International Journal of Instrumentation Control and Automation

Volume 1 | Issue 4 Article 13

January 2012

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Abstract-Composite materials have made way to various fields, including aerospace structures, underwater vehicles, automobiles and robot systems. Due to the high strength to weight ratio of composites, they serve as a suitable alternative to metals, therefore making the need for a reliable database of structural design more important. Most of the modern civilian and military aircraft use composite materials for their primary structural components (in addition to metals). One of the key areas in composite structural design involves the tensile strength of joints. In the present work, the lap joints fabricated from different orientations of GFRP (Glass fiber reinforced polymer) specimens are subjected to tensile test. The effect of fibre orientation on the tensile strength of lap joint is investigated both experimentally and computationally using conventional software package. The experimental results are compared with FEA using conventional software package ANSYS.

Keywords*: Composites, GFRP, Bonded Joints, Joint Strength.*

I. INTRODUCTION

Composite structures, used to meet the demand for lightweight, high strength/stiffness and corrosion-resistant materials in domestic appliances, aircraft industries and fields of engineering composites, have been one of the materials used for repairing the existing structures owing to its superior mechanical properties [1]. Applications of composite materials have been extended to various fields, including aerospace structures, automobiles and robot systems. Most of the modern civilian or military aircrafts use the composite material for their primary structural components, in addition to metals. The components are joined together by using either fastener or adhesively bonded joints. Adhesively bonded lap joints are most preferred, because they develop smooth load transfer and have fewer points of stress concentration as compared to fastener joints. The failure prediction of such joints is vital, since their failure might lead to catastrophic accidents of aircraft during its service period [2]. The failure prediction of the composite single lap bonded joints was carried out considering both the composite adherend and the bondline failures [5] [6]. Hence, failure prediction of such joints supplemented by testing is required to ensure the safety of aircraft. The damage zone method based on 3D finite element analysis to predict the failure loads of single-lap bonded joints with dissimilar composite-aluminum materials was carried out by Khanh-hung et al [3]. Using bonded structure has advantages including cost saving and weight reduction; therefore, new applications are expanding and challenging the qualified workforce [7]. Development of guidance and training is a high priority to maintain the required level of aviation safety both for initial and continued airworthiness. The analysis and design of bonded joints in the evaluation of the stress and strain fields at the adhesive layer was given by Baldomir et al [12].

II.EXPERIMENTAL PROCEDURE

A. Specimen Fabrication

GFRP composite laminates of dimensions 300 x 300mm are fabricated using hand layup procedure with different orientations (0^o, Cross ply [$0^o/90^o$], Angle ply [$\pm45^o$]). Three layers of uni-directional glass fiber along with LY556 epoxy are employed for the purpose of fabrication of the laminates [10-11].

1) Single lap joint

Tensile specimens of size 102x25x3mm are cut from the laminated composite in accordance with ASTM D5868-01 standard [8]. Water-jet cutting was employed to avoid machining defects and to ensure good surface finish. Tensile test specimen fabricated in accordance to ASTM D5868-01 standard shown in figure 1.

2) Double Lap Joint

Tensile test specimens shown in figure 2 are prepared in accordance with ASTM D 3528–96 from the fabricated laminate. Here again water jet cutting was used to ensure god surface finish.

