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INVESTIGATIONS ON STRENGTH ANALYSIS OF LAP JOINTS FOR ALUMINUM- EPOXY COMPOSITE PLATES USING FINITE ELEMENT METHOD WITH EXPERIMENTAL VERIFICATION

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ABSTRACT:

In this dissertation, the mechanical behaviour of 2-bolted single-lap Aluminum glass-fiber composite plate with high strength bolts is investigated, both analytically and experimentally. A detailed 3D non-linear FE model of composite bolted joints has been developed. The model replicates with good agreement the experimental tensile tests up to the point where bearing damage occurs and reproduces the joint behaviour correctly. The evolution of contact during the test is studied showing a correlation with the joint stiffness.

Using the developed FE model, the distribution of the stress components around the holes of the composite joints is studied together with the effects of hole clearance and position of bolts. The stress along the fibres is identified as the critical stress component and the compressive fibre failure of the 0° oriented plies as the start of the bearing damage. The 0° oriented plies in the cylindrical part of the hole are found to be the plies carrying the bearing load. Increasing clearance reduces the extent of the bolt shank-hole contact and leads to higher stresses and lower joint stiffness. The 45° and -45° oriented plies are found to have a key role in the joint bearing strength and shear-out failure.

KEYWORDS: Progressive failure, Lap joints, Laminate, Fiber orientation.

I .INTRODUCTION

Composites are widely used in different disciplines of engineering and structural systems as in aerospace and automobile industries, power plants, etc. These applications generally use mechanical fasteners, such as pinned and bolted joints for joining parts (to each other) in assemblies. Under loading, defects such as fibre breakage, matrix cracks, fibre/matrix de-bonding occurring in a ply do not cause the immediate collapse of a laminate when they appear. Therefore, investigation on strength analysis of Lap Joints of Composite plate is an essential.

II.MATERIAL AND SAMPLE PREPARATION

The sample preparation of the single lap bolted joint specimen consist of the facings which are nothing but the aluminum sheets of (150 x 50 x 1.5) and the composite structure used inside is a glass fiber/epoxy plates thickness varied from1.5 mm,2 mm and 3 mm used to maintain the strength to weight ratio of the composite specimen. M8 High tensile carbon steel bolt is used for the single lap bolted joint. Specimens of size with geometry are shown below in the table 3.1

Table 1: Specimens size

Length of Aluminium plate	150 mm
Width of Aluminium plate	50 mm
Thickness of Aluminium plate	1.5mm
Plate overlaps	50 mm
Diamter of the holes in plates	8 mm

III.Design Calculation's and Material Properties

Design for Single lap bolted Joint for E- Glass fiber material.

Consider,

Tensile Stress acting on mild steel, σt = 175 MPa

Crushing Stress for Mild steel, σc = 207MPa

Crushing Stress for E-Glass fiber, σc =5000MP

width (b) = 50 mm , thickness(t) = 6 mm ,

length (l) =150mm ; Factor of safety = 2

Maximum load carring capacity of bolt=Ft= 155 x 103 N

Ultimate Tensile stress = 2050 Mpa

σttheoretical = Ultimate tensile stress / Factor of safety

Tensile Stress for E-Glass Fiber,

σt theoretical=1025 MPa;

Stress (σt) = Force / Area

Ft = (b x t) x (σt)theoretical

$155 \times 103 = (50 \times 6) \times (\sigma t)_{Cal.}$

$(\sigma t)_{Cal.} = 516.756$ Mpa

$(\sigma t)_{Cal.} < (\sigma t)_{theoretical}$

Where,
Ft = Tensile force,
b = width, t = thickness.

"The obtained Dimensions are safe for the Design, so the Design is safe." Consider the Crushing Stresses induced in Single Bolted Joint made of E-Glass Fiber.

Design calculations for bolts

Consider Tensile Force on Plate, for two bolted joint is

$F_t = 620 \times 10^3 N$

$F_t = n \times (b \times t) \times \sigma_{theoretical}$

$620 \times 10^3 = n \times 50 \times 6 \times 1025$

$n = 2.08$

i.e. n = 2

Where,
Ft = Tensile force, n = Number of bolts,
b = width, t = thickness

Therefore, Two bolts are required for transferring force.

