International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 7, Issue 8, August 2017)

# Design and Analysis of Bonded, Riveted and Hybrid Joints for Composite Laminates

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***Abstract*— Now a days it is common trend to replace conventional metals with the advanced composite materials. Many parts in automobiles are also being replaced with the composite materials such as Glass Fiber Reinforced Polymer. It is necessary to define the best suited joining method for the new replacement of the conventional materials with maximum possible strength given to the joint. For finding the best joining process 3 D models of different joints using standard specimens of GFRP are created in Catia V5 R15. Finite Element Analysis is performed on the joints in ANSYS 16.2 with standard loading. Best alternative is known from the FEA and validated through manufacturing and testing. The testing of the specimen is performed on the Universal Testing machine. From the testing, it is observed that the hybrid joint made from epoxy and bolt is the best among bonded, riveted, bolted and hybrid joint.**

***Keywords:* - Finite Element Analysis, GFRP, Universal Testing Machine.**

## I. Introduction

Nowadays the composite materials like plastics reinforced with carbon fibers (CFRP), glass fibers (GFRP), and aramid fibers (AFRP) are widely used in various industries such as automotive, chemical, electrical industry, aircraft and even in cryogenics. Due to its superior properties, composites have been one of the materials used for repairing the existing structures in various applications and also for joining composite parts together, using adhesives or mechanical fasteners nowadays, a new method called hybrid joint is also being employed where a combination of both mechanical fasteners and adhesive are used. In the present project, an attempt is made to analyze the stress distribution in 3D models of three configurations of double riveted Single lap joint namely bonded, riveted, hybrid. A major advantage of adhesive joint with fastener may be designed and made in such a way that they can be stronger than the ultimate strength of many metals and it is broadly used in the fuselage panels in aircrafts structures etc. [6]

A composite is a structural material which consists of two or more constituents combined at a macroscopic level. The constituents of composite materials are a continuous phase called matrix and a discontinuous phase called reinforcement. Matrix gives shape and protects the reinforcement from the environment. It also makes the individual fibers of the reinforcement act together and provides transverse shear strength and stiffness to the laminated composites. The matrix factors which contribute to the mechanical properties of composites are transverse modulus and strength, shear modulus and strength, compressive strength, inter-laminar shear strength, thermal expansion co-efficient, thermal resistance and fatigue strength. Reinforcement provides strength and stiffness and controls thermal expansion co-efficient. It also helps to achieve directional properties. Reinforcements may be in the form of fibers, particles or flakes. The fiber factors which contribute to the mechanical performance of a composite are length, orientation, shape and material. The factor which influences the mechanical performance of composites other than the fiber and the matrix is the fiber matrix interface. It predicts how well the matrix transfers load to the fibers. [3].

Type of Joining Methods [11]

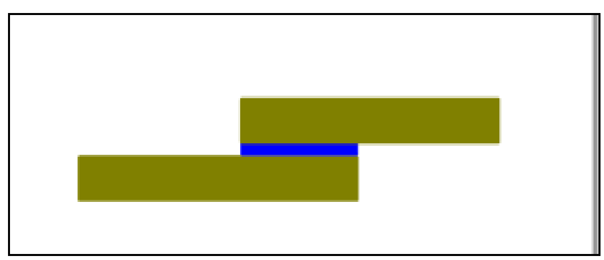

**Fig 1.Adhesive joint (Permanent Joint) [11]**

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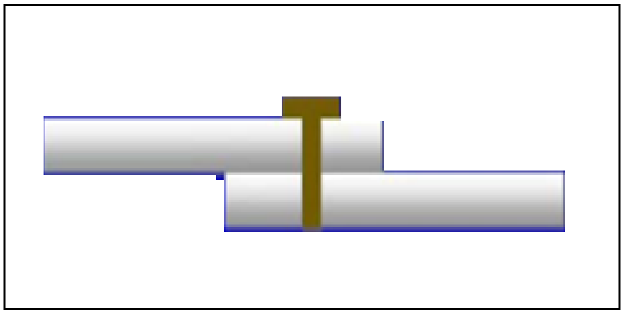

Fig.2 Mechanical Joint (Temporary Joint) [11]

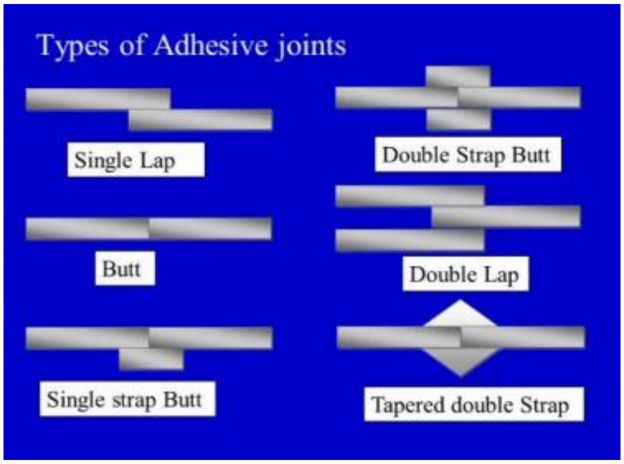


Fig.3 Type of adhesive joints [11]