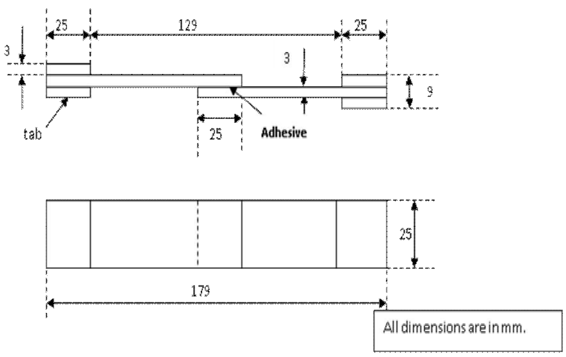


Figure 1. Tensile test specimen of ASTM D 5868-01

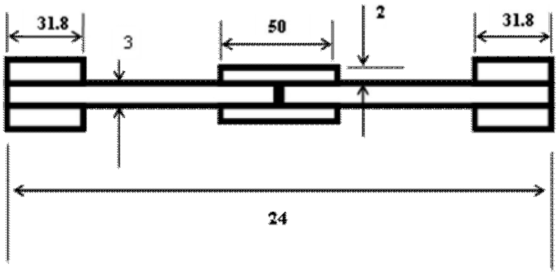
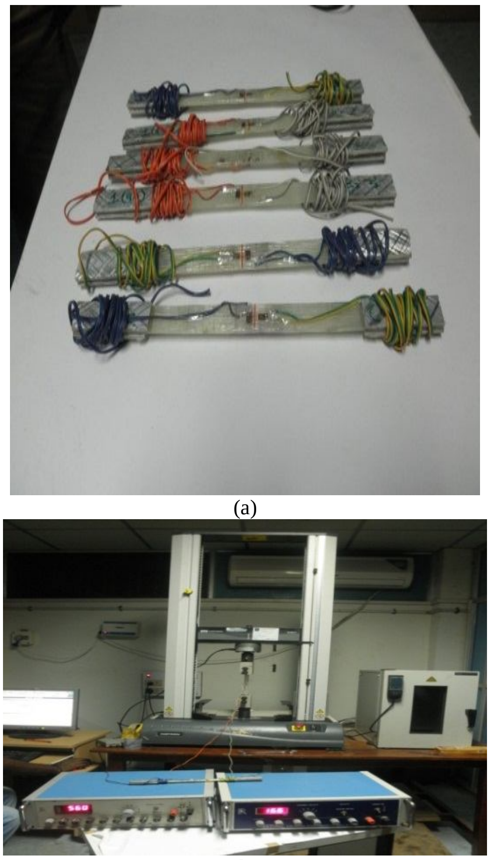


Figure 2. Tensile test specimen of ASTM D 3528–96

B. Tensile testing procedure

Tensile specimens obtained from the laminates are subjected to uni-axial tension using INSTRON 3367 universal testing machine. Eighteen specimens, three in each orientation (0°, cross-ply [0°/90°] and angle-ply [±45°]) are tested. The crosshead speed was maintained at 0.15 mm/min throughout the testing process.

Tensile properties of unidirectional glass/epoxy composite are determined through testing. The testing procedure adheres to the ASTM Standard Test Method for Tensile Properties of Epoxy Matrix Composite Materials, D3039.Figure 3 shows the prepared tensile test specimens with strain gages and wiring to obtain the strain values during the testing process.



(a)

(b)

Figure 3. Prepared tensile test specimens with (a) strain gauges (b) wiring and display

III. RESULTS AND DISCUSSION

A. Ultimate load for different orientations in composite lap joints

The ultimate strength obtained for different orientations of single and double lap joints are shown in tables 1 and 2 respectively.

TABLE I. Ultimate Load for Different Orientations in single Lap joint

. No	Specimens	Load (kN)		
		0°	*Angle Ply*	*Cross Ply*
	sp1	6. 9	3 .08	3 .08
	sp2	6. 8	4 .4	3 .47
	sp3	6. 2	3 .1	3 .5

TABLE II. Ultimate load for Different orientations in double lap joint

S. No	Specimens	Load (kN)		
		0°	*Angle Ply*	*Cross Ply*
1	Sp1	9.3	4.1	5.66
2	Sp2	7.9	5.27	6.4
3	Sp3	7.5	4.27	5.75

It can be inferred that the 0° orientation in single lap and double lap joints carried the maximum amount of load which is in accordance with the literature since the load is applied along fiber direction for 0°. In case of the angle ply specimen, for the single lap joint the failure occurred in the bonded area, however in case of double lap joint, the failure occurred in the specimen. In 0° and cross ply orientation the failure occurred in the bonded area for both single and double lap joints.

B. Finite Element Model

The geometry of the joint used for modeling is shown in figures 1 and 2 for single and double lap joints respectively. The width of all members is 25mm. The thickness of adherends was taken to be 3mm, and the thickness of adhesive layer was 0.2mm. The adherends are considered to be made of the material plain woven glass-fiber reinforced epoxy laminate see figure 4, glass fiber fabric and the adhesive was considered to be resin-fusion AW106 epoxy. Table III gives the properties of this material. The mechanical properties listed in the table are determined experimentally. The behavior of all the members is assumed to be linear elastic. In some of the research papers, the adhesive behavior was considered to be elastic–plastic [4]. Since the adhesive used in the present work is quite brittle, and reinforcing the adhesive by fibers makes it more

brittle, the adhesive layer was assumed to be linear elastic. The mechanical properties of adhesive was E=3.4GPa and ν=0.3.
The SOLID 46 elements were used for meshing the members. These elements have 8 nodes and 3 degrees of freedom at each node. They are suitable to model laminated orthotropic composites. The element size in the adhesive layer was refined to get better and accurate results. The co-ordinate z-axis is in the thickness direction.

