The Strength Analysis of Hybrid (Bolted and Bonded) Single Lap joints for Composite Materials

Mahesh J. Patil, Rajendrakumar N. Patil

***Abstract**: The two joining techniques i.e. adhesive bonding and mechanical fastening combined are termed as hybrid joints. These kinds of joints mix the benefits of each the joining ways. The composite materials are used in structures at larger extend because of its properties like high strength to weight ratio, high fatigue resistance, high impact strength etc. The paper evaluates the mechanical behavior of Hybrid joint using composite as adherents subjected to tensile loading. The joint was observed to fail in two stages. Initially because of failure of adhesive and later by the failure of the bolt. The different parameters like overlap length, bolt size, tightening torque and adhesive thickness were studied and the significant factor were found to be overlap length, bolt size and tightening torque*

Keywords: Adhesive, Bolt, Composite material, Hybrid joint.

I. INTRODUCTION

The crucial feature in a hybrid joint structure is the joint geometry. The inappropriate design might result into surplus increase in weight and defective structures. Historically the change of integrity is achieved by mechanical fastening or adhesive bonding for hybrid materials. In adhesive bonding no cutting of fiber is required hence load distribution is better than mechanical joints and over larger areas. On the other hand, the disadvantages of adhesive joints are catastrophically failure, materials sensitivity towards surface treatment, temperature at adherent interfaces, humidity and other environmental situations. The two totally different connection techniques are concerned in hybrid joints. Primarily, the benefits of the two totally different connection techniques are brought along. The bolting or adhesive joining is done either simultaneously or one after the other and the joint properties are enhanced. The joints are given priority in numerous sections like assembly of contemporary lightweight weight automotive and business vehicle structures, aircraft design and conjointly in ship building. the mixture of adhesive bonding and the bearing and method abilities enhance with mechanical type of connections. Numerous papers can be found regarding bolts, rivets or pins in mechanical joints.

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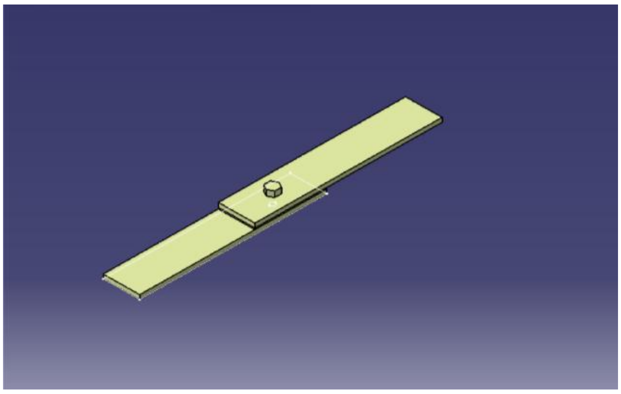

Figure 1 The Hybrid joint

Design of Experiment, Taguchi analysis are the different analysis techniques used. In this paper the joint is prepared by using composites as the adherents and joint them using bolts and adhesives. Individually tensile loading of joints results into failure of mechanical joints in shear and adhesives are subjected to peel off failures at the edges. Therefore, to overcome the disadvantages of each joining technique it is suggested that hybrid joints be employed. The individual adhesive joints show maximum stresses generated at the overlap edges and the bolted joints shows stress concentration near the holes.

II. LITERATURE REVIEW

The load distribution in single lap composite joint is predicted by using finite element analysis. The relation in bolt hole contact and nonlinear material behavior is additionally used. The experimentally measured bolt load results were compared with finite element technique [1]. The hybrid joint formed by welding and riveting was compared with simple adhesive joint by [2]

[7] The single lap joint is made from aluminum with adhesive as joining material was investigated. Using optimum overlap length, the maximum strength is achieved. Also, the impact of adherent material and surface preparation of the adherent plays an important role in the strength improvement.

In [8] this paper, the automotive chassis, optimization is carried out by using obliges resembling chassis defection, equivalent stress and maximum shear stress. The finite element analysis method can help to analyze the structures like chassis efficiently.[9] In this paper behavior of joints with use of bolts and Fiber reinforced polymer was carried out. The bolt torque and adhesive effect on failure modes and load capacity was tested.

The results showed slight increase in load capacity with the innovative joint.[10] studied the bending and coupled in-plane analysis using a semi-analytical technique for the bolted-bonded single lap hybrid joint. The adhesive takes all the initial load as it does not have any defects nor any debounding has started. The bolt starts sharing load as soon as some debonding takes place.

