Stress Analysis of Adhesively Bonded Hybrid Tubular Lap Joints in Laminated Frp Composites

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Abstract. Tubular composite structures are used extensively in the petroleum, chemical, and aerospace sectors for the transportation of diverse fluids. Among these applications Adhesive bonded laminated Tubular Single Lap Joints (TSLJ) are one of the utmost common type of lap joint. In present paper stress analysis is carried out to examine the stress behaviour & failure characteristics with effect of different adhesive thicknesses in Hybrid Tubular Lap Joints (HTLJ) with interlayer hybridization under tensile loading. The adhesively bonded Hybrid Tubular bonded lap joint was subjected to three-dimensional stress analysis using the appropriate ANSYS Parametric Design Language (APDL) of ANSYS 2020R1. Based on the evaluation of magnitude of stresses and failure index of TSLJ and HTLJ it is revealed that it marginally effects within the adhesive mid layer. Examining the numerical results it is observed that adhesive thickness influence stresses in mid adhesive layer by introducing interlayer hybridization of composite adherends.

Keywords: HTLJ · TSLJ · FRP composites

1 Introduction

Adhesive bonded tubular composite structures are used extensively in many industries like aerospace and chemical industries. Laminated tubular adhesive bonded lap joints are the utmost common type of lap joints in application of energy and construction industries. Interlayer hybrid Composite pipes have also been used for fluid transportation in waste water treatment systems, power and petroleum production, and other industries. The strength efficiency and life time of tubular bonded joints can be enhanced by lowering stress concentrations at the ends of over-lap & uniformly distributing the stresses over complete bond length. A significant amount of literature on stress analysis of adhesive-bonded Tubular lap joint (TLJ) is available. The literature related to hybrid laminated FRP TLJ are very limited. The stresses in tubular structures undergoing axial load in which the tubes are considered to be of reduced thickness for which the thin-shell theory was applied to create stress field. Further it was assumed that magnitude of peel & shear stresses in the two tubes is insignificant relative to the stresses in the adhesive layer [1, 2].

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Analyzed an adhesive tubular joint obeying a nonlinear stress-strain law subjected to an uniaxial load revealed that non-linear performance of adhesive in TLJ makes it to predict a substantial lowering in the max. Stresses at the ends [3]. An approximate closed-form solution to satisfy equilibrium equations based on complementary energy principle was presented. It was observed that high shear stress concentrations and maximum stress occur at ends of joint region [4]. Stress distributions in adhesively bonded with two dissimilar orthotropic laminated cylindrical shell elements. The geometrical parameters are specially effect the stress allocation in the mid layer of adhesive [5]. Analytical model was compared with numerical method of composite pipe joint under tensile load based on laminated anisotropic plate theory and also variation principle applied to the model and accomplished [6, 7]. Distribution of stresses in adhesive with Hybridization effect, stacking sequence on overall performance of hybrid filament composite tubes was investigated [8]. By varying a modulus graded bond line adhesive the distribution of stresses are reduced in joint region under the tensile loading was performed [9]. Numerical analysis of laminated FRP composite tubular adherends subjected to tensile load for proper joint performance was performed [10]. The appropriate overlap length was determined using the Tsai-Wu failure criterion. Hybrid effect in composite tubes under axial compression concluded that with hybrid effect strength and stiffness of hybrid tubes was improved compare to conventional tubes [11]. The effect of stacking sequences and orientation angles influence the stress distributions through thickness direction in hybrid composite tubes was performed [12].There are different parameters which influence the stresses in the joint region are adhesive thickness, adherend thickness, overlap length, stacking sequence and orientation angle. In current study aims to develop a numerical model of Hybrid Tubular Lap Joint and analyze the stress concentrations in the mid adhesive layer by varying adhesive thickness 0.1mm, 0.15mm and 0.2mm for overlap length of 20mm under tensile load of 10Mpa.

2 Geometry and Boundary Conditions of HTLJ

The geometrical parameters and boundary-conditions for HTLJ has been examined in the current analysis which was taken from the work of Pradhan [10]. Hybrid Tubular Lap Joint with interlayer hybrid FRP tubular adherends with two materials properties of T300-graphite/epoxy and E-glass/epoxy and adhesive epoxy and geometrical properties are considered from reference of Pradhan [10] and Thomsen [5]. And was shown in Table 1 the sectional view of HTLJ was shown in Fig. 1 (Table 2).

3 Finite Element Modelling Of HTLJ

Modelling of HTLJ was done by using ANSYS 2020R1. For modelling the adherends and adhesive- layer the solid 185, 8-node brick elements have been used. The geometrical model of HTLJ and lay up sequence as shown in Fig. 2(a) and (b). At the ends of the joint a refined mesh has been adopted. Simulating boundary conditions of HTLJ under axial load all the nodes have been restrained at the clamped end $U = V = W = 0$ at outer adherend & $U = 0$, at the loaded end of inner adherend. The mesh pattern should be made finer at joint & coarse towards boundary edges which is shown in Fig. 3(a) and (b).