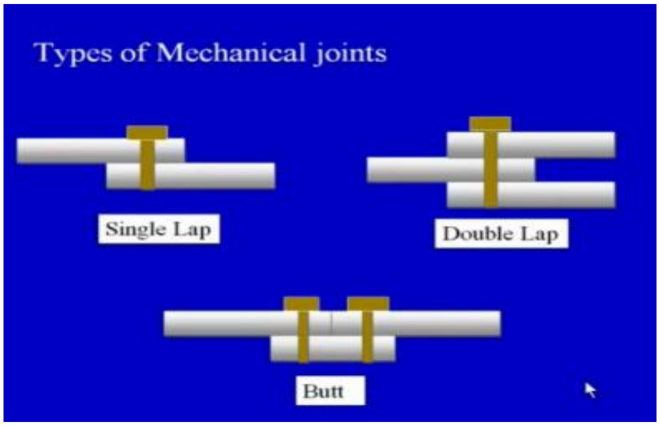


Fig.4 Type of Mechanical joints[11]

Raviraja S., L. and Nafeez Ahmed,[3], Analysed the static analysis of 3D models and Manufacturing of the composite joints like bonded, riveted and hybrid were carried out using FEA software.

The results were interpreted in terms of Von Misses stress. To utilize the full potential of composite materials like Glass Fiber epoxy as structural elements, the strength and stress distribution of these joints namely, bonded, riveted and hybrid joints must be understood while conducting experimental works. Various joint like bonded, riveted and hybrid joint were prepared by glass fiber epoxy composite laminates. And then undergo for tensile test by universal testing machine with data acquisition system. T. Subramani, and A. Arul,[5], the prediction of stress distribute on in bonded, riveted and hybrid joints have been carried out 3D models were created by using PROE and analysed using ANSYS workbench FEA software . Shear stress was used to compare the results with three joining methods. The shear stress with hybrid joint has less value of stress and also the carbon fiber reinforced plastic is more strength than any other composite material. The stress induced by using ANSYS is lower than the material ultimate stress and ultimate limit. The total deformation for both the materials in hybrid joint is low. It was found that a well-designed hybrid joint is very efficient when compared to bonded, riveted joints in case of repair situation in aircraft fuselage panels, structures increasing the strength of composite single-shear lap joints using bonded inserts. CFRP with aluminum alloy plates tested in experimental. CFRP with aluminum alloy plates tested in experimental and can find the strength and stress distribution with different composite materials. The joint design made and optimization of riveted joint can be performed. Stress and Failure Analysis of Laminated Composite Pinned Joints performed. S. Venkateswarlu, and K. Rajasekhar, [7], Analyzed prediction of stress distribution in bonded, riveted and hybrid joints have been carried out; 3-D models were created by using pro-E and analyzed using ANSYS workbench FEA software. The results were found in terms of von-misses stress, shear stress, and normal stress for stress distribution. ANSYS FEA tool has been used for stress distribution characteristics of various configurations of double riveted single lap joint with three joining methods namely bonded, riveted and hybrid the present work deals with the analysis of single lap joint subjected to the given tensile load and the stress distribution in the members under various design conditions are found. In this analysis, Shear stress was used to compare the results with three joining methods. The shear stress with hybrid joint has low value of stress and also the glass Fiber reinforced plastic material theCost is less than other composite material.

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The stress induced by using ANSYS is less than the material allowable stress. It was found that a well-designed hybrid joint is very effective when compared to bonded, riveted joints in case of repair situation in aircraft structures. The GFRP strength is less than that of the CFRP strength. K. Mohamed Bak, et.al, [8], presented on parametric study of bonded, riveted, hybrid composite joints using FEA". In the present study, FEA for the prediction of stress distribution in bonded, riveted and hybrid joints has carried out. Von misses stress was used to compare the results. It was found that a well-designed hybrid joint is very efficient when compared to bonded or riveted joint. Kale Suresh, et.al, [9], describe the analysis of adhesively bonded single lap riveted joints. This work involves the appropriate configuration and characterization of these joints for maximum utilization. This study includes the effectiveness of bond line thickness, the bonded layer configuration. This is also applicable to dissimilar thickness joints, but in this study they have placed the adhesives at different places for riveted joints. The finite element technique was used throughout the analysis of present work. The present work showed that riveted bonded joints are superior in strengthening to the riveted joints. The riveted bonded joint seems to strengthen and balance the stress and distributed uniformly. This improves the efficiency and life time of the riveted joints; this is also applicable to dissimilar thickness and dissimilar metals joints for balancing, uniform distribution of stress and without any effect of corrosion on dissimilar metals.

## II. PROBLEM SPECIFICATION

Conventionally automobile industry uses steel as a material for the manufacturing of the body and connecting parts which are attached to body. Different joining processes are used while making joints riveting is the most preferred method for joining duralumin. It is common trend to replace conventional metals with the advanced composite materials now a day.

Research is being done and many parts in the automobiles are being replaced with the Glass Fiber Reinforced Polymer. We need to define the best suited joining method for the new replacement of the steel joints with maximum possible strength given to the joint.

