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Finite Element Analysis of Adhesive Bonded Laminated Shaft Used For Torque Transmission

[1]Mr. Mahesh S. Shendkar, [2]Mr. Santosh V. Mahajan, [3]Dr. Kiran C. More
[1]Masters Students, [2]Assistant Professor, [3]Associate Professor
[1]Mechanical Engineering Department,
[1] D. Y. Patil Institute of Engineering & Technology, Ambi, Pune India

Abstract: There is an increasing attention towards the investigation of adhesive tubular joints subjected to torsion, as the many studies have been on the axial load. Adhesives has the advantages over the fasteners like flexibility in manufacturing, uniform stress distribution and more cost effective product for joining structural members in some application. Joining of cylindrical components subjected to different load is a common requirement in industrial manufacture and there is a need to design and optimize the adhesively bonded joint. The present work aims to design and optimize the adhesively bonded joint for the tubular cross section by varying the thickness and overlap length of the adhesive joint subjected to torsion loading. The numerical approach has been done for the analysis of torsional capability of tubular joints using finite element code in ANSYS. The analysis is based on classical torsion theory and equations of theory of elasticity are used to obtain stress field in the adhesive layer and optimize joint profile. The effect of thickness and overlap length on the maximum shear stress and total deformation is investigated. A special type of tubular joint will be produced by modifying the joint profile, thus ensuring that the stress field in the adhesive is constant and thereby optimizing the tubular joint for uniform torsional strength. It can be concluded from the results that, the oversize thickness and the length of the adhesive has a lesser effect on the optimum values. This study helps for the designing of the bonded joints under torsional loading.

Index Terms - Adhesively Bonded joints, Torsion, Tubular, FEA, Stress**.**

1. INTRODUCTION

In recent years, adhesively bonded joints are used extensively to replace the conventional mechanical joints due to its various advantages like flexibility in manufacturing and design, uniform stress distribution, competency to joint dissimilar material. It is a well-known fact that, the joints are the weakest links of the mechanical structure, hence the different joints can be accomplished either mechanically (using bolting and fastening) or adhesive material bond. Mechanical joints having the limitations of localized stress concentrations and complex manufacturing (Parashar and Mertiny 2012). Adhesively bonded joints are used in various industrial and technological applications including space technology, microelectronic packaging, as well as aerospace and automobile industries. The adhesive can be used to ease of joints the complex layouts of petroleum industries with piping system. The drawbacks associated with the mechanical joints diverts the research towards the adhesive bonded joints for the power transmission system. The adhesively bonded tubular joints are classified in various types *viz.* lap joints, prepreg joints, filaments wound sleeve couplers, scarf joints and hybrid joints (Parashar and Mertiny 2012) [1]. Now a days, Adhesive are most commonly implemented to the joints due to their reliability and ease of use. Adhesive bonding is a suitable method for assembling components such as composite laminates and tubular joints used for torque transmission. Adhesive material have less stress concentration under fatigue loads compared to other joining techniques. Due to better performance and fatigue resistance adhesive are continuously receiving attention from the aerospace industry. Adhesive joints are more often employed to restore stiffness and strength of damaged/ cracked structures.

Many researches were focuses on improving the torque transmission capacity of adhesively bonded composite joints used in various mechanical application. Choi and Lee et al. (1995) examine the static torque transmission capability with effect of thickness of adhesively bonded lap joint using experimental method. A stacking sequence such as triangular, tetragonal, hexagonal and elliptical joint and adhesive thickness are used for the study. They found that, the strength of the joint was depended on the thickness of adhesive [2]. Similarly, Kim and Lee et al. (1995) also investigates the torque transmission capability of tubular joints connected with adhesive bond. A three different adhesively bonded joint *viz.* circular, hexagonal and elliptical lap joints were used for the analysis of stress and torque transmission. An experimental results had been compared with the results achieved from finite element study [3]. Xu and Wei (2013) studied the influence of thickness of adhesively bond on the overall strength. A cohesive properties and overall strength of metallic adhesive bonding. The results found that, both cohesive properties and strength were much depended on the adhesive thickness [4]. Albiez et al. (2018) study an adhesively bonded joint with effect of various overall length, angular and misalignment, and different types of imperfections [5]. Suryawanshi et al. (2013) did a review study on the hybrid shaft with dissimilar materials used in automobiles [6]. Aimmanee and Hongpimolmas (2016) did an analysis of tubular joints with optimum variations in stiffness to find stress under torsion. A mathematical model had been developed for axisymmetric, linearly elastics joints under uniform torsion. The influence of geometric parameters on the stress was studied with optimisation. The results were used for the designing of the shaft [7]. Xu and Li (2010) did a finite difference 3D solution for adhesively bonded tubular joints across the boding thickness with constant shear and peel stresses [8]. Pallavi et al. (2015) did an experimental investigation of static and dynamic parameters of dissimilar material shafts.