For Two Bolts (n = 2)

$620 \times 10^3 = 2 \times 50 \times 6 \times (\sigma t)_{cal}$

$(\sigma t)_{cal.} = 993.5$ MPa.

"Which is less than (σt) theoretical. Therefore, the Design is safe."

3.5.3 Mass Calculation

I) For Composite laminate Plate:

Mass = Density x Volume
= 2000 x l x b x t
= 2000 x 0.150 x 0.050 x 0.006
= 0.09 kg

II) For mild steel Plate:

Mass = Density × Volume
Mass = 7845 x l x b x t
= 7845 x 0.150 x 0.050 x 0.006
= 0.3530 kg

Weight Reduction % = [(0.3530−0.09) / 0.3530] ×100
=74.5042%

Fig. 1: Aluminum-Glass fiber composite plate bolted single lap joint

CAD Modeling

Figure 2 shows the 3D CAD model of Aluminum-Glass Fiber Composite Plate Bolted Single Lap Joint.

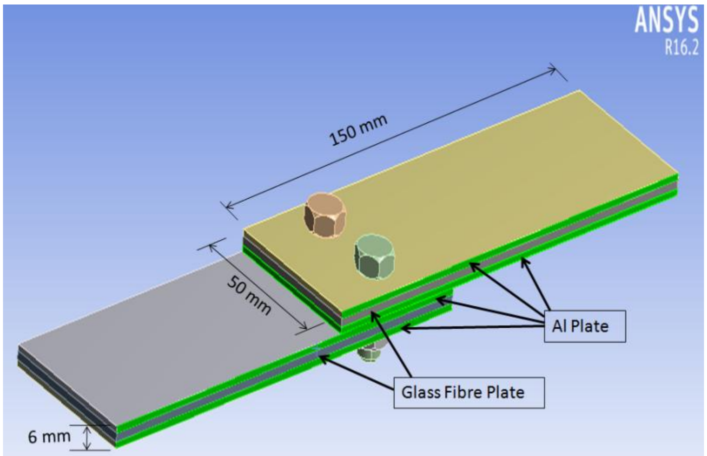

Fig. 2: 3D model of Aluminum-Glass fiber composite plate bolted single lap joint.

IV Finite Element Analysis

The commercial Finite Element Analysis (FEA) software, ANSYS has been used to create and analyze the models.

Analysis for 0^0 Fibre Orientation

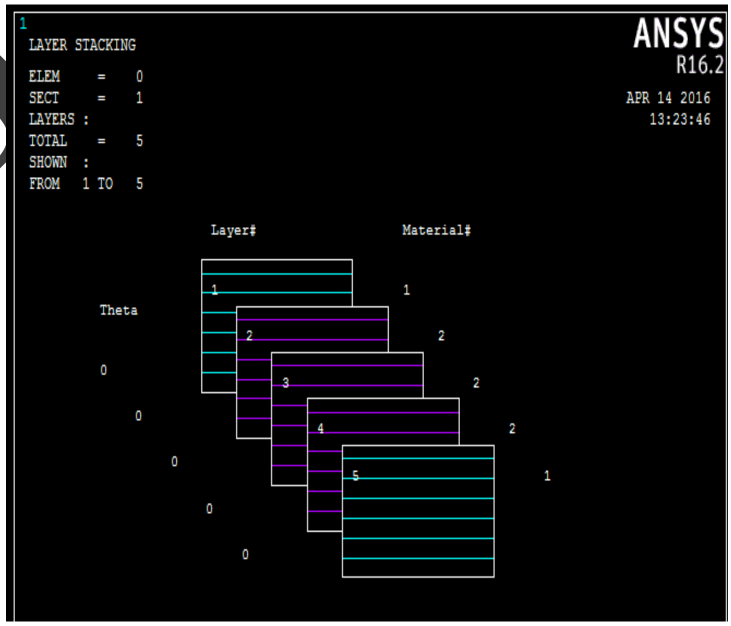

Fig. 3: Arrangement for 0^0 Fibreorientation.