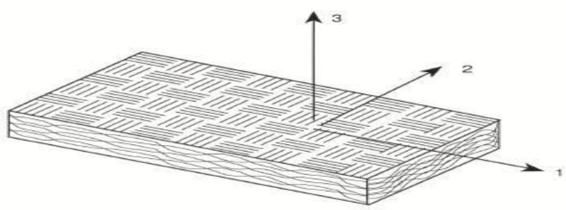


Figure 4. Glass- fiber reinforced epoxy laminate

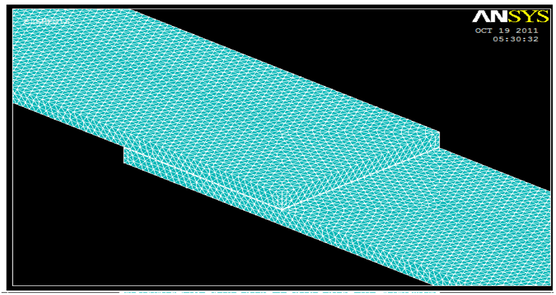
1) Single Lap joint
The static elastic analysis of the joints was performed for in-plane (tensile) loading of the joint.
Elements = 117655
Nodes = 21327
In the case of in-plane loading of the joint, one end of the adherend was constrained from x, y and z translations, while the other end was constrained from y and z translations. The load of 80 N/mm^2 (for zero orientation lap joints) was applied in the form of pressure to this end towards the positive x-direction.

TABLE III. Experimentally determined Mechanical properties of specimen

Property	Values
E_{11} (GPa)	16.450
E_{22} (GPa)	5.517
E_{33} (GPa)	5.517
ν_{12}	0.01168
ν_{23}	0.241
ν_{13}	0.241
G_{12} (GPa)	6.651
G_{23} (GPa)	6.651
G_{13} (GPa)	6.651

2) Double Lap Joint
The static elastic analysis of the joints was performed for in-plane (tensile) loading of the joint.
Elements = 186864
Nodes = 39354

In the case of in-plane loading of the joint, one end of the adherend was constrained from x, y and z translations, while the other end was constrained from y and z translations. The load of 109N/mm^2 (for zero orientation lap joints) was applied in the form of pressure to this end towards the positive x-direction.



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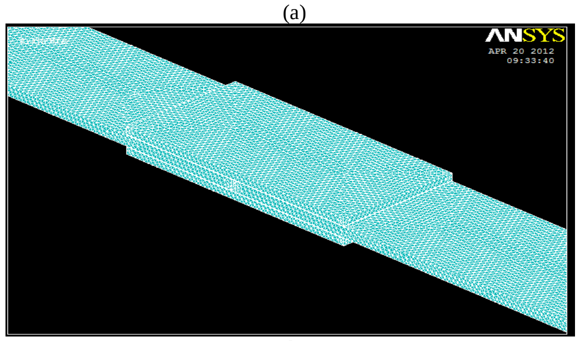


(b)

Figure 5. Meshing in (a) single lap joint (b) double lap joint

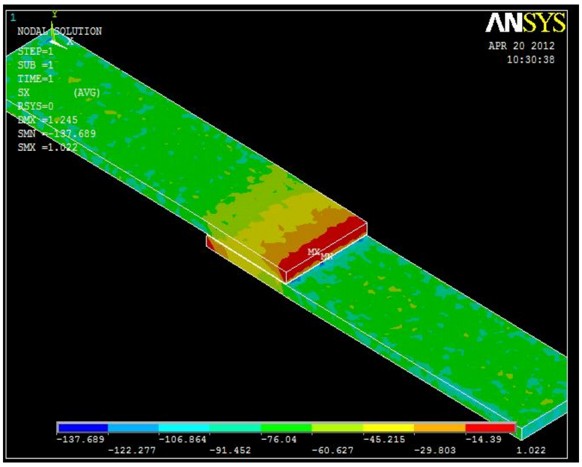
C. Results and Discussion
Figure 6 and 7 shows the variations of stresses along the adhesive length for different orientation lap joints when subjected to tensile loading. The maximum values of stresses occurred near both the ends of the adhesive region. Table IV shows the values of displacement for different orientation of fibers in single lap joint, while Table V shows the displacement value for different fiber orientations in double lap joint.

D. Experimental and computational Results
Table VI shows the result obtained experimentally, whereas Table VII shows the results obtained by using standard FEA Package ANSYS.

IV. CONCLUSION

In the present paper, the response of single and double lap joints with composite adherend subjected to tensile load was investigated for different fiber orientations. The results indicate that the stresses were maximum near both ends of the adhesive region, but towards the central part of the adhesive layer these stresses reduces in magnitude. A finite element simulation was also performed. The mechanical properties obtained experimentally were incorporated in the FEA package and the results were compared with the experimental results and 4%

deviation was observed. The strength of the joints is investigated.