III. MATERIAL SELECTION

The lap joint is prepared by using, Glass Fiber Reinforced Polymer i.e. composite material is used as the substrate material because of its high strength to weight ratio, high fatigue resistance, high impact strength and non-corrosive properties. The adhesive used for experimentation is a hybrid grade Loctite 4090 (Cyanoacrylate and Epoxy) which consists of two parts in a product, one is hardener and the other one being the resin, once both the hardener and the resin are mixed, the curing time starts, and it cures within minutes. Available in one-part or two-part form and can be supplied as flowable liquids, as highly thixotropic products with gap-filling capability of up to 25mm, or as films. Along with adhesive to prevent the catastrophic failure of the joint mechanical joining technique i.e. bolts are also used. The ISO grade 5.8 bolts having yield strength of 400 N/mm^2 is used in sizes M4*0.5, M5*0.5 and M6*0.75.

Fig. 2. Adhesive used in Experimentation

IV. TAGUCHI ANALYSIS AND ANALYSIS OF VARIANCE

The surface preparation of adherents plays a very important role in the joints. The specimens are prepared by initially polishing them with 400 grit emery paper and then cleaning the surfaces with acetone to remove the dirt, dust and other impurities on the surface. The adhesive was applied using fixtures. Than the specimens are kept for curing. The bolts were preloaded with appropriate torque. The specimens were mounted on tensile testing machine where the adhesive and bolt are subjected to shear stresses. The tests are conducted on the Universal Testing Machine (STS – 248) where one end of the specimen is held in the grippers. The grippers are used at both the ends to keep a tight hold of the specimen. The maximum load machine can apply is 100 KN. The Lower end is fixed, and the upper gripper is moved at a velocity of 10 mm/min.The tensile testing machine is used to carry out the experimentation work. The specimens are prepared by initially polishing them with 400 grit emery paper and then cleaning the surfaces with acetone to remove the dirt, dust and other impurities on the surface. The adhesive was applied using fixtures. Than the specimens were kept for curing. The bolts are preloaded with appropriate torque. The specimens were mounted on the machine as shown in fig. 4.

Table -I: Threaded Fasteners Strength Details [12]

Property Class	3.6	4.6	4.8	5.6	5.8	6.8	8.8	9.8
Tensile Strength , S_T (N/mm^2)	300	400	400	500	500	600	800	900
Yield Strength, S_Y (N/mm^2)	180	240	320	300	400	480	640	720

Fig. 3. The Specimens

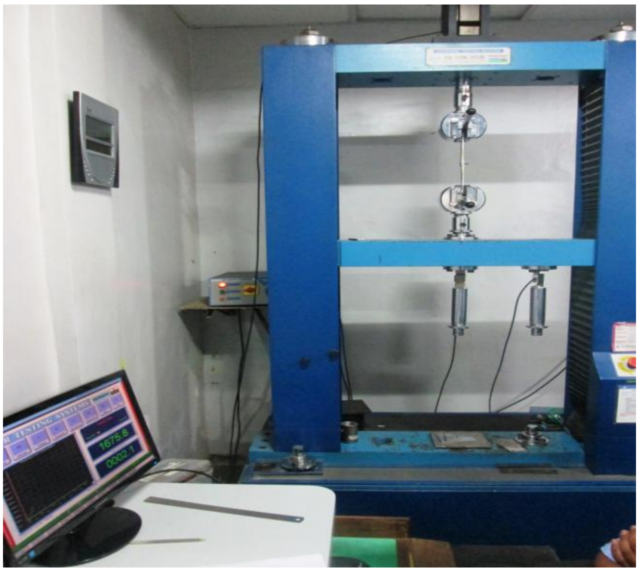

Fig. 4. Experimental Setup

A. Experimental Procedure

Table-II: The Factors and Levels

Sr. No.	Factors	Levels		
		1	2	3
1	Overlap Length (mm)	20	25	30
2	Bolt Size (Metric)	M4*0.5mm	M5*0.5mm	M6*0.7
3	Tightening Torque (N-m)	4	5	6
4	Adhesive Thickness (mm)	0.5	1	1.5

Table-III: The Parameters in Coded Form

Runs	Parameters			
	Overlap Length (mm)	Bolt Size	Tightening Torque (N-m)	Adhesive Thickness (mm)
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table-IV: The Actual Values and Responses

Runs	Overlap Length (mm)	Bolt Size (type)	Tightening Torque (N-m)	Adhesive Thickness (mm)	Failure Load (N)	
					Repetition 1	Repetition 2
A	20	M4	4	0.5	2322.6	2554.86
B	20	M5	5	1	2132.48	2345.728
C	20	M6	6	1.5	2548	2802.8
D	25	M4	5	1.5	2698.92	2968.812
E	25	M5	6	0.5	2340.24	2574.264
F	25	M6	4	1	3105.6	3416.16
G	30	M4	6	1	2405.9	2646.49
H	30	M5	4	1.5	2554.8	2810.28
I	30	M6	5	0.5	2943.9	3238.29

The experiment was designed by using four factors at three levels. The four factors under consideration are overlap length, bolt size, tightening torque and Adhesive thickness. The parameters and their levels are as shown in table 2 so by using Taguchi's L9 orthogonal array nine runs were required to be conducted.

