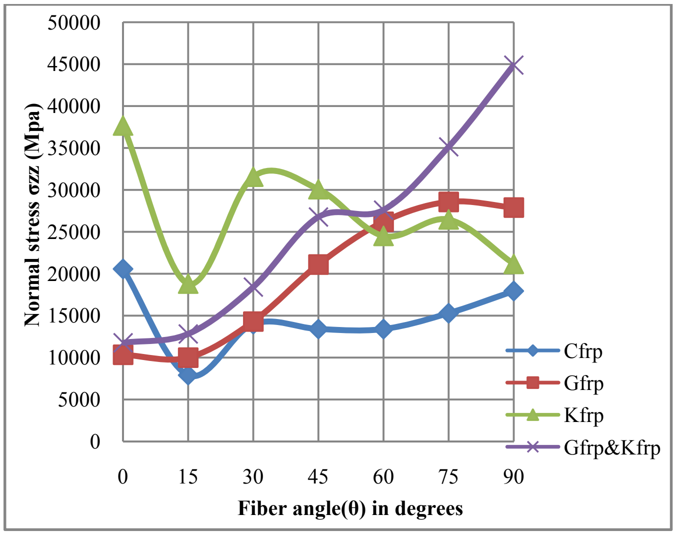


Fig. 7 Variation of σ_{zz} w.r.t θ

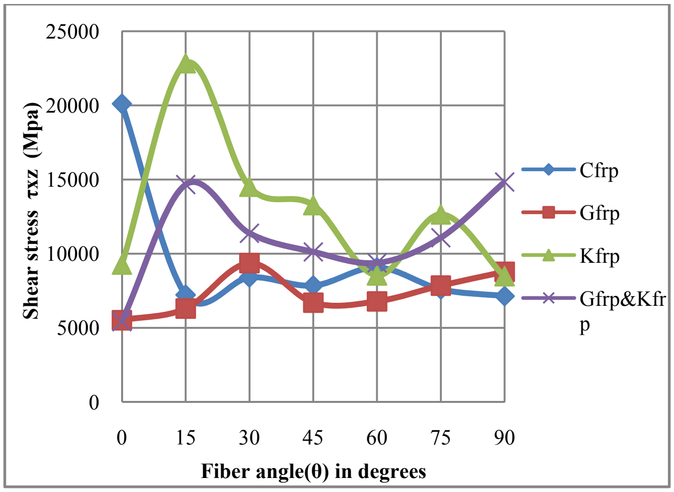


Fig. 10: Variation of τ_{zx} w.r.t θ

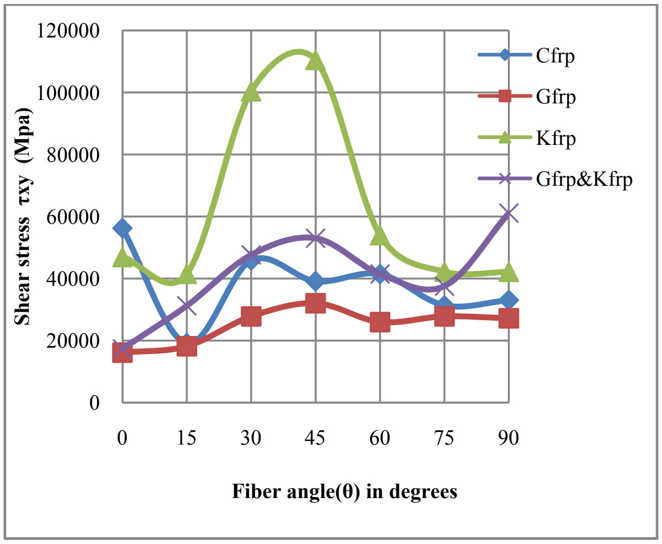


Fig. 8: Variation of τ_{xy} w.r.t θ

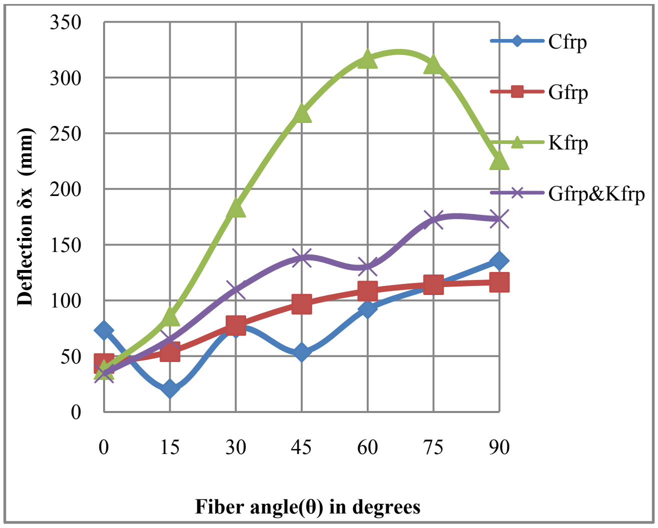


Fig. 11: Variation of displacement δ_x w.r.t to θ

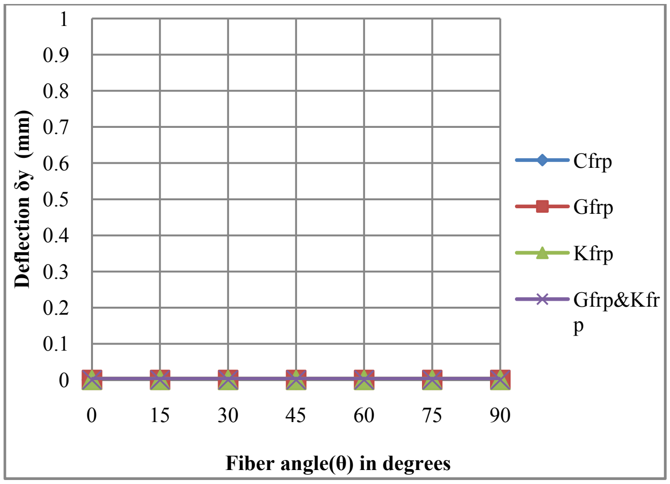


Fig. 12: Variation of displacement δ_y w.r.t to θ

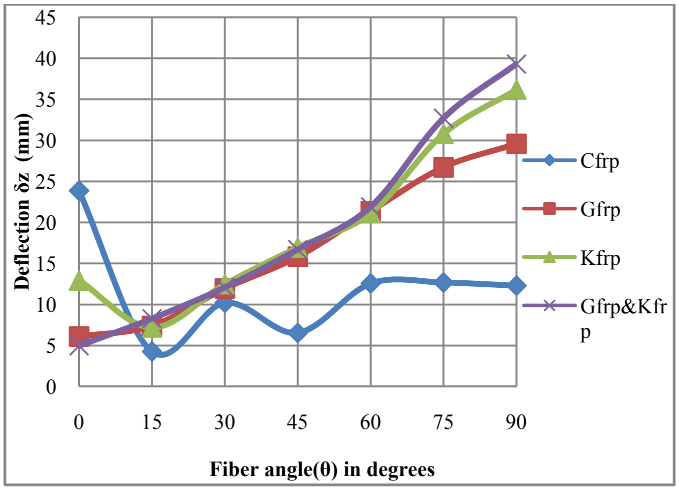


Fig. 13: Variation of displacement δ_z w.r.t to θ

4. CONCLUSIONS

Three-dimensional finite element analysis has been taken up for the evaluation of the stresses and deformations in the structure in Double riveted single lap joint made of FRP laminates of generally orthotropic nature subjected to Transverse loading. The following conclusions are drawn:

- Variation of the stresses in the width direction is significant and therefore three- dimensional analysis is necessary.
- Intensity of normal stresses found is minimum between 0^0 and 15^0 for the GFRP fibre .The fiber angle range from 0^0 to 15^0 is recommended as the stresses are observed to be minimum in that range.
- The fiber angle range from 0^0 to 15^0 is recommended as all shear stresses are observed to be minimum in that range for GFRP fibres.
- 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 fiber angle and then decreasing of the values later.
- The displacement of the structure δ_x , δ_z is increasing with the increase of fibre angle θ for Transverse loading. The displacement of the structure δ_y is zero for all fibre materials at all fibre angle orientations.

REFERENCES

[1] Delale, F., Erdogan, F., and Aydinogluy, M.N., ‘Stresses in adhesively Bonded Joints: A closed-form solution’, Journal of Composite Materials, 15, 1982, p249-271.

[2] Suyogkumar W. Balbudhe, S. R. Zaveri“stress analysis of riveted lap joint subjected to tensile loading”, International Journal of Engineering Research & Technology (IJERT) Vol. 2 Issue 3, March – 2013,ISSN: 2278-0181

[3] S.Venkateswarlu1**,** K.Rajasekhar “analysis of single lap joint in laminated Frp composites subjected to tensile loading”, Journal of Mechanical Engineering (IOSR-JMCE) e-ISSN:2278-1684,Volume 6,Issue 6 (May. - Jun. 2013), PP 01-06s