A torque transmitting capacity, stiffness and weight saving of the composite is the main objective of the study. A FEA analysis also done and results were compared with the experimental results. Authors concluded that, composite propeller shaft has a great torque transmission capacity than the steel shaft [9].

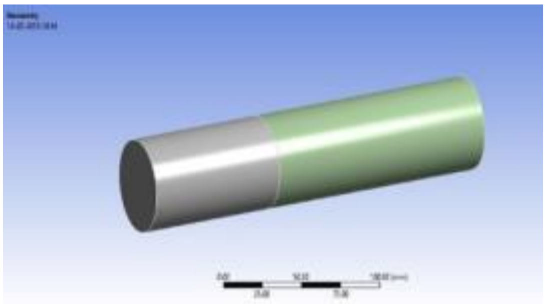
From the above literature it is concluded that, there is a lot of study had been study with varying geometric parameters with similar materials. The present study did a numerical study of circular lap joints under torsion by varying overlap length and thickness of adhesively bonded joints. The strength of the circular lap adhesive joints under torsion was predicted using finite element analysis by varying thickness and overlap length. Different overlap length (L_b = 40, 60, 80, 100 and 120 mm) and thickness (t_b = 0.5, 0.75 1 and 1.5 mm) was selected for the analysis to find out the total deformation and maximum shear strength of the bonded material by keeping constant torque (T = 2 kN-m). The influence of these parameters on the shear stress was investigated and discussed.

2. NUMERICAL MODEL DEVELOPMENT

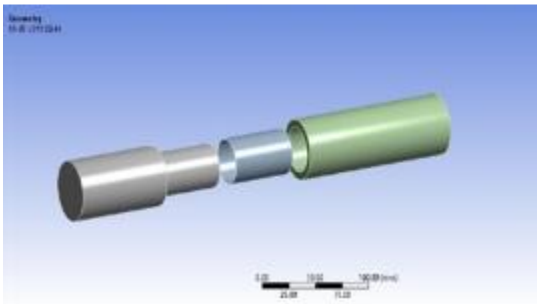
In order to better understand the analysis of a tubular joint and adhesive bond has been modelled and simulated using the finite element analysis code of ANSYS 14.5. A static structural analysis has been done for the calculation of total deformation and maximum shear strength of the bonding material by varying geometrical parameters. A particular mesh refinement has been done and a grid independency study has been done for selection of the mesh size, so the reducing the time and cost of simulations. The geometry, configuration, and boundary conditions of the tubular joints are shown in figure 1. The torque is applied on the male part of the specimen while the female part has the fixed support. A C45, epoxy and Loctite material has been selected for the analysis. The properties of the material are tabulated in the table 1. The geometric configuration of the tubular circular lap joint with different material adherends and the schematic of the drawing is shown in figure 2. Total length of the specimen is fixed 150 mm with the overlap length of the bonding material varying. The overlap length of the specimen bonding material is varying from 40 to 120 mm while thickness vary from 0.5 to 1.5 mm.

Table 1: Properties of Material used for the analysis.