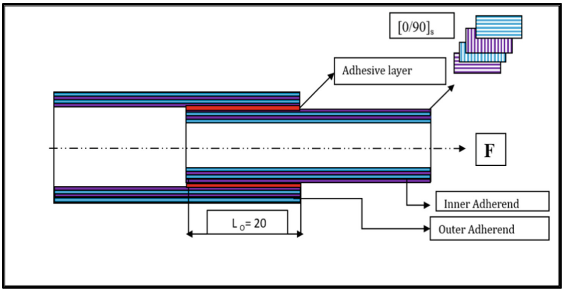

Fig.1. Sectional view of Hybrid Tubular lap joint

Table 1. Material properties of composite adherends & adhesive

Adherend & Adhesive Materials	**Material-constants**	**Material strengths**
1. T300/934 - graphite/epoxy	$E_Z = 127.5$GPa $E_r = 4.8$ GPa $E_\Theta = 9$Gpa,$\upsilon_{zr} = \upsilon_{z\Theta} = 0.28$ $\upsilon_{\Theta r} = 0.41$, $G_{zr} = G_{z\Theta} =$ 4.8GPa $G\Theta r = 2.55$GPa	$Z_T = 1586$ MPa $Z_C = 1518$ MPa $\Theta_T = \Theta_C = 80$MPa $R_T = R_C = 49$ MPa
2. E-glass/epoxy	$E_r = 41.4$Gpa,$E_\theta = E_z =$ 10.4Gpa $Gr\theta = Grz = 5.1$GPa, $G_{z\Theta} =$ 4.1GPa $\upsilon_{r\theta} = \upsilon_{rz} = 0.24$ $\upsilon_{\theta z} = 0.21$	$Z_T = 1340$ MPa $Z_C = 541$ MPa $R_T = 288$MPa $R_C = 100$MPa
3. Epoxy-Adhesive	$E = 2.8$ GPa $\upsilon = 0.4$	Yield-strengths: $Y_T = 65$MPa $Y_C = 84.5$MPa

Table 2. Geometric parameters of Composite adherends

Geometry	Magnitudes
Adherend lengths	$L = 80$ mm
Overlap length	$l = 20$ mm
Adhesive thickness	$ta = 0.15$ mm
Adherend thickness	$t_1 = t_2 = 1$ mm
Inner-radius of inner-Adherend	18.9 mm
Inner-radius of outer-Adherend	20.05 mm

For better results. Such that finer mesh toward joint region is observed to concede stress gradients in the mid-adhesive which relates well with the literature. The stress results are

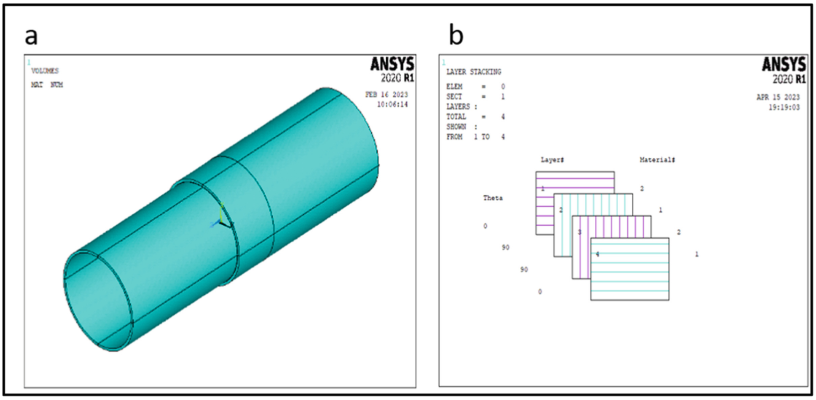

Fig. 2. (a) Geometrical model of bonded HTLJ (b) lay-up sequence of HTLJ.

high at joint ends in over-lap region. The numerical outcomes are good understanding with available literature. It was shown in Figs. 4 and 5.