## III. FINITE ELEMENT ANALYSIS

The Finite Element method is a numerical method, which can be used for accurate solution of complex engineering problems. The method was first developed in 1956 for the analysis of aircraft structural problems. Thereafter, within a decade, the potentialities of the method for the solution of different types of applied science and engineering problems were recognized. Over the years, the finite element technique has been so well established that today it is considered to be one of the best methods for solving a wide variety of practical problems efficiently.

The basic idea in finite element method is to find the solution of a complicated problem by replacing it with a simpler one. Since, in finding the solution, the actual problem is replaced by a simpler one; I will be able to find only an approximate solution rather than the exact solution. The existing mathematical tools will not be sufficient to find the exact solution (and, sometimes, even an approximate solution) of most practical problems.

Thus in absence of any other convenient method to find even an approximate solution of a given problem, we have to prefer the finite element method. Moreover, in the finite element method, it will often be possible to improve or refine the approximate solution by spending more computational effort.

Static Analysis is performed on the each type of joint to find out maximum load taken by the joint before failure and results will be re simulated using UTM machine testing of the manufactured joints. Comparison will compare the FEA results.

### *A. Bonded Joint FEA*

Layered composite plates are created with 30 mm overlap to create the lap joint between the two. Bonded joint is simulated by using contact between two surfaces. Contact de-bonding method is used to studying the maximum force taken by the joint.

Boundary condition simulates the UTM testing in which one end is fixed and other end is provided with uni-directional axial displacements. Stresses at the peak and maximum load taken are observed. Results for the simulation are given below.

Force taken by the joint can be given by the graph below as

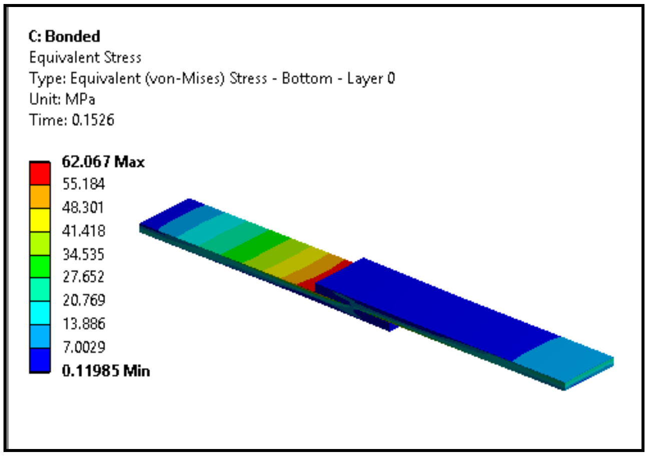


**Fig.5. Von Mises stress plot at peak load bonded joint**

Maximum stress observed in the analysis performed is 62.1 MPa for bonded joint specimen before separation.

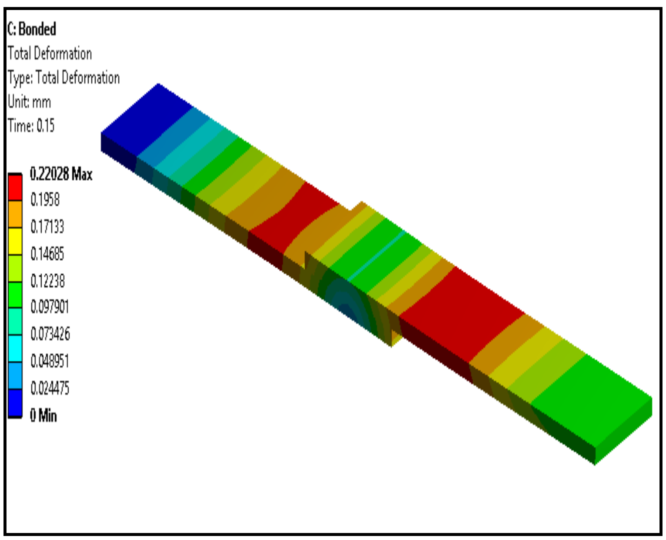


**Fig.6. Deformation at maximum load**

Deformation at the maximum load is observed to be 0.22 mm. which is shown in fig. 6.

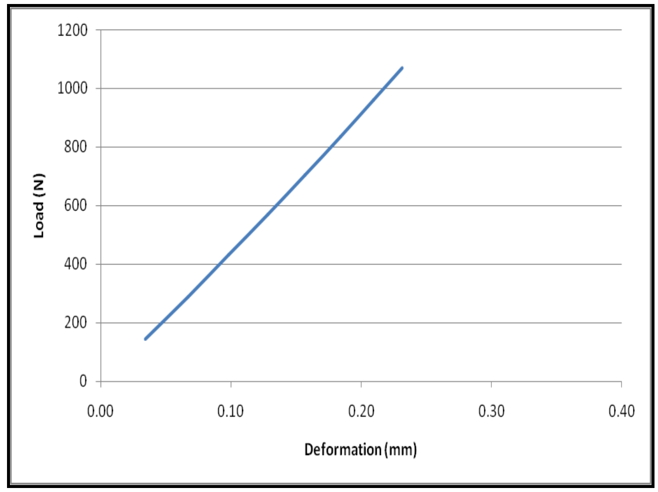


**Fig.7. FEA graph of bonded joint Load vs deflection**

Figure 7 shows graph of load vs deflection for the bonded joint and that shows the total load taken by the joint before separation is observed to be 1069.6 N in FEA.