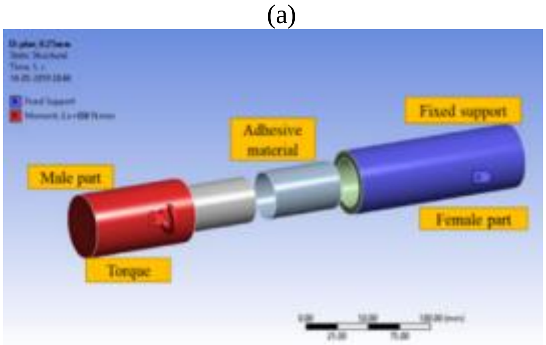
	C45	**Loctite**	**Epoxy**
Density (kg/m^3)	8000	1170	1250
Modulus of elasticity (mPa)	2.1 x 10^5	2580	10500
Poisson's Ratio	0.3	0.39	0.35



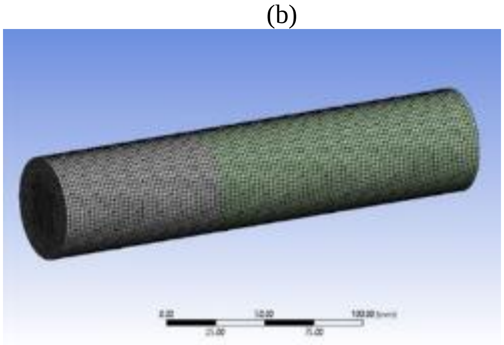
(a)



(b)



(c)



(d)

Fig. 1 (a to c) Numerical domain for the plain tube analysis without groove, (a) Assembly of the test specimen, (b) Extractive parts of the test specimen (c) The boundary conditions applied (d) Mesh used for the analysis.

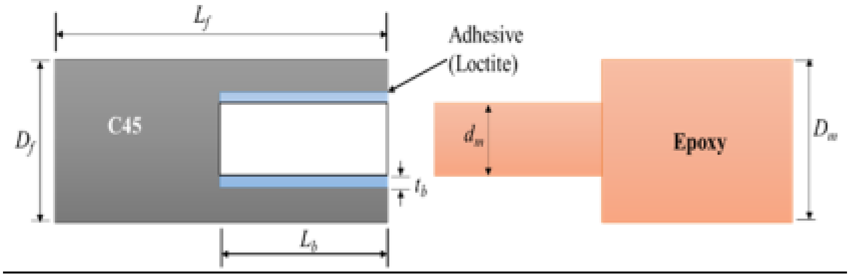


Figure 2. Schematic of the test specimen.

3. RESULTS AND DISCUSSION

In order to find the effect of the thickness and overlap length of the adhesive joints on the torsional strength of the circular tubular joints. A numerical approach has been used to figure out the effect. Five overlap lengths has been used *viz.* L_b = 40, 60, 80, 100 and 120 mm while four adhesive thickness are selected *viz.* t_b = 0.5, 0.75, 1 and 1.5 mm. the following results has been found.

3.1 Effect Of Overlap Length

Figure 3 shows the graph of effect of overlap length of adhesive on the total deforestation and maximum shear stress. Five different overlap lengths has been considered for the analysis by keeping constant thickness of 0.75 mm. It can be concluded that, the total deformation has been found less for 60 mm overlap length