B. Taguchi Analysis

In Taguchi analysis, the quality loss function plays a major role. It states that as the variance (variation from the target value) increases the loss incurred due to reduction in quality, also increases. Thus, it is expected the variance to be minimum.

The results obtained from experiments were analyzed by using Taguchi analysis. Table III shows the coded form of L9 Orthogonal Array design in which three levels of parameters are considered. Table IV gives the actual values of the parameters set and the results obtained of failure load after

Table- V: S/N Ratio values

Sr. No.	R1	R2	Test Response total	Mean	S/N Ratio
A	2322.6	2554.86	4877.46	2438.73	67.71372
B	2132.48	2345.728	4478.208	2239.104	66.97193
C	2548	2802.8	5350.8	2675.4	68.51822
D	2698.92	2968.812	5667.732	2833.866	69.01803
E	2340.24	2574.264	4914.504	2457.252	67.77944
F	3105.6	3416.16	6521.76	3260.88	70.23714
G	2405.9	2646.49	5052.39	2526.195	68.01978
H	2554.8	2810.28	5365.08	2682.54	68.54137
I	2943.9	3238.29	6182.19	3091.095	69.77269

experimentation is also mentioned in it. Two repetitions of the results are carried out. The values of Signal to noise ratio (n is number of repetitions and y_i are experimental values) are given in table V. Greater values of S/N are expected. The S/N ratio are found out by using larger the better value formulae given by

$$S/N\ Ratio = -10 log_{10}\left(\frac{1}{n}\sum\frac{1}{y_i^2}\right) \quad (1)$$

C. Analysis of Variance (ANOVA)

The Analysis of variance is also carried out which gives significance of each of the parameter related to the output. Here the F test is conducted which is the ratio of Parameter variance to the error variance. The F value is found out from the data books and whichever calculated F value is greater than F value stated, are the significant factors. The percentage contribution of each factor is also found out and it is the maximum for the parameter bolt sizeAt 95% confidence level with degrees of freedom for numerator 2 and degrees of freedom for denominator 9, F limit value referred from standard table is **4.2565.** All the values greater than 4.2565 have significant effect on the output. Thus, from the ANOVA table it is observed that the Bolt size, overlap length and Tightening torque parameters affecting the output parameter i.e. Failure load.

Table-VI: ANOVA Table

Factors	**DOF**	**SS**	**V**	**F**	**P (%)**
Overlap Length	2	532592.848	266296.42	8.01	26.50
Bolt Size	2	978491.882	489245.94	14.72	48.69
Tightening Torque	2	183549.672	91774.84	2.76	9.134
Adhesive Thickness	2	15750.0518	7875.03	0.24	0.783
Error	9	299109	33234.33		
Total	18				

V. RESULTS AND DISCUSSIONS

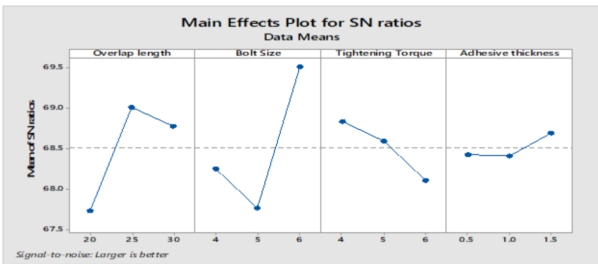

Fig.5. Main effects plots

The main effect plot for SN ratios were plotted and it was observed that the difference between the readings is maximum for the parameters bolt size and overlap length i.e. the significant factors are Bolt size and overlap length as compared to tightening torque and adhesive thickness. The optimum combination for the hybrid joint is found out to be $A_2B_3C_1D_3$The load displacement curve is obtained for different runs with different combinations of parameters. From the graph it is observed that there is a linear growth at the initial loading conditions with excessive slope. During tensile loading the load is initially taken by the adhesives and the static friction between the composite materials. Also, because the stiffness of adhesives is greater than the bolts. During this period there is no relative movement between the two adherents. After a specific load there is a section in graph where the slope reduces almost to zero .Here the adhesive fails and then there is a relative movement in the adherents and the graph again raises with a slope which indicates that the load is taken by the bolt .The graph reaches till the ultimate strength of the joint and then fails.