*B. Riveted Joint*

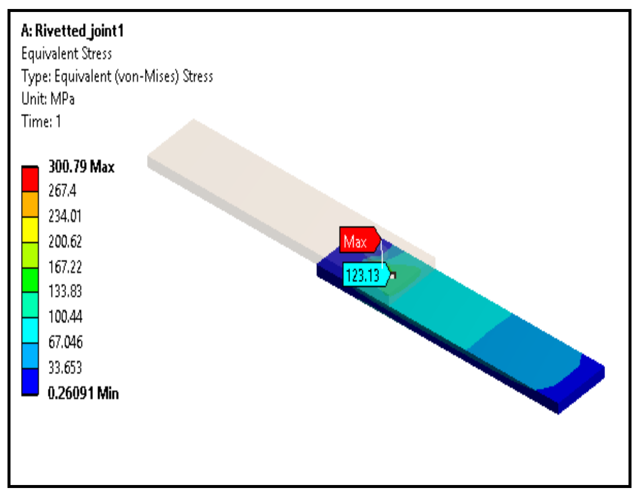


**Fig.8. Von Mises stress plot at specimen**

In fig.8 Specimen shows maximum stress near contact stress area as 123 MPa. This is below the acceptance criteria for the GFRP failure which is 150 MPa.

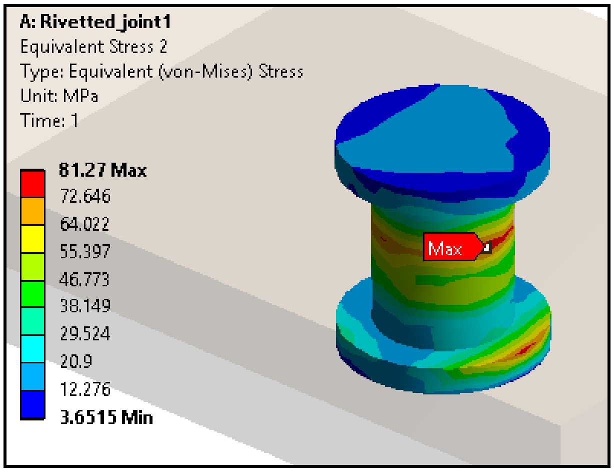


**Fig.9. Von Mises stress plot at Rivet**

Fig.9. shows Von Mises stress plot at rivet is shown as 81.27 MPa. Rivets material generally fail at 80 MPa.

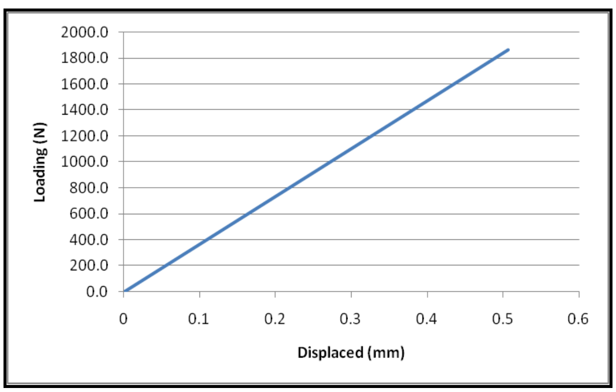


**Fig.10. FEA graph of Riveted joint Load vs deflection**

So from fig.10. it can be safely said that maximum load taken by the riveted GFRP joint by the failure of rivet is at 1864.4 N.

*C. Bolted Joint:-*

In Bolted joint creation model is created and steel material is applied to the bolted joint area and GFRP plates are modeled and analyzed.

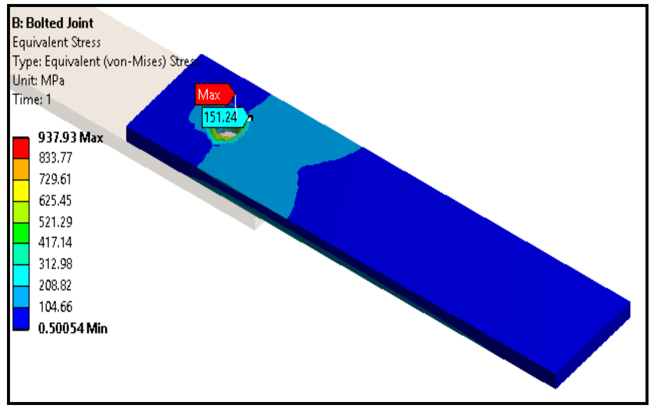


**Fig.11. Von Mises stress plot at maximum load**

From fig.11 maximum Von Mises stress just near the stress concentration area of the contact is observed to be 151 MPa which is crossing the tensile strength of the GFRP material. So GFRP will break in the testing. Von mises stress at the bolt is very high but it is not crossing the UTS of the steel away from the contact zone area.