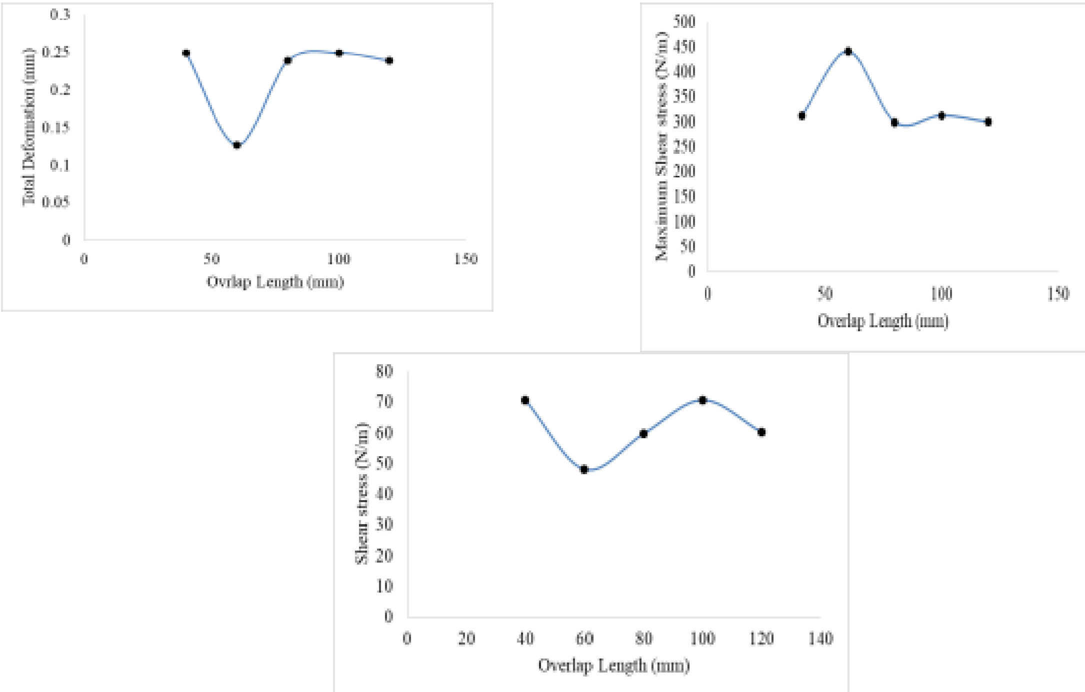
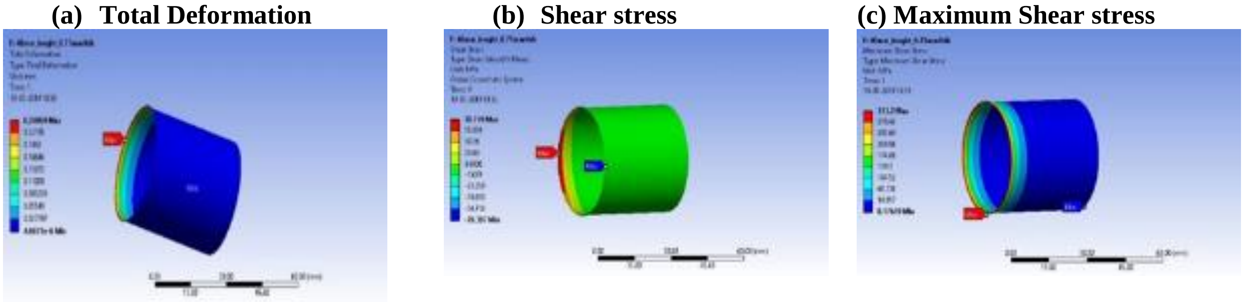


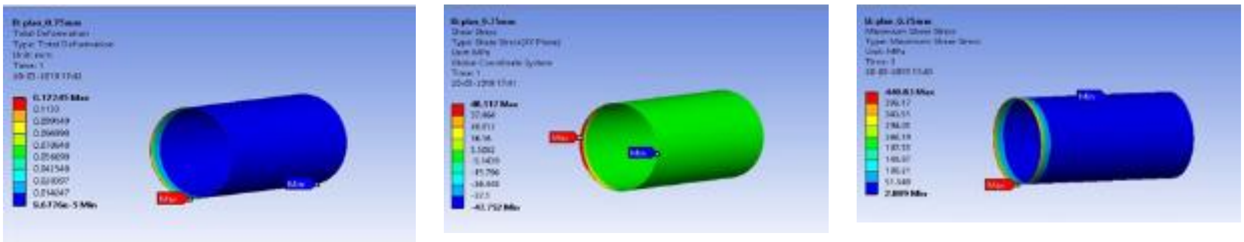
Figure 3 Graph of effect of overlap length of adhesive on the total deforestation and maximum shear stress.

Figure 4 depicts the contours of total deformation and maximum shear stress for different overlap length of the adhesive joints. The deformation of the adhesive bond have been found maximum at the male side of the test specimen due to the fixed end female part. Similarly the shear stress and the maximum shear stress is also found at the edge of the adhesive joint on male side.

