# Three Dimensional Stress Analysis and Identification of Failure Location in Adhesively Bonded Composite T-Joint Structures

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***Abstract*-- Joints are the weakest part of a structure, therefore efficient and effective joining techniques are required. This will lead to decrease the strength to weight ratio and manufacturing cost of composite structures. Adhesively bonded structures are widely used in the aerospace industry and automotive sectors, specially the T-joint structures. These T-joint structures are mainly subjected to out-of-plane loads and failures in the joint structure mainly occur due to the out-of-plane normal stress (i.e. peel stress) and shear stresses. So, the present study represents the three dimensional stress analysis and to identify the exact failure location of an adhesively bonded T-joint structure. The joint structure has been modelled with $[0/90/90/0]_s$ laminated composite plates subjected to out-of-plane load and the stresses has been calculated for each lamina of the joint structure using Ansys parametric design language (APDL) code. To verify the accuracy of the present formulation, intensive comparisons are made with existing results available in the literature and good agreements are obtained. At first the out-of-plane normal stresses are computed for each layer of the laminated composite. Then the failure indices are computed for each layer to identify the failure location. It has been found that the failure stresses are maximum at the top layer of the laminated joint structure.**

***Keywords: Adhesive Bonding, ANSYS APDL, Failure index, Lamina, Out-of-plane stress, T-joint***

## I. INTRODUCTION

The demand for composite materials is in every engineering field because of the requirement of lightweight materials. Composite materials have wider applicability which leads to increase the performance of that material. The demand is also because of its high strength to weight ratio compare to other material in any composite structure. Composite materials also reduce the manufacturing and operation cost by 20-30%.

Joints are the weakest link of any structure. Therefore efficient and effective joining techniques are required for the composite structures to reduce the structural weight. Now-a-days adhesive bonded joints are mostly used to improve the performance of joint structure and machine components as the applied load is uniformly distributed throughout the structure or components. It has wide application in many structural components to be used in aerospace industry, marine industry, automotive sector, chemical industries and defense industries. It has many advantages which can differ from industry to industry. Its resistance to corrosion, improved fuel efficiency makes it more effective in marine industry. Similarly in case of structures adhesive joints offers light weight, stiffness and economical benefits. While joint configuration, properties of joint material and types of joining process are some of the important parameter on which performance and effectiveness of the structure mainly depends.

Composite materials have low interlaminar strengths; therefore it is not easy to design composite materials as it will affect the performance of the composite structure. Similarly laminated composite structures fail due to interlaminar cracking, termed as delamination and also due to the adhesive and cohesive failure. Therefore it is important to understand and have a proper analysis of the bonded joint structure.

The three dimensional analysis using finite element method is highly demanded as it can provide effective and efficient results. Extensive effort has been given to analyze the behaviour of adhesively bonded joint structure. Budhe and Banea [1, 2] has done investigation to know the responses of adhesively bonded composite joints. Similarly experimental and numerical analysis of aluminium composite L-joints done by Domingues [3]. Li [4] has designed and analysed the behaviour of adhesively bonded T-joints. Similarly Parida and Pradhan [5] investigated the stress distribution and strain energy release rates for composite lap shear joints. Riberio [6] done damage analysis of adhesively bonded composite lap joints. Burns [7] used novel ply design approach to determine the strength of composite T-joints. Finite element method used by Wang, et al [8] to analyse composite T-joints used in wind turbine blades. Koricho [9] analysed CFRP composite T-joints used in vehicle structures. Zhou, Yinhua, et al [10] done 3D finite element analysis to study the damage in single lap multi bolt composite joints. Nimje, S. V., and S. K. Panigrahi [11]used fracture mechanics approach to do failure analysis of laminated FRP composites. Similarly Theotokoglou [12] investigated composite T-joint structures under pull-off load.

From the above mentioned literatures it has been found that finite element codes can be used to do analysis on adhesively bonded composite joint. We can also apply loads and different boundary conditions to the structures. In finite element methods software like Ansys, we have to define the material type, material parameters and model the structure in the pre-processing part. Then we can apply the boundary condition and get the solution in the post processing part which may take some time. The time for post processing generally depends upon the mesh size, the more finer the meshing the more accurate will be the result. So, the effectiveness and accuracy of the result depend upon the refinement of the mesh. The advantage of analytic study is that it will analyze quickly compared to the experimental method and we can use different boundary conditions and assumptions.