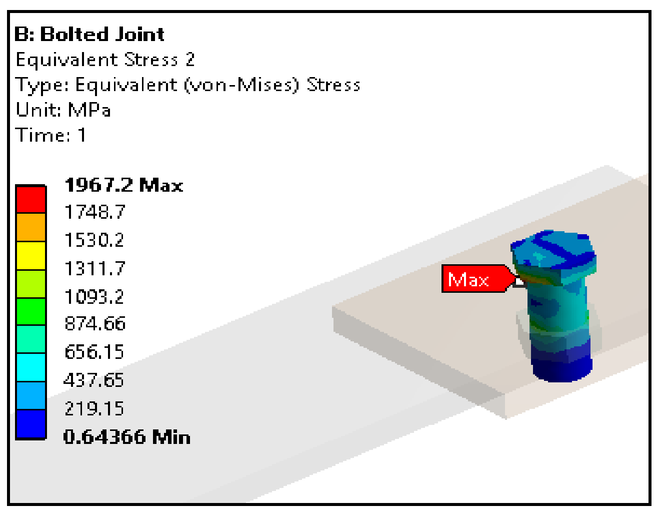


**Fig.12.Von mises stress plot at bolt**

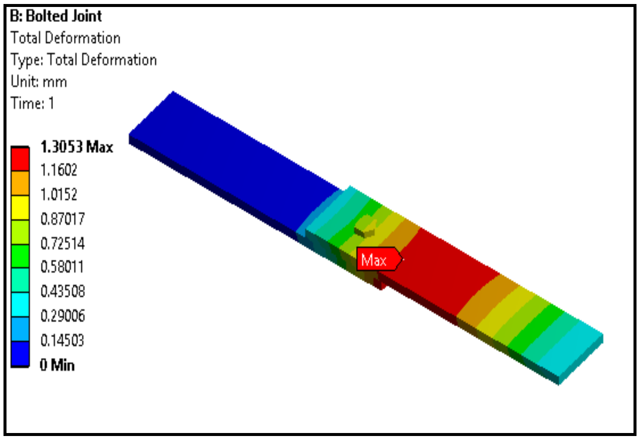


**Fig.13. Total deformation plot**

As shown in fig.13. and fig.14.Total deformation of 1.31 mm observed at the maximum loading which is 4530.5 N.

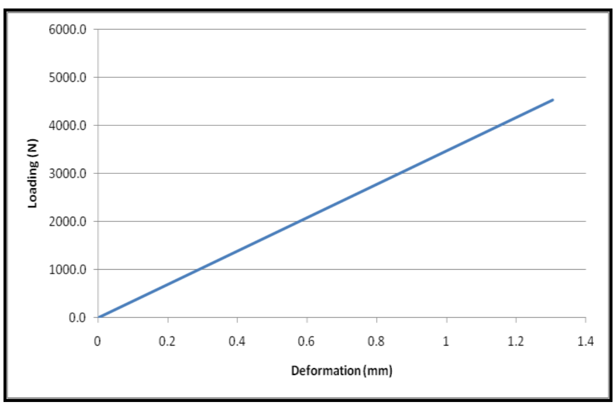


**Fig.14. FEA graph of Bolted joint Load vs deflection**

*Hybrid Joint:*

In hybrid joint combination of adhesive joint and bolted joint is created. Two plates are bolted together and before bolting adhesive is applied to the mating surfaces to create the test specimen. In addition to bolted joint model one more contact is to be created to simulate the bonded joint between the plates.

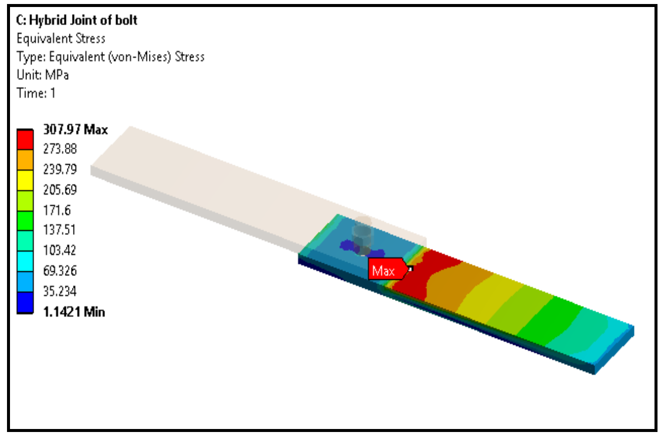


**Fig.15. Von mises stress plot at GFRP plate**

As shown in fig. 15 GFRP plate is highly stresses near the contact area. And maximum of 308 MPa stress on the surface of the model is observed. This will initial the perpendicular cut on the GFRP plate near bolted zone. Maximum stress plot of bolt shows non-contact zone on the bolt are not showing any high stress zones.