In figure 3 green colour orientation shows aluminium material and violet colour shows glass fibre orientation. in this analysis all fibre are oriented at 0^0. Aluminium plate thickness is 1.5 mm and glass fibre epoxy plate thickness is 3mm.

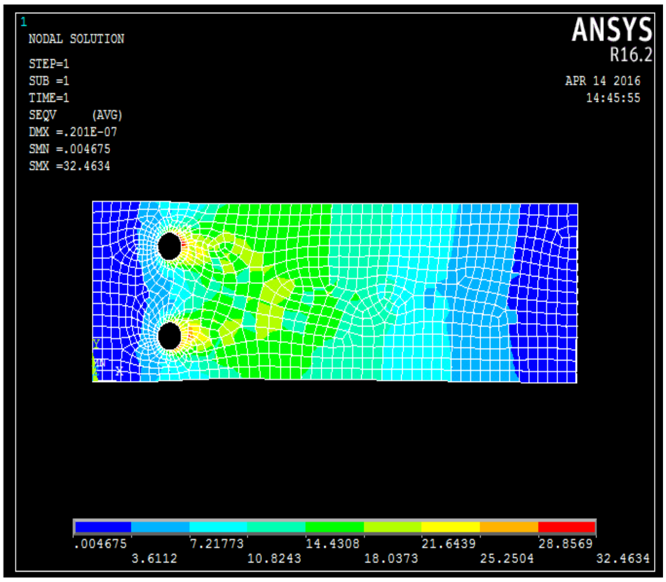

Fig. 4: FEA Result for 0^0 fibre orientation

In figure 4 Maximum stress appears around the hole area. Red colour shows maximum value of stress and probable region of failure at this particular section. Maximum stress value obtained from FEA is 32.46 MPa.

Analysis for 90^0_45^0 Fibre Orientation

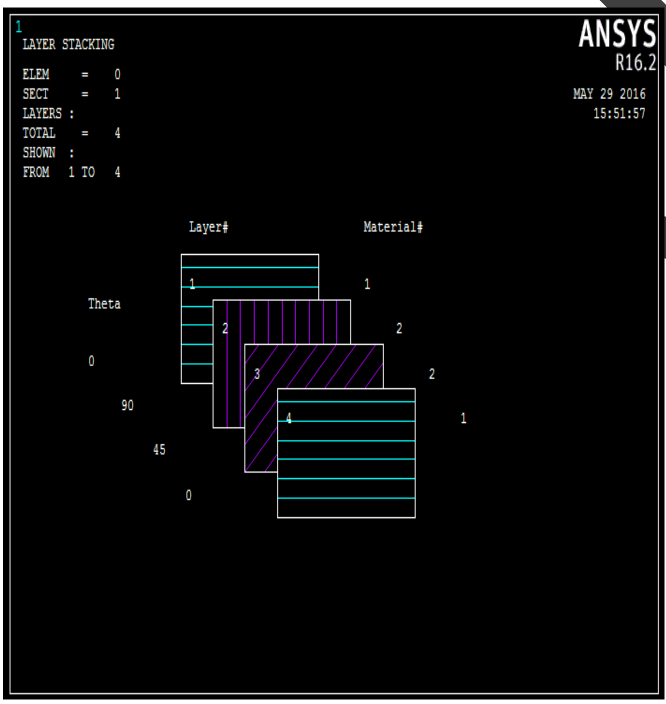

Fig.5:Arrangement for 90^0_45^0 fibre orientation

In figure 5 green colour orientation shows aluminium material and violet colour shows glass fibre orientation. In this analysis all fibre are oriented at 90^0-45^0 .Aluminium plate thickness is 1.5 mm and glass fibre epoxy plate thickness is 1.5mm.

