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Research Article

Failure Prediction of Glass Fiber Composite Material Single Lap Joint: Finite Element Analysis

Meher Ashish[†*], Gawhale Prashant[†], Khobare Prasad[†], Amol Bhanage[†]

[†]Mechanical Engineering Department, Marathwada Mitra Manadal's Institute of Technology , SPPU, Pune-47, India.

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Abstract

In this paper, Single lap joint is prepared by three different joining methods namely adhesive bonding, riveted and bolted joints. The physical response of the single lap joints of Glass fibre reinforcement material subjected to tensile test was studied using finite element method. In adhesive bonding, finite element analysis was carried out using ANSYS 16.0 for different overlap thickness as 0.2, 0.4 and 0.6 mm. Similarly, analysis carried out in riveted joint and bolted joint by varying the number of rivet and bolt. Virtually, ultimate strength and mode of failure in single lap glass fibre rein forced polymer (GFRP) joints were predicted at design stage to save time, fabrication and testing for complete product realization.

Keywords: *Adhesive joint, bolted joint, finite element Analysis, GFRP, Joint strength, Riveted joint*

1. Introduction

The technological advances in the aircraft industry have created a demand for newer materials, where they are required to perform in stringent conditions – high pressure and temperature, highly corrosive environment, with high strength requirement. This has triggered the development needs for engineered materials to cater to customized needs. Aviation industries have recognized the ability of composite materials to produce high quality, durable and cost effective products (Nikhil V Nayak, 2014). Generally, a composite material is composed of reinforcement (fibers, particles, flakes, or fillers) embedded in a matrix (polymers, ceramics, or metals). Fibers are the reinforcement and main source of the strength while the matrix 'glues' all the fibres together in shape and transfers stresses between the reinforcing fibers. There are three main types of synthetic fibers used to reinforced plastic materials: Glass, aramid and carbon. Glass is by far most widely used reinforcement fiber in the aircraft industry as it is the lowest in cost (P.K. Mallick 1993).

Most of the airframe structure consists of an assembly of simple elements connected to form load transmission path. The connections and joints are potentially weakest points in the airframe (N.Senguttuvan, J.Lillymercy, 2015). So the relative analysis of joints of different configurations is to be carried out in order to understand the best approach to designing joints. Many methods exist for bringing the materials together, in terms of the joining technique utilized. These components are joined together by using either fastener joints or adhesively bonded joints (K.N. Anyfantis, N.G. Tsouvalis, 2012). In the present project, an attempt is made to analyze the joint strength of single Lap joint glass fiber reinforced plastic (GFRP) joined by adhesive bonding by varying the adhesive thickness, by fasteners in the way of increasing the number of rivets & bolts by Finite Element Analysis method).The results were interpreted in terms of shear stress. To utilize the full potential of composite materials as structural elements, the strength and stress distribution of these joints must be understood (K. Mohamed Bak, K. Prasanna Venkatesn, K. Kalai Chelvan, 2012).

2. Problem definition

The present work deals with the analysis of a single lap joint for airframe structure. In this paper, GFRP plate material having 100 x 25.5 x 3 mm dimension is overlapped with length 25 mm. The ultimate loads of 627.6N, 460.9N and 588.4N considered for bonded joints with thickness of 0.2, 0.4 and 0.6 mm. Similarly, ultimate loads 1392.6N, 2020.2N and 2932.3N considered for riveted joints and 5756.5 N, 6609.9 N & 8434 N are considered for bolted joints with increasing number of rivets and bolts (i.e. 2, 3 & 4).

3. Objective

Aim of the work is to compare the effects of adhering conditions on the joint strength. The physical response of the lap joints studied using finite element method

*Corresponding author: **Meher Ashish**

with keeping geometrical conditions constant and changing adhering conditions. Virtually, ultimate strength and mode of failure in single lap glass fibre reinforced polymer (GFRP) joints were predicted at design stage to save time, fabrication and testing for complete product realization. The following figure shows the sample geometry of adhesive (fig.1), riveted (fig.2) and bonded joint (fig.3) structure.