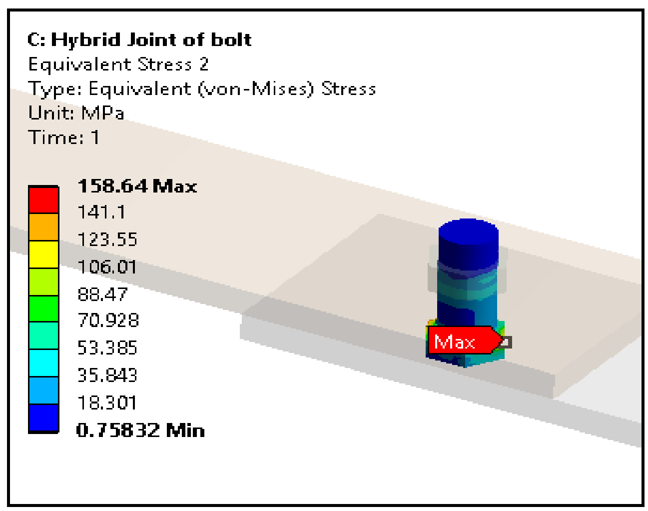


**Fig.16. Stress plot at the bolt**

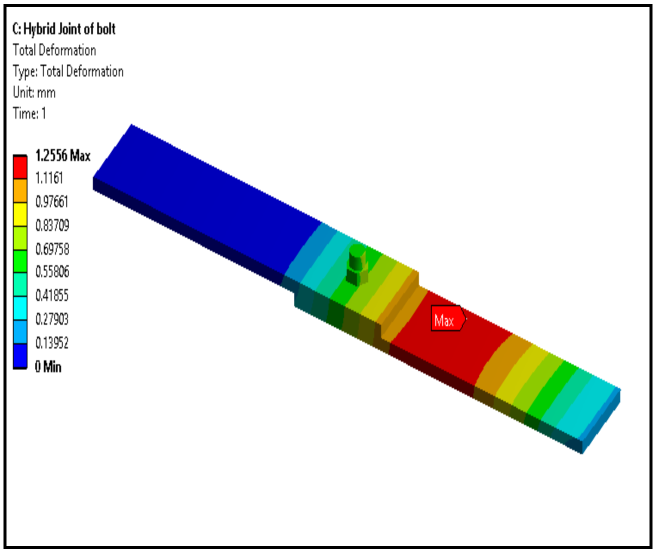


**Fig.17. Total deformation plot**

As shown in fig 17 Total deformation plot of the object shows us that maximum of 1.26 mm deformation is observed in the hybrid joint.

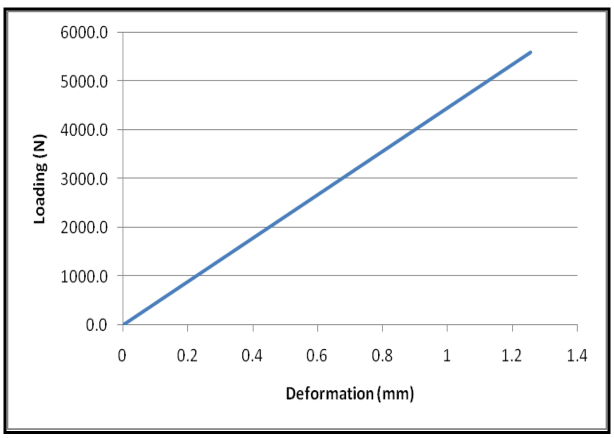


**Fig.18. FEA graph of Hybrid joint Load vs deflection.**

Fig.18 Shows maximum load taken by the hybrid joint is 5601 N. with displacement of 1.3 mm.

## IV. Experimental Validation With FEA

Manufacturing of the glass fiber is done using hand lay-up process. GFRP plate is created using GFRP layup method and specimen are cut using water jet machining for the specimen uses.

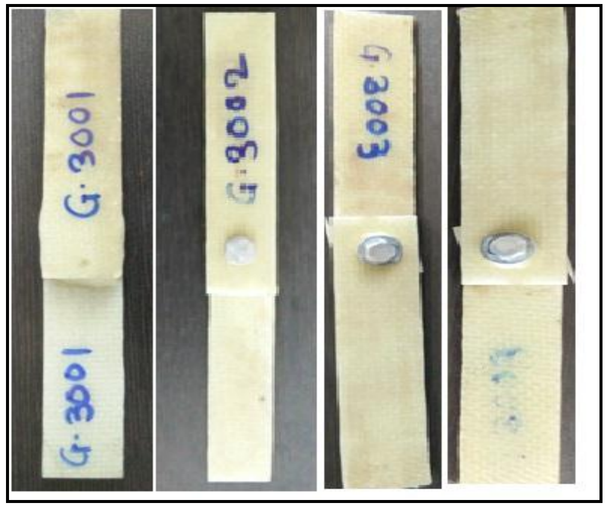

**Fig.19. Four Different Specimen Joints**

Fig.19 shows the four different specimen on which experimental work will be done.

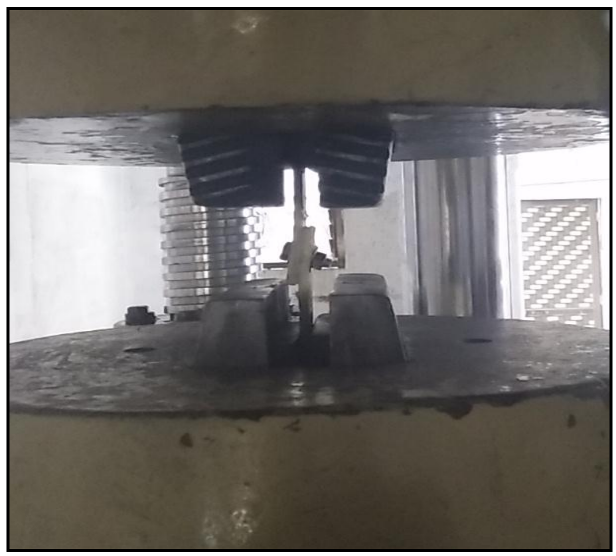

**Fig.20. UTM testing of Specimen 4**

Fig 20 shows Experimental testing is performed on the UTM machine with all 4 different types of joint manufactured. We will perform UTM load testing on the each of them and results are observed as follow.