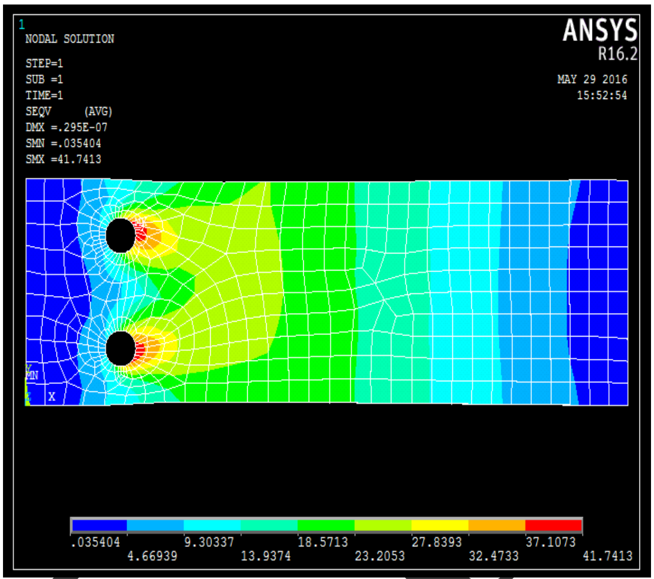

Fig.6: FEA Result for 90^0_45^0 fibre orientation

In figure 6 Maximum stress appears around the hole area. Red colour shows maximum value of stress and probable region of failure at this particular section. Maximum stress value obtained from FEA is 41.74 MPa.

Analysis for 0^0_45^0_90^0 Fibre Orientation

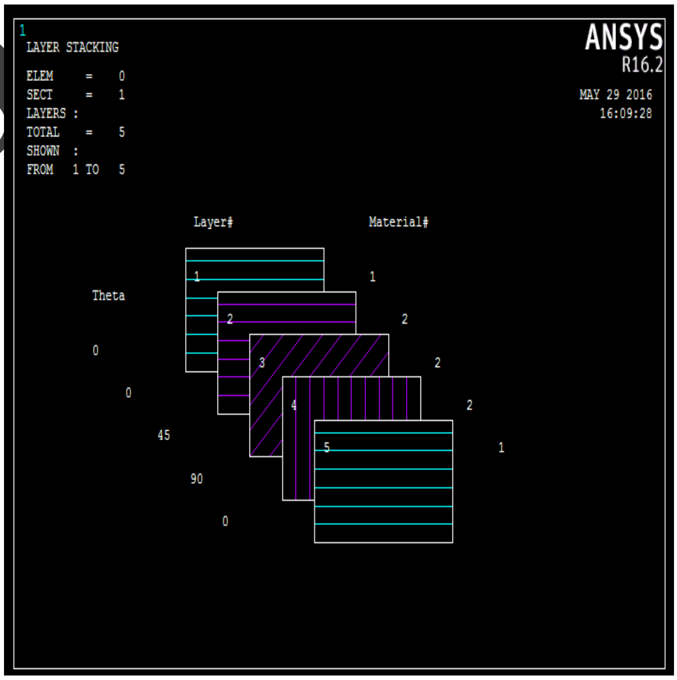

Fig. 7: Arrangement for 0^0_45^0_90^0 fibre orientation.

In figure 7 green colour orientation shows aluminium material and violet colour shows glass fibre orientation. In this analysis all fibre are oriented at 0^0-45^0-90^0. Aluminium plate thickness is 1.5 mm and glass fibre epoxy plate thickness is 1.5mm.

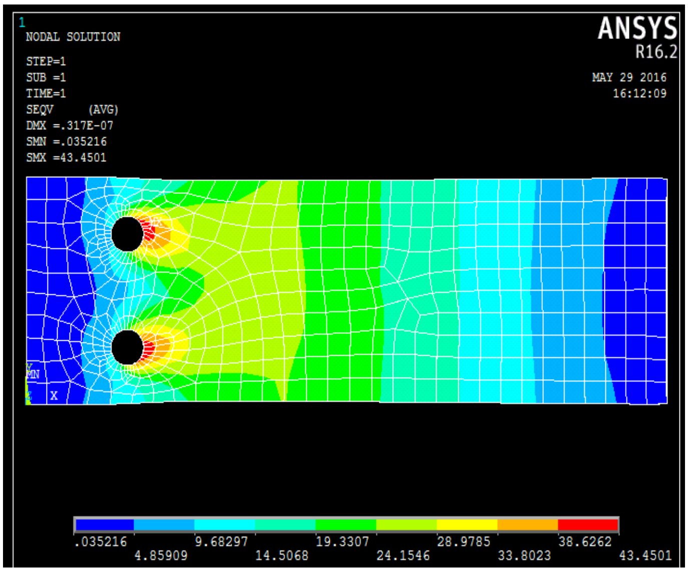

Fig. 8: FEA Result for $0^0\_45^0\_90^0$ fibre orientation

In figure 8 Maximum stress appears around the hole area. Red colour shows maximum value of stress and probable region of failure at this particular section. Maximum stress value obtained from FEA is 43.45 MPa.