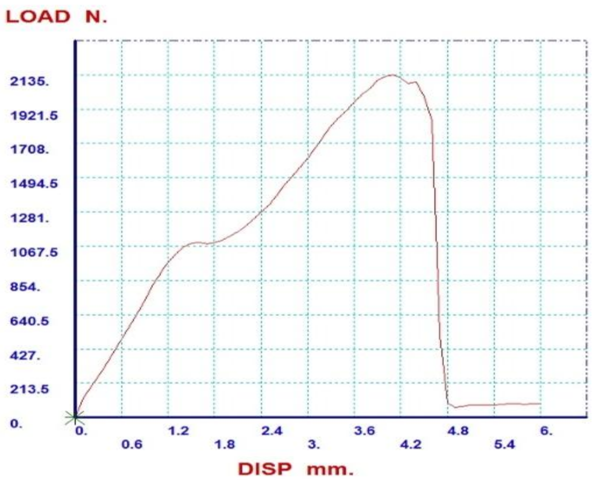

Fig.6. Load Vs Displacement Curve

VI. CONCLUSION

Total of 9 experimental runs were analyzed using Taguchi method. All the test samples are tested using the experimentation and load displacement curve has been extracted. The best combination of factor is calculated from the ANOVA, and the best combination is found out to be A2B3C1D3 i.e. hybrid joint having bolt of diameter 6mm with applied overlap length 25mm, tightening torque of 4 N-m and adhesive thickness of 1.5mm

The result from the parametric study is summarized as follows;

Load capacity of joint increases with increase in bolt dimension as larger bolt are having larger shear area

Load capacity of joint increases with increase in adhesive thickness which result in less stresses.

Load capacity of joint decreases with increase in overlapping length which seems opposite to physics but reason for dropping in the load capacity is shear stress in the area reduces which is obvious and hence the less load being transferred to the bolt due to less relative displacement between the plates. Increasing the load from 20mm to 25mm.

REFERENCES

1. Gordon Kelly, "Load transfer in hybrid (bonded/bolted) composite single-lap joints," Composite Structures 69 (2005) 35–43.
2. F. Moroni, A. Pirondi, Kleiner, "Experimental analysis and comparison of the strength of simple and hybrid structural joints," International Journal of Adhesion & Adhesives 30 (2010) 367–379.
3. Vincent Cassese, Jean-Paul Kabche, Keith A. Berube, "Analysis of a hybrid composite/metal bolted connection subjected to flexural loading," Composite Structures 81 (2007) 450–462.
4. Aldas, K., and Sen F, "STRESS ANALYSIS OF HYBRID JOINTS USING DIFFERENT MATERIALS VIA 3D-FEM," International Journal of Engineering & Applied Sciences (IJEAS) Vol.3, Issue 1(2011)90–101.
5. Peng Hao Wang, "The Effects of Adding Attachments in Conventional Composite Hybrid Joints on Tensile Strength," Purdue University Purdue e-Pubs, 12-1-2010.
6. Jin-Hwe Kweon, Jae-Woo Jung, Tae-Hwan Kim, Jin-Ho Choi, Dong-Hyun Kim, "Failure of carbon composite-to-aluminum joints with combined mechanical fastening and adhesive bonding," Composite Structures 75 (2006) 192–198.
7. M. Lucić, A. Stoić, J. Kopač, "Investigation of aluminum single lap adhesively bonded joints," Journal of Achievements in Materials and Manufacturing Engineering, VOLUME 15, ISSUE 1-2, March-April 2006.
8. Patel Vijaykumar V, Prof. R. I. Patel, "Structural Analysis of Automotive Chassis Frame and Design Modification for Weight Reduction," (IJERT) Vol. 1 Issue 3, May - 2012 ISSN: 2278-0181.
9. A.C. Manalo, H. Mutsuyoshi, S. Asamoto, "Mechanical behavior of hybrid FRP composites with bolted joints," Japan.
10. A. Barut, E. Madenci, "Analysis of bolted–bonded composite single-lap joints under combined in-plane and transverse loading," Composite Structures 88 (2009) 579-594.
11. Thomas Bus SAE Article, automotive Engineering 2005.
12. Machinery's Handbook, 2008, 28th Edition, Industrial Press, New York

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Mahesh J. Patil Has a teaching experience of 18 years. He has completed his graduation in Production Engineering from Shivaji University and did his post-graduation in Mechanical Engineering with specialization in CAD/CAM from Bharati Vidyapeeth (Deemed to be University) College of Engineering, Pune. He is pursuing his Ph.D. from the same university. He stared his carrier as a Trainee engineer in Maharashtra scooters Satara. Than he joined as a design Engineer in Ashiyana Auto bodies Private Limited, Satara as a design engineer. After working there for one year he joined Jawaharlal Nehru Institute of Technology and worked there for two and half years. Than he joined Bharati Vidyapeeth (deemed to be University) College of Engineering, Pune.

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