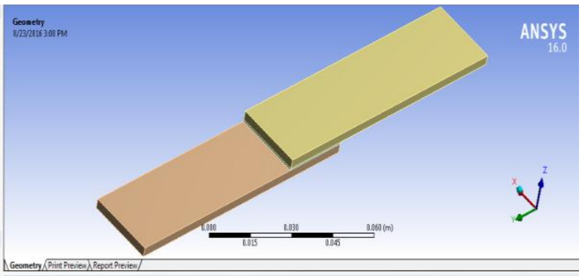


Fig.1 lap joint with adhesive thickness 0.2mm

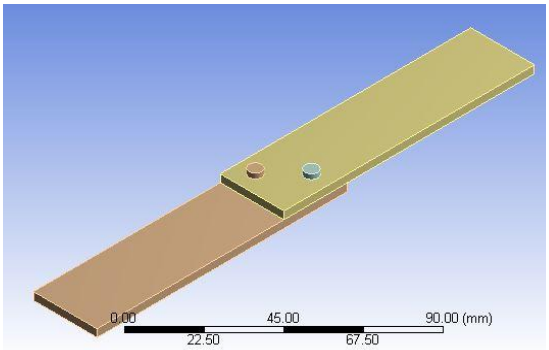


Fig.2 sample riveted lap joint with two rivets

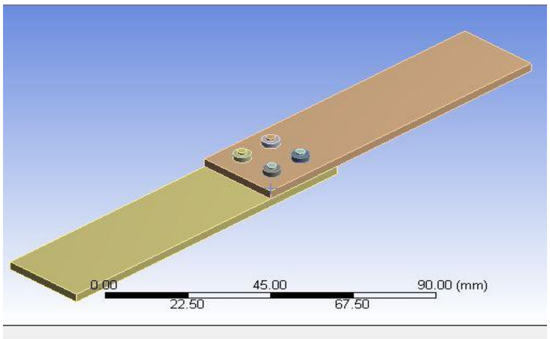


Fig.3 sample bolted lap joint with four bolts

4. Material properties

The following properties are assigned to the materials as shown in the table below

Table 1 material property for isotropic materials

Element	Adhesive	Rivets & bolts
Material	Resin epoxy	Stainless steel
Young's modulus, MPa	3780	193000
Poisons ratio	0.3	0.31
Shear modulus , MPa	1400	73000
Bulk modulus ,MPa	4200	169000

Table 2 material properties for orthotropic material

Element	Plate
Material	GFRP (glass fibre reinforced plastic)
Young's modulus (E_x),MPa	21000
Young's modulus (E_y),MPa	21000
Young's modulus (E_z),MPa	7000
Poisons ratio	0.26
Shear modulus (S_x), MPa	1520
Shear modulus (S_y), MPa	1520
Shear modulus (S_z), MPa	2650

5. Establishment of contacts

When two separate surfaces touch each other that they become mutually tangent, they are said to be in contact. In this analysis the contacts between all the elements is bonded contact. Bonded Contact is a special case of contact analysis where the two contacting surfaces are assumed to be "glued" together throughout the analysis. The two contacting surfaces form a contact pair. One of the surfaces is designated as the target surface and the other surface is called the contact surface. Bonded contacts are convenient for quick analysis of assembly as faster solutions are obtained since there are no contact convergence issues.

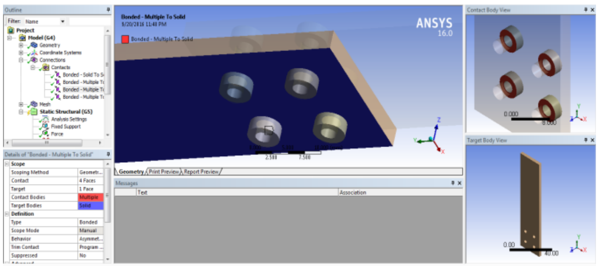


Fig.4 sample establishment of contact for 4 bolts

6. Meshing

Meshing involves division of the entire of model into small pieces called elements.It is the most important part of an analysis and can determine the efficiency and effectiveness of an analysis. In this analysis meshing method us is HEX DOMINANT method. The element size was kept default which was 1mm for adhesive, rivets and bolts while 3mm for the plates.

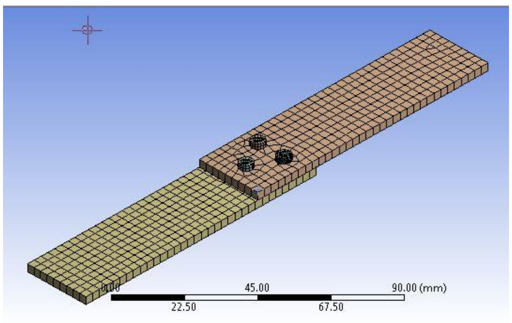


Fig.5 sample mesh of lap joint with three bolts

7. Boundary conditions & Forces applied

The analysis for joints was performed by applying a tensile load at the end of the joint which was free to move in the longitudinal direction only ($U_Y = U_Z = 0$). The opposite end of the joint was fixed with boundary condition ($U_X = U_Y = U_Z = 0$).