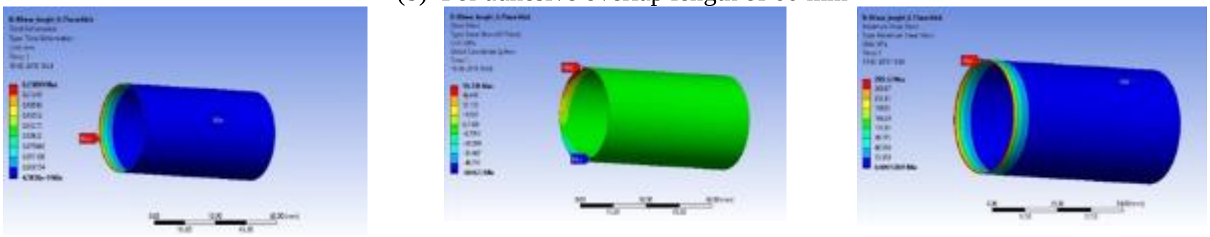
(a) Total Deformation **(b) Shear stress** **(c) Maximum Shear stress**



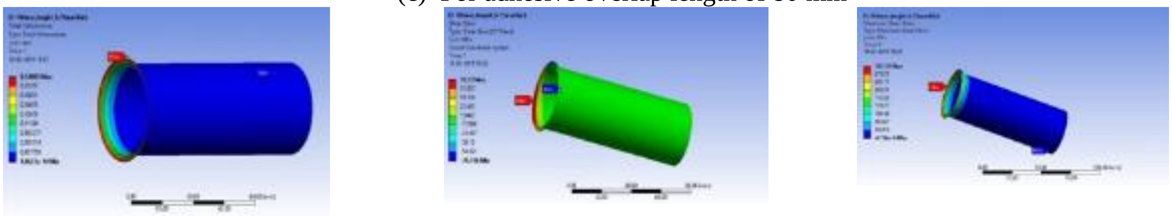
(a) For adhesive overlap length of 40 mm



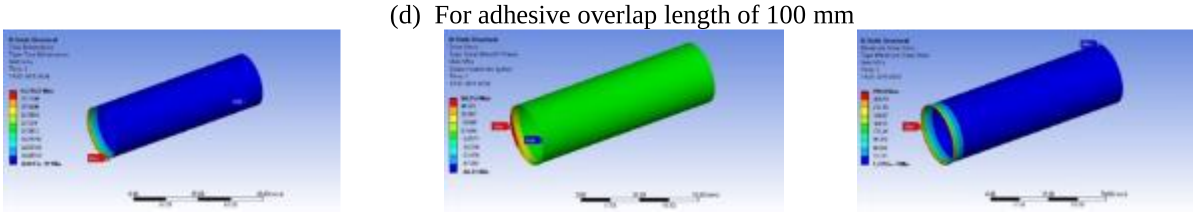
(b) For adhesive overlap length of 60 mm



(c) For adhesive overlap length of 80 mm



(d) For adhesive overlap length of 100 mm



(e) For adhesive overlap length of 120 mm

Figure 4 Contours of total deformation and maximum shear stress for different overlap length of the adhesive joints

The values of total deformation and the shear stress are tabulated in table 2. It can be seen from the table that, the difference between the total deformation of the 60 mm overlap length is lower as compared with other length. The other total deformation are found to be similar as maximum for the same torque application.

Table 2: Results for different overlap length

NO.	Length (mm)	Total Deformation (mm)	Shear stress (N/m)	Max Shear stress (N/m)
1	40	0.24969	70.719	313.37
2	60	0.12745	48.117	440.83
3	80	0.23899	59.749	299.32
4	100	0.24983	70.72	313.37
5	120	0.23922	60.253	299.8

3.2 Effect Of Thickness

Figure 5 shows the graphs for effect of thickness on the adhesively bonded joints. The total deformation and the maximum shear stress found maximum for the 0.75 mm thickness. It can be seen from the graph that, as the thickness of the bonding material increased after 0.75 mm thickness the total deformation of the in increased while the strength of the material is going reduced. The maximum shear strength is found maximum for the 0.75 mm thickness. Similarly, as discussed in above section the contours of the maximum shear stress and the total deformations are found maximum at the male part side. Figure 6 shows that the different contours for the varying bonding material thickness.