*A. Bonded Joint*

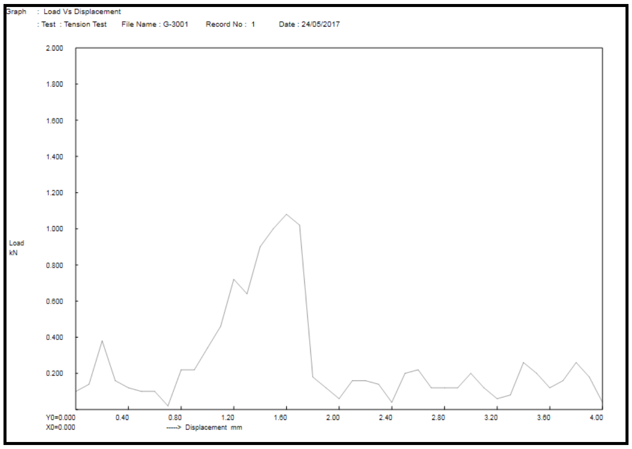


**Fig.21. Testing graph of bonded material test Load vs deflection**

As shown in fig.21 Maximum load taken by the bonded joint is around 1140 N.

*B. Testing for riveted specimen:-*

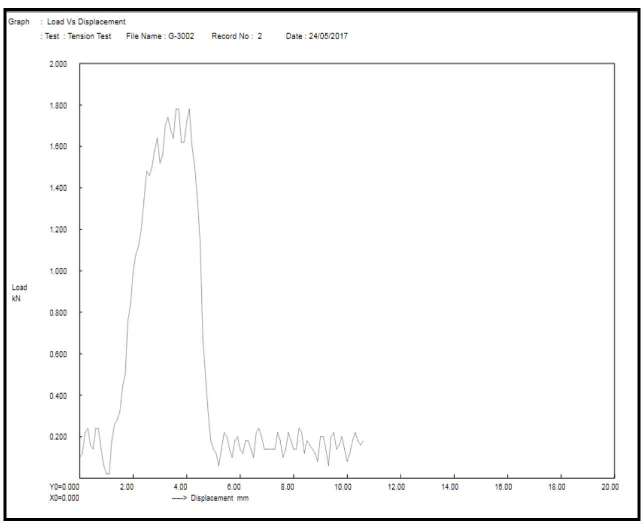


**Fig.22. UTM testing results for Riveted Joints**

As shown in fig 22 maximum load taken by the bonded joint is around 1800N

*C. UTM testing of GFRP bolted joints*

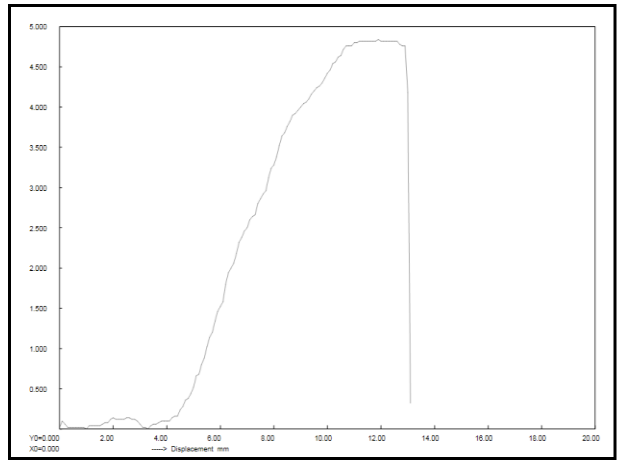


**Fig.23. Graph of load vs displacement at bolted joint**

As shown in fig.23 total of 4860 N load is taken by the girder according to actual measurements.

*D. UTM testing of GFRP Hybrid Joint*

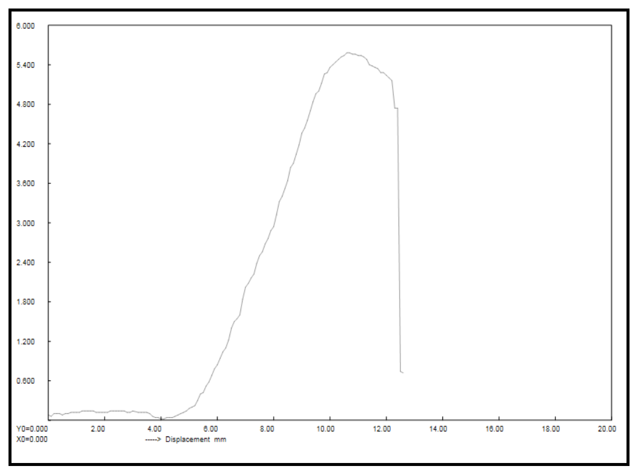


**Fig.24. Graph of load vs displacement for hybrid joint**

From fig.24 it will see that in hybrid joint material takes up to 5250 N load.