V Experimental Results

A universal testing machine (UTM), is used to test the tensile strength

The tensile strength of a material is the maximum amount of tensile stress that it can take before failure. During the test a uniaxial load is applied through both the ends of the specimen. The dimension of specimen is (150 X 50 X Thickness of epoxy fiber) mm.

The tensile test is performed in the universal testing machine Instron 1195 and results are analyzed to calculate the tensile strength of composite single lap bolted joints.

Fig. 9: Actual image of sample breaking condition for tensile testingon UTM machine

Experimental test for 0^0 Fibre Orientation

Table 2 :Experimentalresult for 0^0 Fibre Orientation

Input Data			Output Data		
Specimen Shape	Flat		Load At Yield	17.16	kN
SpecimenType	Mild Steel		Elongation At Yield	11.160	mm
Specimen Description	Al-Glass fibre sand. plate- 00 Deg.		Yield Stress	28.6	N/mm2
			Load at Peak	21.500	kN
Specimen Width	50	mm	Elongation at Peak	14.700	mm
Specimen Thickness	12	mm	Tensile Strength	35.833	N/mm2
Gauge Length For % Elong..	50	mm	Load At Break	5.760	kN
Pre Load Value	0	kN	Elongation At Break	16.030	mm
Max. Load	1000	kN	% Reduction Area	- - -	%
Max. Elongation	250	mm	% Elongation	- - -	%
Specimen C S Area	600	mm2			
Final Specimen Width	50	mm			
Final Specimen Thickness	12	mm			
Final Gauge Length	50	mm			
Final Area	600	mm2			

Table 2 shows experimental result for 0^0 Fibreorientation for load at yield and load at peak

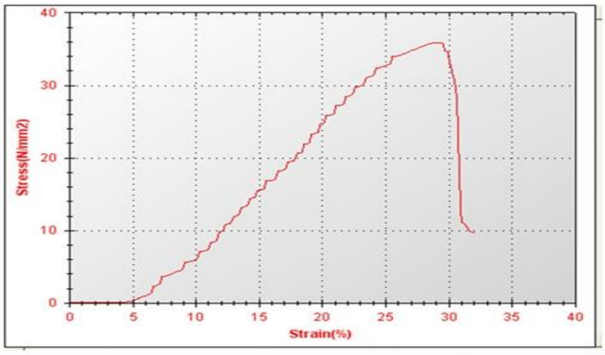

Fig. 10: Stress strain graph for 0^0 fiber orientation.

Figure 10 shows stress strain graph for 0^0 fiber orientation. Maximum stress value is 35.83 MPa. with strain value 29 according to experimental result.

Experimental test for $90^0\_45^0$ Fibre Orientation

Table3:Expt. result for $90^0\_45^0$ Fibre Orientation

Input Data			Output Data		
Specimen Shape	Flat		Load At Yield	15.08	kN
SpecimenType	Mild Steel		Elongation At Yield	9.180	mm
Specimen Description	Al-Glass fibre sand. plate- 90-45 Deg.		Yield Stress	33.511	N/mm2
			Load at Peak	17.430	kN
Specimen Width	50	mm	Elongation at Peak	11.640	mm
Specimen Thickness	9	mm	Tensile Strength	38.733	N/mm2
Gauge Length For % Elong..	50	mm	Load At Break	0.130	kN
Pre Load Value	0	kN	Elongation At Break	21.420	mm
Max. Load	1000	kN	% Reduction Area	- - -	%
Max. Elongation	250	mm	% Elongation	- - -	%
Specimen C S Area	450	mm2			
Final Specimen Width	50	mm			
Final Specimen Thickness	9	mm			
Final Gauge Length	50	mm			
Final Area	450	mm2			

Table 3 shows experimental result for $90^0\_45^0$ Fibre Orientation for load at yield and load at peak.