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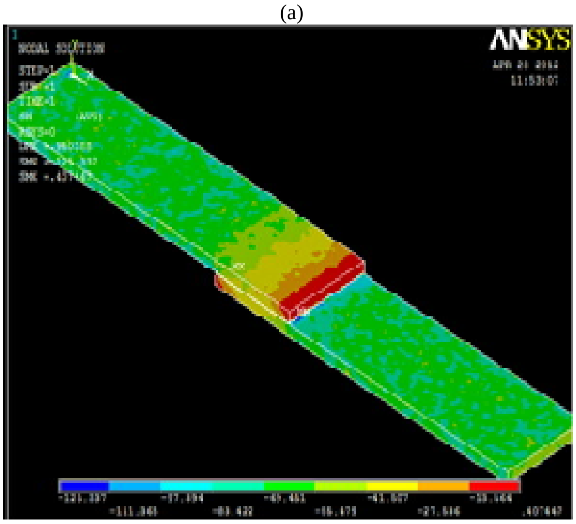

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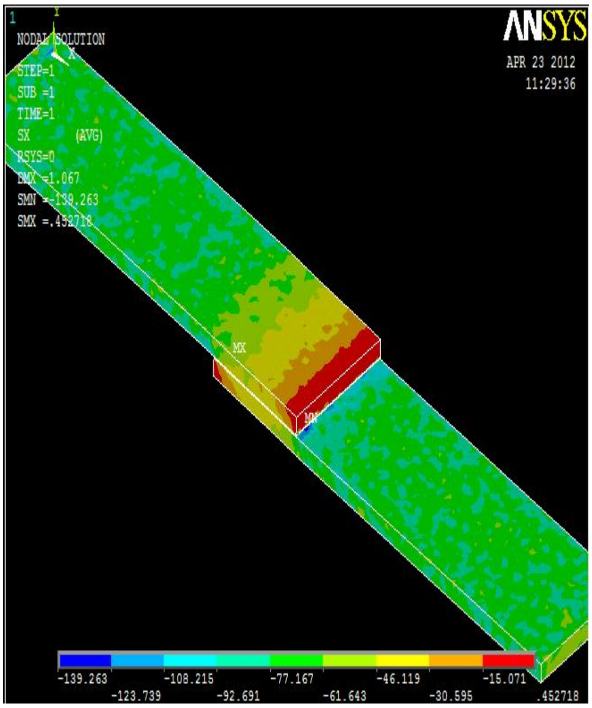
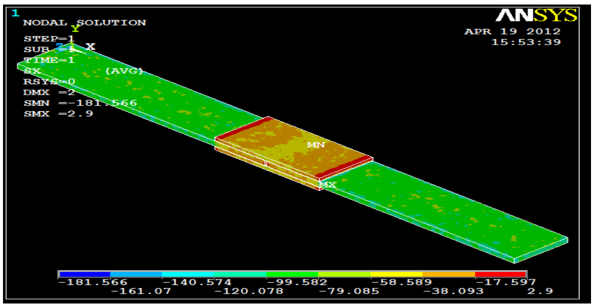


(c)

Figure 6. Single lap joint (a) Zero fiber orientation (b) Cross fiber orientation (c) Angle fiber orientation



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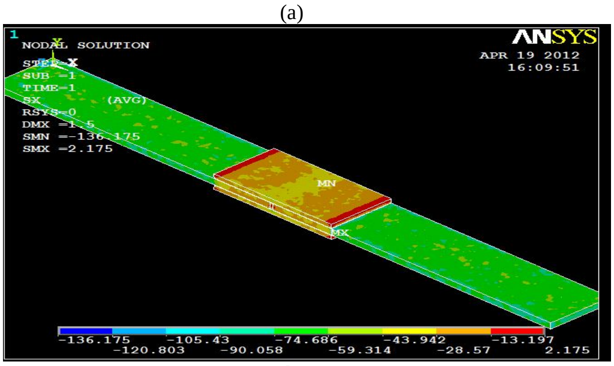

(b)

Figure 7. Double lap joint (a) zero fiber orientation (b) cross fiber orientation

TABLE IV. Displacements for Different orientation single lap joint

S. No	**Fiber Orientation**	**Computational Displacement(mm)**
1	Zero	1.24
2	Cross	0.96
3	Angle	1.06

TABLE V. Displacements for different orientation double lap joint

S. No	**Double Lap Joints Orientation**	**Computational Displacement (mm)**
1	Zero	2
2	Cross	1.5

TABLE VI. COMPARISON FOR DOUBLE LAP JOINT

S.No	**Orientation**	**Experimental Displacement (mm)**	**Computational Displacement (mm)**	**Deviation %**
1	Zero	2.18	2	4.7
2	Cross	1.55	1.5	3.2

TABLE VII. COMPARISON FOR SINGLE LAP JOINT

S.No	**Orientation**	**Experimental Displacement (mm)**	**Computational Displacement (mm)**	**Deviation %**
1	Zero	1.2	1.24	3.23
2	Cross	1	0.96	4
3	Angle	1.1	1.06	3

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