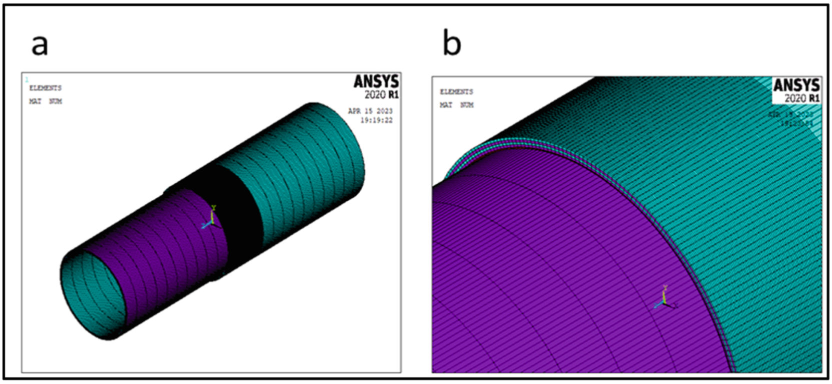

Fig. 3. (a) Finite element mesh model of HTLJ (b) Overlap region of HTLJ

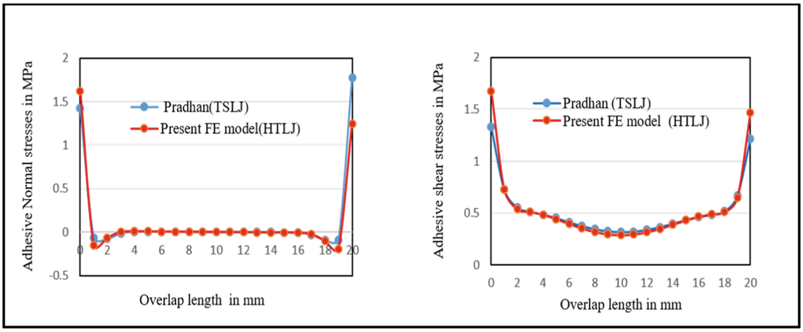

Fig. 4. Adhesive Normal and shear stresses distribution in HTLJ and Pradhan (TSLJ).

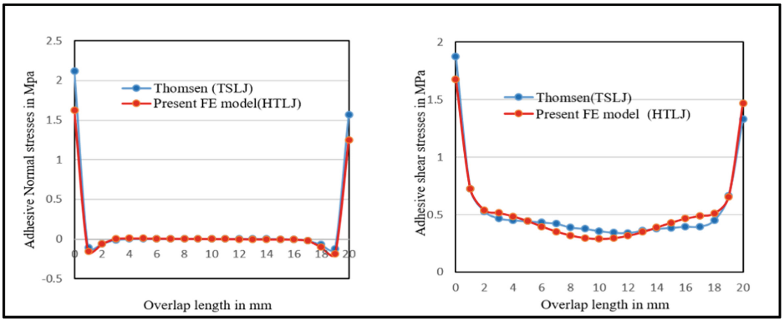

Fig. 5. Adhesive Normal and shear stresses distribution in HTLJ and Thomsen (TSLJ)

4 Failures studies of adhesive-bonded TLJ

In Composite adhesive-bonded tubular lap joints the interfaces between adherend & adhesive in the joint areas are critical bond line areas. These critical bond line regions are considered as failure regions. The three bond line interfaces: (i) the inner adherend & adhesive interface (ii) the adhesive mid-surface (iii) the outer adherend & adhesive interface. Failure-index (e) is the variable that estimate the state of adhesive bonded TLJ. If the failure-index value e $\geq$ 1 failure occurs. To evaluate the failure-index value in mid adhesive layer of HTLJ the parabolic yield criterion was taken [12].

$$(\sigma_1 + \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 + 2(/Y_C/ - Y_T)(\sigma_1 + \sigma_2 + \sigma_3) = 2/Y_C/Y_T e \quad (1)$$

σ_1, σ_2 and σ_3 = Principal stresses
Y_C and Y_T = compressive & tensile yield strengths.

5 Results and Discussion

The Numerical study is done to account the influence of geometrical parameter i.e. adhesive thickness on stresses at joint edges of over-lap area of joint. The validation results of HTLJ revealed that the stress values are high at the edges of the joint. Which are similar with TSLJ results of available literature. It was observed from Fig. 6. The numerical outcomes are good understanding with analytical results of Pradhan [10] and Thomsen [5].The stresses in mid-adhesive layer of HTLJ for all adhesive thickness was compared with the work of Pradhan [10].

5.1 Normal Stress Distributions Within the Adhesive Mid Layer of HTLJ With Effect of Varying Adhesive Thickness

From Fig. 7. The Normal stress profiles have similar tendency in both TSLJ and HTLJ where the magnitude of stresses 2% increase 0.1mm adhesive thickness and 1% increase for 0.15mm and 0.2mm of adhesive thickness in HTLJ.