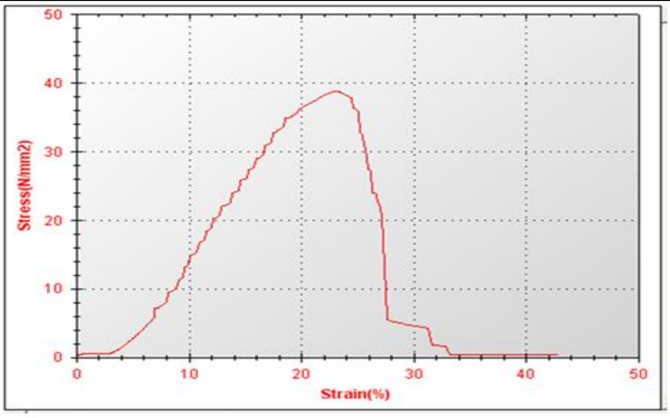

Fig. 11 : Stress strain graph for $90^0\_45^0$ fiber orientation.

Figure 11 shows stress strain graph for $90^0\_45^0$ fiber orientation. Maximum stress value is 38.73 MPa. with strain value 23 according to experimental result.

Experimental test for $0^0\_45^0\_90^0$ Fibre Orientation

Table 4:Expt. result for $0^0\_45^0\_90^0$ Fibre Orientation

Input Data			Output Data		
Specimen Shape	Flat		Load At Yield	16.18	kN
SpecimenType	Mild Steel		Elongation At Yield	10.980	mm
Specimen Description	Al-Glass fibre sand.plate-0-45-90 Deg.		Yield Stress	35.956	N/mm2
			Load at Peak	20.850	kN
Specimen Width	50	mm	Elongation at Peak	14.350	mm
Specimen Thickness	9	mm	Tensile Strength	46.333	N/mm2
Gauge Length For % Elong..	50	mm	Load At Break	2.340	kN
Pre Load Value	0	kN	Elongation At Break	15.780	mm
Max. Load	1000	kN	% Reduction Area	---	%
Max. Elongation	250	mm	% Elongation	---	%
Specimen C S Area	450	mm2			
Final Specimen Width	50	mm			
Final Specimen Thickness	9	mm			
Final Gauge Length	50	mm			
Final Area	450	mm2			

Table 4 shows experimental result for $0^0\_45^0\_90^0$ Fibre Orientation for load at yield and load at peak

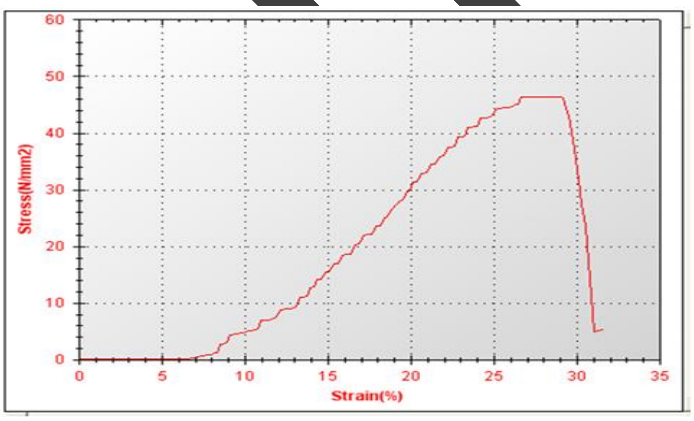

Fig. 12: Stress strain graph for $0^0\_45^0\_90^0$ fiber orientation.

Figure 12 shows stress strain graph for $0^0\_45^0\_90^0$ fiber orientation. Maximum stress value is 46.33 MPa. with strain value 26.5 according to experimental result.

Comparison between FEA results and Experimental Results

Table 5 presents percentage error in FEA results and experimental results of tensile strength. It is clear from this table that there is an error of around 10 to 11 % percent in both of these results. This error in the results obtained by both methods is because of the assumptions made in the FEA process and the measurement errors and preparation in the experimental method.