[4] Ch. Aswini Kumar1, G. Pattabhi2, S.Santosh3, I. Bhanu Latha4, Analysis of Adhesively Bonded Double Lap Joint in Laminated FRP Composites Subjected To Longitudinal Loading, I*nternational journal of engineering science & advanced technology volume-2, issue-2, 307 – 316 ijesat | Mar-Apr 2012.*

[5] Adams,R.D., ‘Strength predictions for lap joints especially with composite Adherends: A Review’, J. Adhesion, Vol.30, 1989, p219-242.

[6] Panigrahi, S.K., and Pradhan, B., ‘Three Dimensional Failure Analysis and Damage Propagation Behaviour of Adhesively Bonded Single Lap Joints in laminated FRP Composites’, Journal of Reinforced plastics and Composites, Vol.26, No.2, 2007, p183-200.

[7] Tong, L., ‘An assessment of failure criteria to predict the strength of Adhesively bonded composite double lap joints’, J. of Reinforced plastics & composites, 16 (8),1997, p698-713.

[8] Huang, H., Yang, C., and Tomblin, J.S, Harter, P., ‘Stress and Failure analysis of Adhesive-Bonded composite Joints using ASTM D31 Speciments’, Journal of compositesTechnology and Research, V. 24, 2, 2002, ISSN: 0884-6804.

[9] Li, G., Lee-Sullivan, P., and Thring, R.W., ‘Non-linear finite Element analysis of stress and strain distributions across the adhesive thickness in composite single-lap joints’, Composite Structures, 46 (4), 1999, p395-403.

[10] Tsai, M.Y., and Morton. J., ‘Experimental and numerical studies of a laminated composite single-lap Adhesive Joint’, Journal of composite Materials, Vol.29, No.9, 1995, p527-538.

[11] Jones, R.M., ‘Mechanics of Composite Material’,Scripta book company, Wasington , D.C, 1975.

[12] Isaac, M.D., and Ishai Ori., ‘Engineering Mechanics of Composite Materials’, Oxford University Press, 1994.

[13] Mallick, P.K., ‘Fiber-reinforced Composites’, MARCEL DEKKER, INC, 1988, P159- 162.

[14] ANSYS reference manuals (2006).

[15] A Text Book Of Machine Design by V.B.Bhandari, R.S.kurmi, J.K.Gupta

[16] Introduction to Finite Elements in Engineering Tirupathi R.Chandrupatla / Ashok D.Belegundu