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## V. RESULTS AND DISCUSSION

**Table.1**
**FEA Load vs Actual Load**

| Joint Type | FEA Load | Actual Load | Error % |
|---|---|---|---|
| Bonded | 1069.6 | 1140 | 7% |
| Riveted | 1864.4 | 1800 | 3% |
| Bolted | 4530.5 | 4860 | 7% |
| Hybrid Joint | 5601.0 | 5250 | 6% |

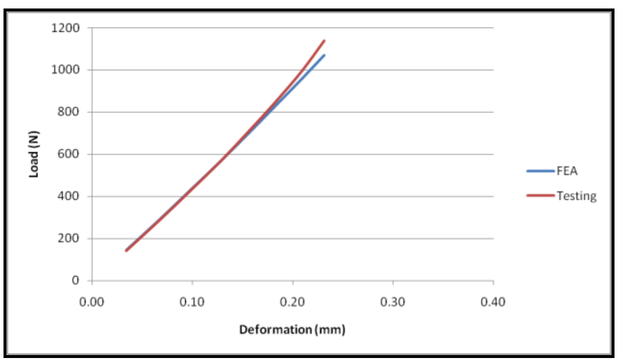


**Fig.25. Comparative Graph of Load vs deflection for bonded joint**

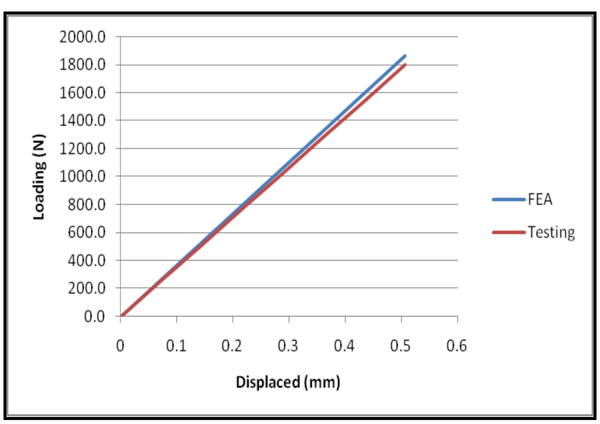


**Fig.26. Comparative Graph of Load vs deflection for Riveted Joints**

*C. UTM testing of GFRP bolted joins*

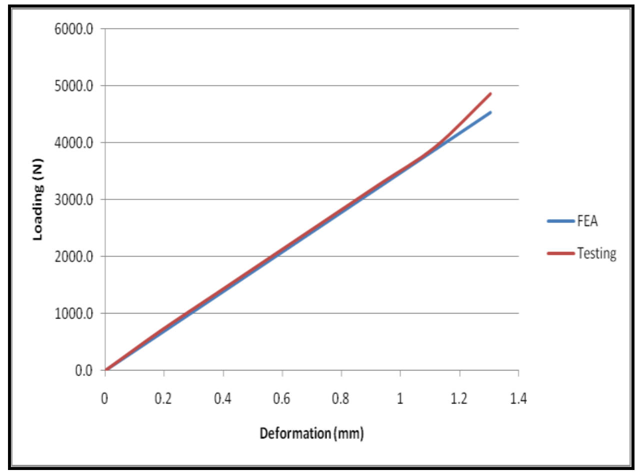


**Fig.27. Comparative Graph of Load vs deflection for bolted joint**

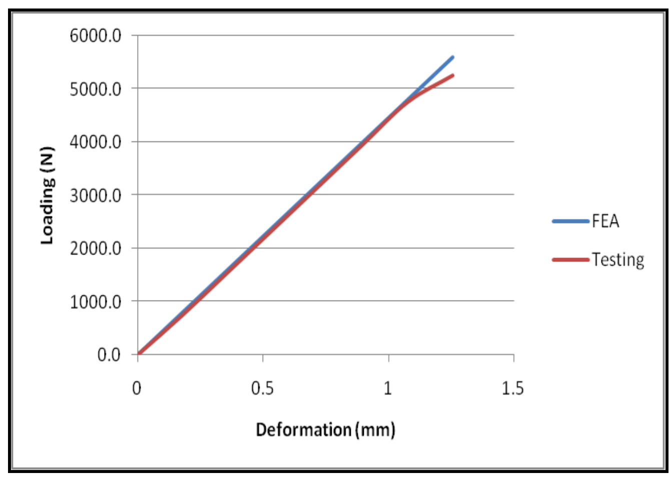


**Fig.28. Comparative Graph of Load vs deflection for hybrid joint**

Fig.25 to Fig. 28 shows the comparison graphs for FEA vs Experimental analysis.

## VI. CONCLUSION

Result summary shows the relation between the actual load and FEA load. There is very little to choose between the two results. Practical results are agreeing with the FEA results and maximum of 7 % error is found between actual and FEA results.

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Before breaking bonded joint takes up to 1140 N . According to UTM testing riveted joint takes up to 1800N in UTM machine. Also bolted joint shows the highest of the lot till now as 4860 N load taking capacity. Bolted joint with epoxy hybrid joint type has hybrid joint shows the highest load taking capacity which is 5250N.

*Future Scope*

Tests can be performed on the different plates with varying layup angles of GFRP. This can be helpful in finding the best layup angle for best bonded joint in GFRP plates.

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