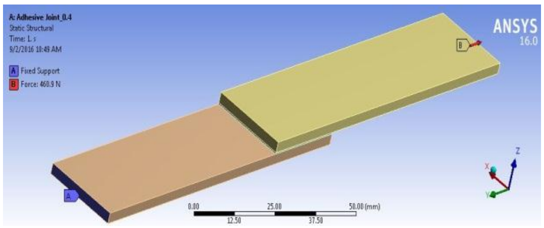


Fig.6 sample Boundary conditions

8. Results and discussions

8.1 Adhesive bonded joint specimen with three adhesive thickness lap area 0.2, 0.4 and 0.6 mm

The ultimate loads of bonded joints with three adhesive thicknesses of 0.2, 0.4 and 0.6 mm were considered to be 627.6N, 460.9N and 588.4N for simulation. The maximum shear stresses are obtained here 0.9782 N/mm², 0.4782 N/mm² and 0.7368 N/mm² respectively shown in the table 3.

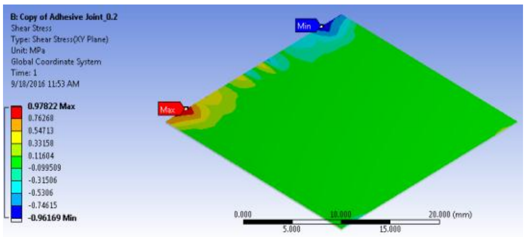


Fig.7 shear stress for 0.2 mm adhesive thickness

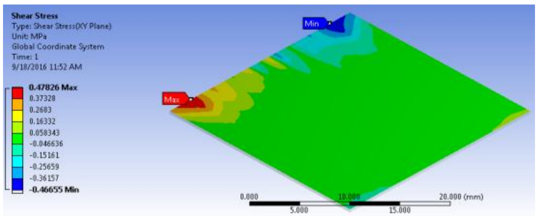


Fig.8 shear stress for 0.4mm adhesive thickness

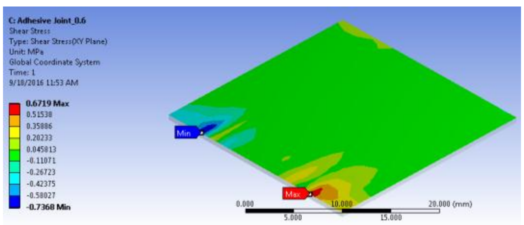


Fig.9 shear stress for 0.6mm adhesive thickness

Table 3 Ultimate load and tensile shear stress of Adhesive bonded joint specimen with three adhesive thickness lap area 0.2, 0.4 and 0.6 mm

S. No	Specimen Types	Ultimate load (N)	Shear stress (N/mm²)
1	0.2mm adhesive thickness	627.6	0.9782
2	0.4mm adhesive thickness	460.9	0.4782
3	0.6mm adhesive thickness	588.4	0.7368

8.2 Riveted joint specimen with two, three and four rivets

The ultimate loads of riveted joints with increasing number of rivets (2, 3 & 4 rivets) were considered to be 1392.6N, 2020.2N and 2932.3N for simulation. The maximum shear stresses are obtained here 2.1598 N/mm², 3.2938 N/mm² and 4.9252 N/mm² respectively shown in the table 4.