The present paper based on the three dimensional finite element analysis of adhesively bonded composite T-joint structure. The analysis is carried out using the Ansys parametric design language code. T-joint is selected due to the above mentioned applications and advantages. Here the joint is subjected to out-of-plane load.

The objectives of this paper are:

i. To find out the stresses in different layers of the laminated T-joint structure.
ii. To identify the crack initiation location of the joint structure.

## II. NUMERICAL MODELLING

The model of the T-joint structure with its geometry and boundary conditions is shown in Figure 1-3. The dimension of the model has been shown in Table 1. While the material properties of the specimen are given in Table 2. Four $[0/90/90/0]_s$ composite are used to model the laminated composite structure in both the flange and web part. Solid 185 material type has been used in Ansys APDL with layered structure. As the accuracy of the result depends upon the meshing size, so very fine meshing is used as shown in Figure 4. All the part of the joint structure meshed individually. In the solution part one end of the flange part has been fixed i.e. with degree of freedom is zero in all direction. As already mentioned T-joints are generally subjected out-of-plane loads, so 100N out-of-plane load is applied in y-direction as shown in Figure 3.

Table 1: Dimensions of the adhesive bonded T-joint

| | |
|---|---|
| Length (L) in meter | .16 |
| Width (w) in meter | 0.18 |
| Height (h) in meter | .16 |
| Thickness (t) in meter | .0025 |

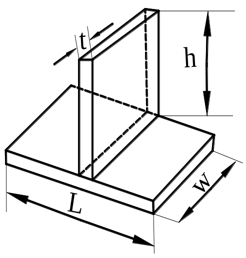


Fig.1: Schematic diagram of the T-joint structure

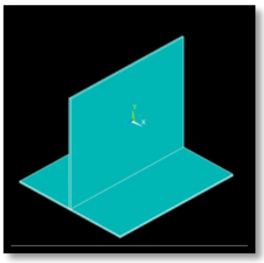

Fig.2: FE-model of the T-joint

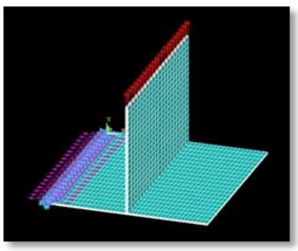

Fig.3: Boundary condition of the T-joint structure

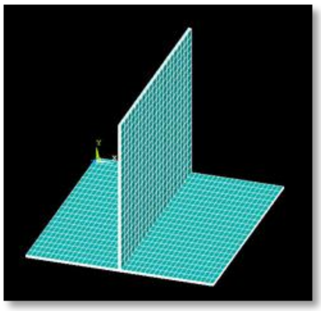

Fig.4: Meshed view of the T-joint Structure

Table 2: Mechanical properties of a ply of T300/934 carbon epoxy plain woven prepreg [13]

| | |
|---|---|
| In-plane Elastic moduli, $E_x$ and $E_y$ (GPa) | 57.226 |
| Transverse modulus, $E_z$ (GPa) | 4.800 |
| In-plane shear modulus, $G_{xy}$ (GPa) | 4.481 |
| Out-of- plane shear moduli, $G_{yz}$ , $G_{xz}$ (GPa) | 4.400 |
| In-plane Poisson's ratio, $\mu_{xy}$ | .05 |
| Out-of- plane Poisson's ratios, $\mu_{xz}$, $\mu_{yz}$ | .28 |

## III. RESULT AND DISCUSSION

### A. *Validation Study*

For the validation and comparison study, stresses induced in the z-direction of the lap joint structure has been analysed as shown in Figure 5. The lap joint is subjected to displacement in x-direction in the top adherend whereas the bottom adherend is fixed from one end. The geometry and material properties are same as the reference [5]. It is found that the result of present FE analysis shows good agreement with the available literature as shown in Figure 5.