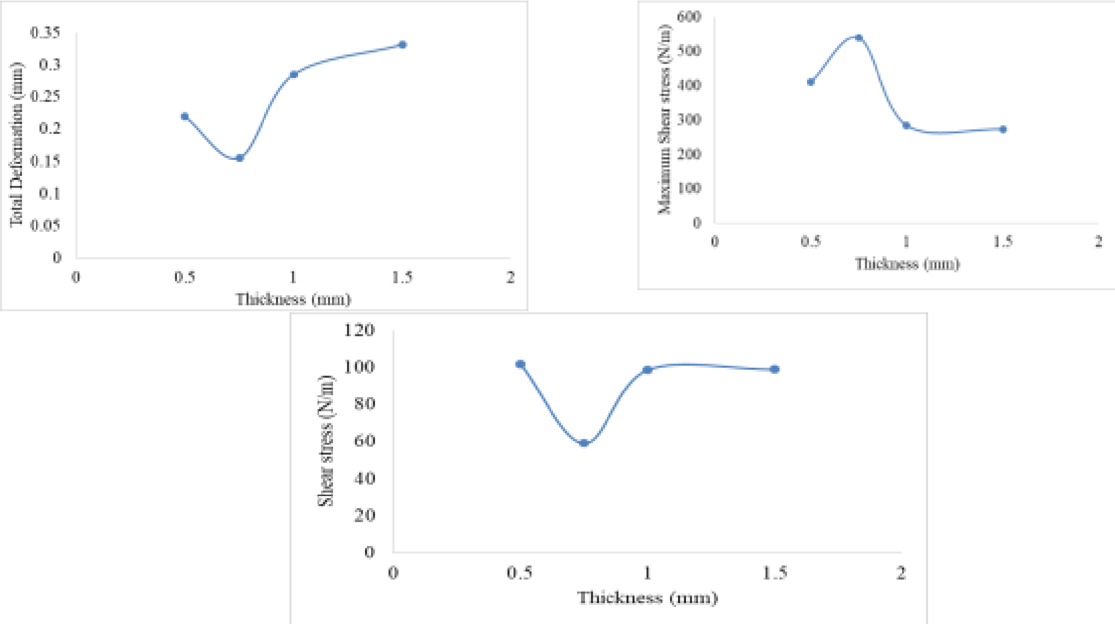
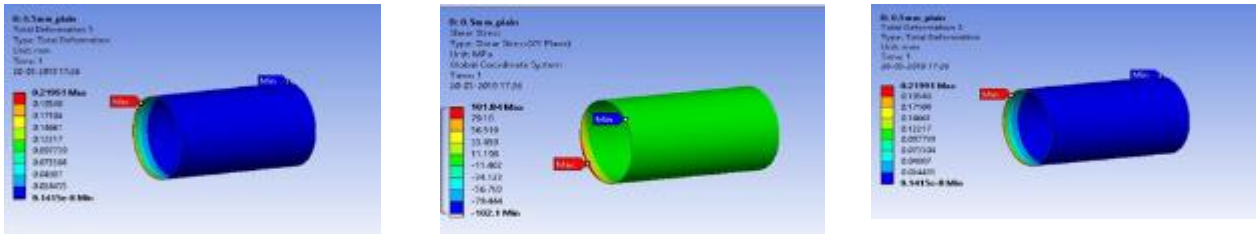
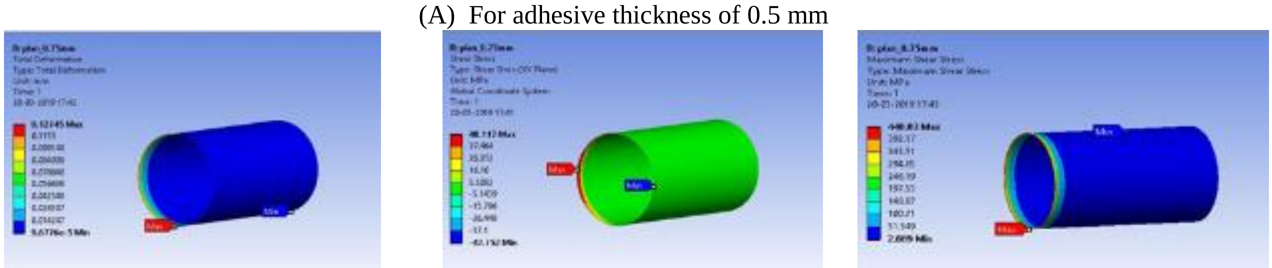


Figure 5 Graph of effect of thickness of adhesive on the total deforestation and maximum shear stress.