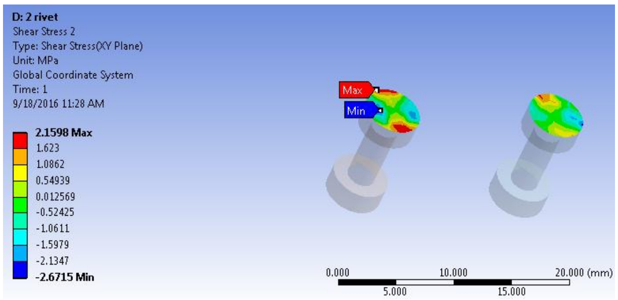


Fig.10 shear stress for specimen with 2 rivets

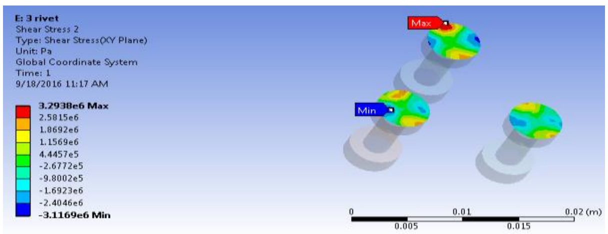


Fig .11 shear stress for specimen with 3 rivets

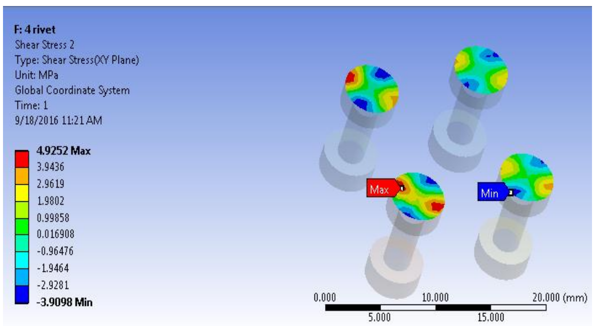


Fig.12 shear stress for specimen with 4 rivets

Table 4 Ultimate load and tensile shear stress of riveted joint specimen with two, three and four rivets

S. No	Specimen Types	Ultimate load (N)	Shear stress (N/mm^2)
1	2 riveted joint	1392.6	2.1598
2	3 riveted joint	2020.2	3.2938
3	4 riveted joint	2932.3	4.9252

8.3 Bolted joint specimen with two, three and four bolts.

The ultimate loads of bolted joints with increasing number of bolt (2, 3 & 4 bolts) were considered to be 5756.8N, 6609.9N and 8434N. The value of bolt pretension applied here is 500N. The maximum shear stresses are obtained here 9.7473 N/mm^2, 11.217 N/mm^2 and 15.511/mm^2 respectively shown in the table 5.

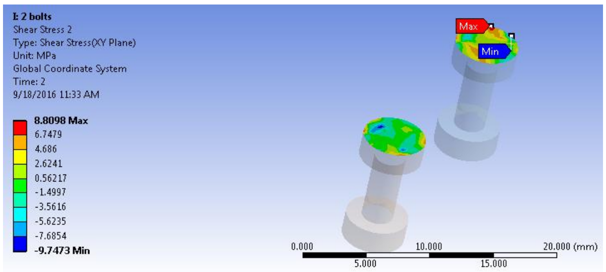


Fig.13 shear stress for specimen with 2 bolts

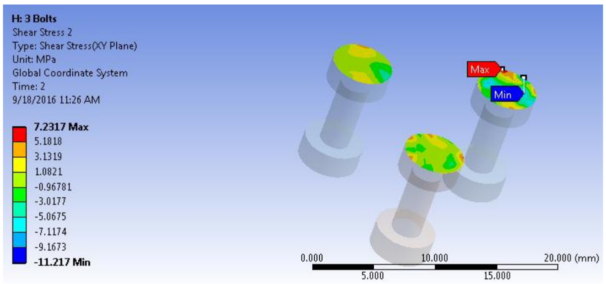


Fig.14 shear stress for specimen with 3 bolts

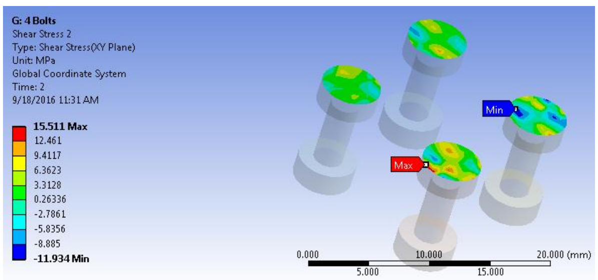


Fig.15 shear stress for specimen with 4 bolts

Table 5 Ultimate load and tensile shear stress of bolted joint specimen with two, three and four bolts

S. No	Specimen Types	Ultimate load (N)	Shear stress (N/mm^2)
1	2 bolted joint	5756.7	9.7473
2	3 bolted joint	6609.9	11.217
3	4 bolted joint	8434	15.511

8.3 Comparison of Results for Adhesive, Riveted and Bolted, Joints

Table 6 Ultimate load and tensile shear stress of Adhesive bonded joint specimen with three adhesive thickness lap area 0.2, 0.4 and 0.6 mm