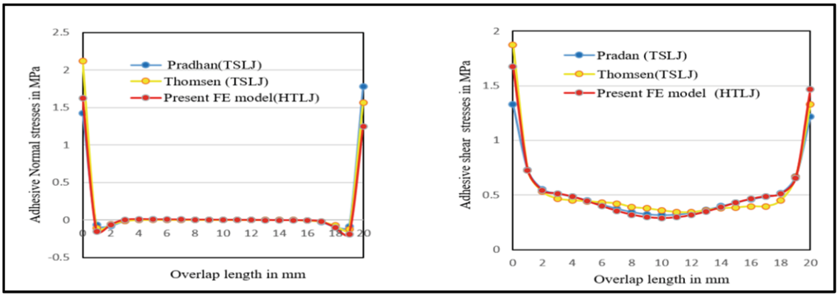

Fig. 6. Normal & shear stress distributions along adhesive mid-layer of HTLJ and TSLJ

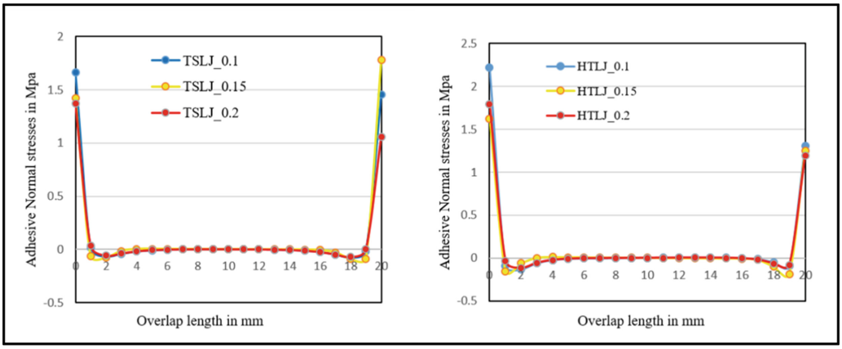

Fig. 7. Shear stress distribution in mid-adhesive layer in TSLJ and HTLJ

5.2 Shear Stress Distributions Within the Adhesive Mid Layer of HTLJ With Effect of Varying Adhesive Thickness

From the Fig. 8. The shear stress profiles are similar but magnitude values are increase 2% for 0.1mm adhesive thickness and 1% increase for 0.15mm and 0.2mmof adhesive thickness in HTLJ.

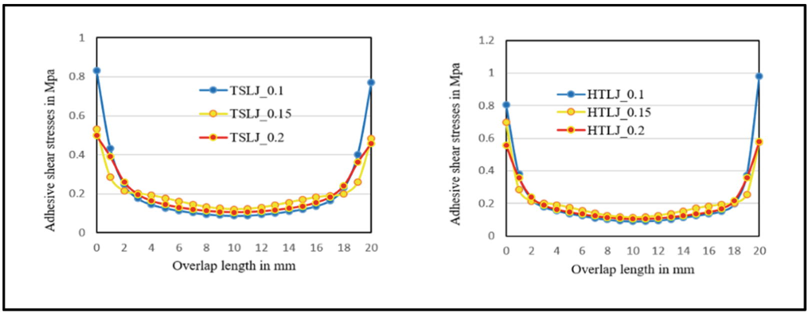

Fig. 8. Shear stress distribution in mid adhesive layer in TSLJ and HTLJ

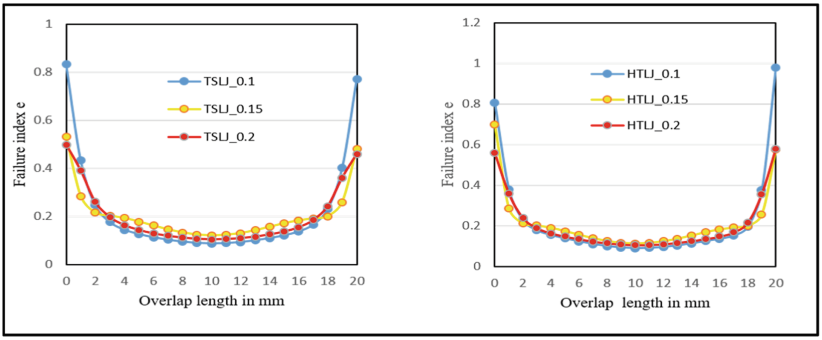

Fig. 9. Failure index values in mid adhesive layer in TSLJ and HTLJ

5.3 Failure Index Values of HTLJ With Effect of Varying Adhesive Thickness

The failure index profiles for TSLJ and HTLJ for varying adhesive thickness has shown in Fig. 9. The Parabolic yield principle based failure-index profile shows similar in both the joints by varying adhesive thickness. But the magnitude of failure index value at loaded end it shows increased to 1 for HTLJ for 0.1 mm adhesive thickness & for 0.15 mm and 0.2 mm adhesive thickness the values are below the limit.

6 Conclusions

Stress analysis of HTLJ with varying adhesive thickness have been studied in the present research. The Normal stress and shear stress values of HTLJ through the thickness of adhesive compared with TSLJ.There is no much variation in stress values but when increasing the adhesive thickness the stress values are reduced in HTLJ.The optimum adhesive thickness for HTLJ have found by using ANSYS2020R1. Failure index value is minimum for adhesive thickness of 0.2mm. The optimum adhesive thickness 0.2 mm was considered for HTLJ.

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