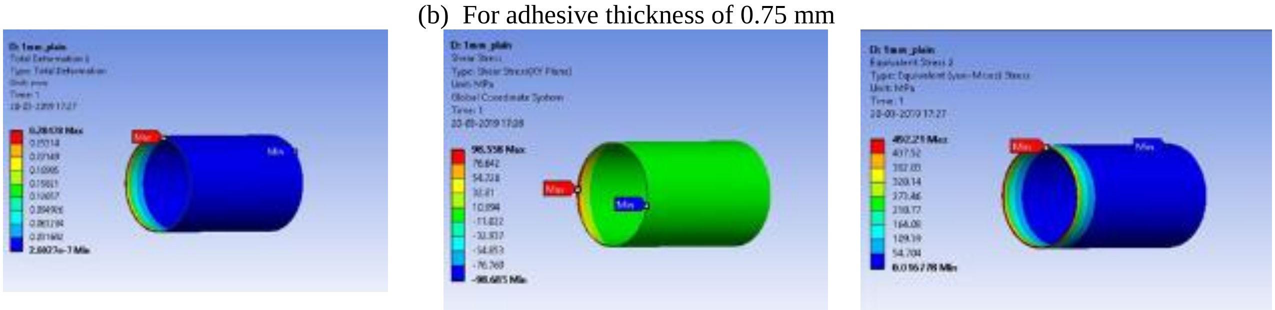
Total Deformation	Shear stress	Maximum Shear stress



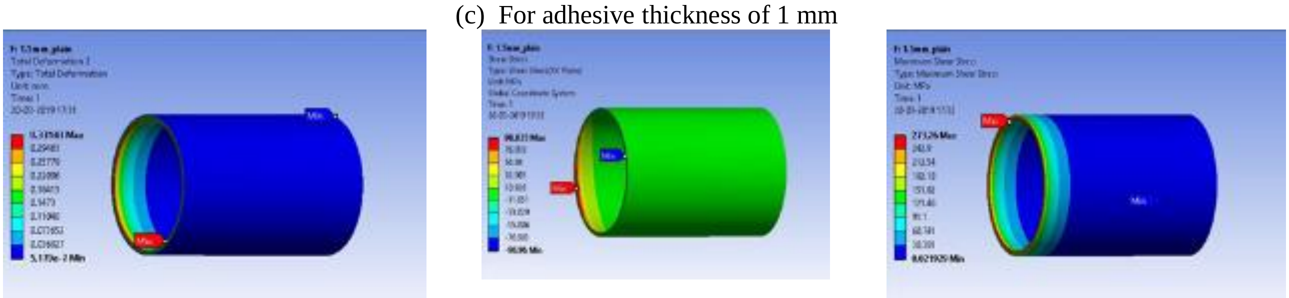
(A) For adhesive thickness of 0.5 mm



(b) For adhesive thickness of 0.75 mm



(c) For adhesive thickness of 1 mm



(d) For adhesive thickness of 1.5 mm

Figure 6 Contours of total deformation and maximum shear stress for different thickness of the adhesive joints

Table 3 tabulated the values of total deformations and the maximum shear stress for different thickness of the bonding material. The maximum shear stress (538.92 mPa) for the thickness of 0.75 mm. The results shows that as the thickness increases after the 0.75 mm the total deformation and the strength are nearby

Table 3: Results of total deformation and maximum shear stress for different thickness.

case number	**Thickness**	**Total deformation**	**Maximum shear stress**	**shear stress**
1	0.5	0.21991	410.61	101.84
2	0.75	0.15572	538.92	59.058
3	1	0.28478	284.18	98.558
4	1.5	0.33143	273.26	98.835

4. CONCLUSION

A numerical analysis has been done to analyze the effect of thickness and overlap length of the adhesive on the strength of the tubular bonded circular lap joint. The following conclusion has been drown from the above study,

1. The minimum total deformation has been found for the overlap length of 60 mm as compared with other length. Similar, the maximum strength of the adhesive found for 60 mm length. The nature of the results shows that, the selection of an optimum value of the overlap length is important for the maximum torque transmission capacity.
2. The maximum shear stress has been found for thickness of 0.75 mm adhesive bond as compared with others. The results are varying with the thickness. For the maximum thickness (t_b = 1.5 mm) the strength of the adhesive bonding is found weaker.

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