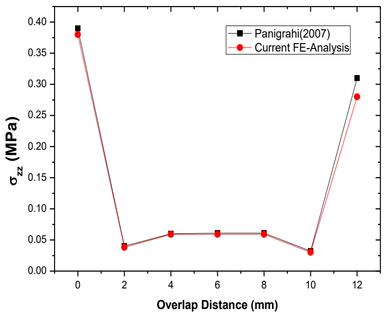


Fig.5: Comparison between current FE analysis and Panigrahy [5]

### B. *Three Dimensional Stress Analysis*

Three dimensional stress analysis of the composite T-joint structure has been conducted using finite element method. The stresses in the x-direction, in y-direction and in z-direction (i.e. $\sigma_{xx}$, $\sigma_{yy}$, $\sigma_{zz}$) have been calculated as shown in Figure 6-8. It can be shown that as the load is applied in the y-direction the stress induced in the y-direction (i.e. $\sigma_{yy}$) will be maximum which can be clearly shown from the graph. The graph demonstrates that the stress is more at the bonded region as compared to the whole joint structure. Similarly stresses are evaluated for each layer of the structure in all the planes.

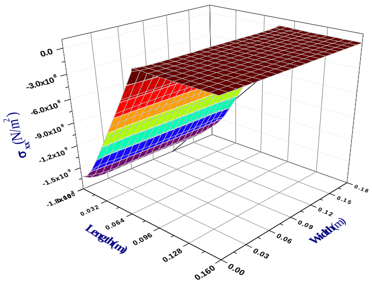


Fig.6: Stress Distribution along x-axis($\sigma_{xx}$)

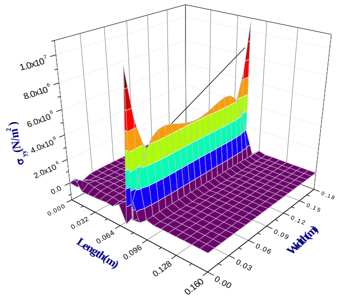


Fig.7: Stress Distribution along y-axis($\sigma_{yy}$)

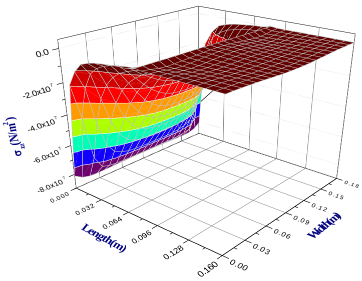


Fig.8: Stress Distribution along z-axis($\sigma_{zz}$)

### C. *Three Dimensional Failure Analysis:*

Three dimensional failure analyses has been conducted for the T-joint structure. Failure indices are evaluated for each layer of the laminated structure. There are four layers of the structure, according to which the flange part has been modeled for every layer of analysis. The failure indices of the first and second layer (from the top) are more significant compared to the bottom two layers for the failure of the joint structure. Therefore failure indices for the top two layers have been plotted as shown in the Figure 9-10.

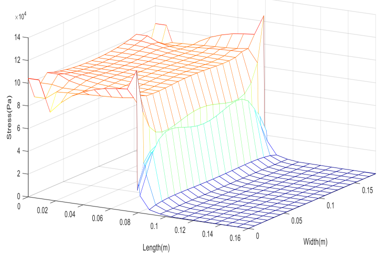


Fig.9. Failure Indices for layer-1 (from top) of the structure

The delamination of the joint structure can be analysed in these layers. The failure indices have been plotted by taking the out-of-plane stresses (i.e. $\sigma_{yy}$, $\sigma_{xy}$, $\sigma_{yz}$) as the failure in the joint structure occur mainly due to these stresses.

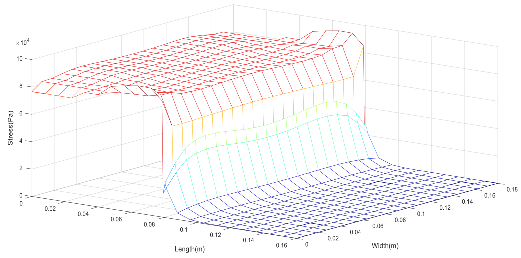


Fig.10. Failure Indices for layer-2 (from top) of the structure

## IV. CONCLUSION

- Three dimensional stress analysis and failure analysis of the T-joint structure has been carried out using finite element method. It has been found that the out-of-plane stresses induced at the bonded region are more due to the application of out-of-plane load to the wing part of the laminated structure.
- From the failure analysis it may be concluded that the failure indices are more significant at the top two layers of the laminated joint structure which can be considered for the analysis of delamination.

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