Table 5: Comparison between FEA and Expt. Results.

Sr. No.	Fiber Orientation and Stacking Sequence	Tensile strength (MPa)		Residual Error C= (B-A)	% Error (C/A)%
		FEA Result (A)	Expt. Result (B)		
1	0^0	32.46	35.83	3.37	10.38
2	45^0	30.19	34.72	4.53	15.00
3	90^0	28.35	33.62	5.27	18.58
4	$0^0\_90^0$	36.64	33.53	3.11	8.48
5	$0^0\_45^0$	39.58	36.02	3.56	8.9
6	$90^0\_45^0$	41.74	38.73	3.01	7.21
7	$0^0\_90^0\_45^0$	37.98	31.65	6.33	16.6
8	$90^0\_0^0\_45^0$	40.28	31.46	8.82	21.8
9	$0^0\_45^0\_90^0$	43.45	46.33	2.88	6.62

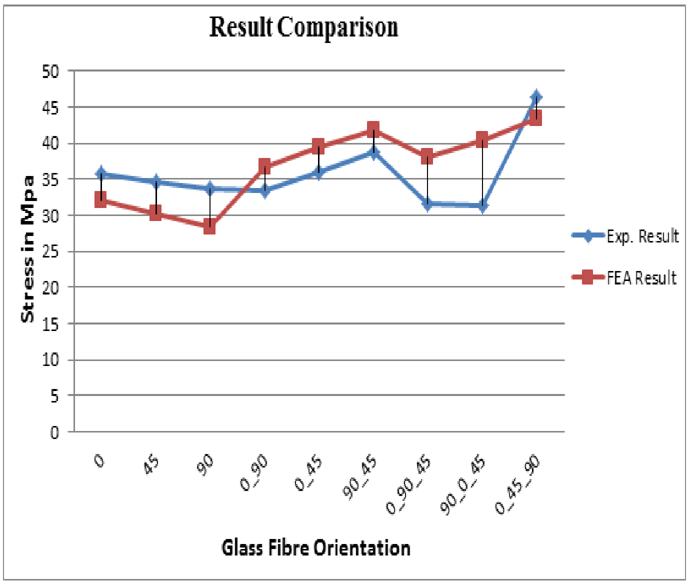

Fig. 13: Graph of FEA Results Vs. Expt.Results.

In the first 13 test glass fibre direction was uni-direction 0^0, 45^0, 90^0, next 3 test specimen was bi-direction like 0^0-90^0, 0^0-45^0, 90^0-45^0 and last three tests was multi-direction glass fibre orientation like 0^0-90^0-45^0, 90^0-0^0-45^0, 90^0-45^0-90^0. When we compile the FEA result with experimental one good thing is all the results under 10% to 11% deviations.

VI. CONCLUSION:

Finite element model of a single lap sandwich composite bolted joint, with carbon steel bolts, under static tensile load was subjected to appropriate boundary condition. The model comprises a high level of CAD model with geometrical details for the plates and bolts (such as the bolt threads and clearance), the simulation of the sandwich plate with different orientation was also accomplished.

The following conclusions can be drawn from the present Study-

1. Optimum tensile strength is observed for single direction at 0^0 fibre orientation with maximum thickness (3 mm).
2. Optimum tensile strength is observed for bi-direction at 90^0-45^0 fibre orientation with minimum thickness (1.5 mm).
3. Optimum tensile strength is observed for multi-direction at 0^0_45^0_90^0 fibre orientation with minimum thickness (1.5 mm).
4. It is observed that the best stacking sequence is 0^0_45^0_90^0 with optimum thickness (1.5mm), this aluminum-glass fibre sandwich bolted joint sustain maximum load and tensile strength is higher than all other aluminum-glass fibre composite joints.
5. Aluminum plate thickness was constant in every sandwich joint but glass fibre thickness varied from 1.5mm, 2mm and 3mm. From the results, experimental and FEA it can be concluded that 1.5 mm thickness of glass fibre is optimum thickness for 00_450_900 stacking sequence.

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