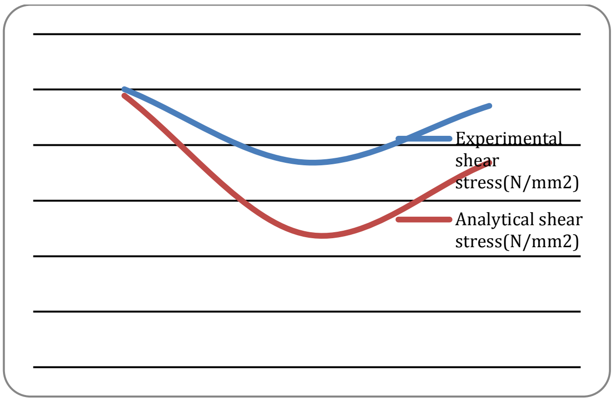
Joint Type	Specimen Types	Shear stress(N/mm^2) Experimental (N. Senguttuvan,et. al.,2015)	Shear stress(N/mm^2) FEA
Adhesive Joint	0.2mm adhesive thickness	1.001	0.9782
	0.4mm adhesive thickness	0.7374	0.4782
	0.6mm adhesive thickness	0.9414	0.7368

Table 7 Ultimate load and tensile shear stress of riveted joint specimen for 2, 3, and 4 rivets

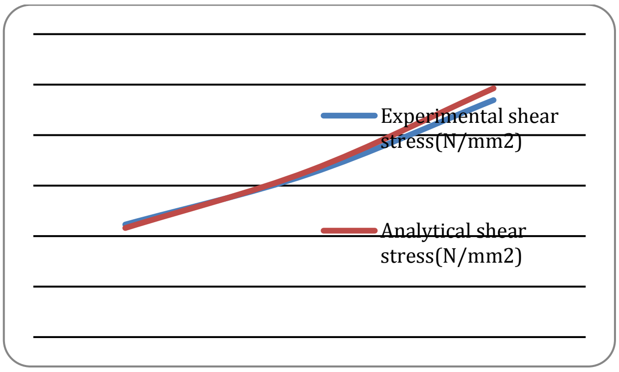
Joint Type	Specimen Types	Shear stress(N/mm^2) Experimental (N. Senguttuvan, et al.,2015)	Shear stress(N/mm^2) FEA
Riveted Joint	2 riveted joint	2.2281	2.1598
	3 riveted joint	3.2323	3.2938
	4 riveted joint	4.6916	4.9252

Table 8 Ultimate load and tensile shear stress of Bolted joints with 2, 3 and 4 bolted joints

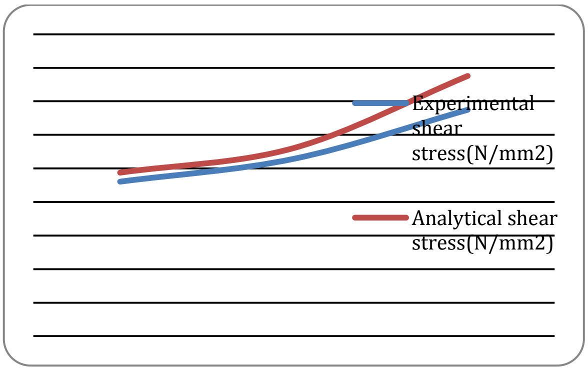
Joint Type	Specimen Types	Shear stress(N/mm^2) Experimental (N. Senguttuvan, et. al.,2015)	Shear stress(N/mm^2) FEA
Bolted Joint	2 bolted joint	9.2108	9.7473
	3 bolted joint	10.5744	11.217
	4 bolted joint	13.4948	15.511



Graph 1 comparison between experimental and analytical shear stress (adhesive joint)



Graph 2 comparisons between experimental and analytical shear stress (riveted joint)



Graph 3 comparisons between experimental and analytical shear stress (bolted joint).

Conclusions

The physical response of the single lap joints of Glass fibre reinforcement material subjected to tensile load was studied for different overlap thickness and also the analysis was carried in ANSYS 16.0 for different mechanical joints like adhesive riveted and bolted by varying the number of rivets and bolts. For adhesive bonded joints, shear stress deceased for 0.4 mm thickness and suddenly increased for 0.6 mm thickness, due to varying load.

For riveted and bolted for their two, three and four joints, shear stress increases with increasing number of rivet and bolt respectively.

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