Evaluation of tensile strength in riveted, adhesive and hybrid joints

K V P Chakradhar¹, A BalaRaju² and Anil Kumar Veerapaneni³

¹Professor, Mechanical Engineering Department, Vardhaman College of Engineering, Hyderabad, India.
²Associate Professor, Mechanical Engineering Department, Sreenidhi Institute of Science & Technology, Hyderabad, India.
³Managing Director, Aarshanano Composite Technologies Pvt. Ltd., Medikonduru, Guntur, India.
E-mail: chakradharkvp@vardhaman.org, info@aarshanano.com.

Abstract. Many automobile industries prefer hybrid joining practices in the part-assembly of advanced lightweight automobile and commercial vehicles. The main cause for this is the greater need for mixed material design. One of the combinations is composite with aluminium, like a combination of Titanium-Aluminium, CFRPs with aluminium etc. This paper deals with comparative study of mechanical strength evaluation in riveted joints, adhesive joints and hybrid single-lap joints. Hybrid joints are a combination of riveted and adhesive joints. The riveted joint produces enormous stress around the holes of the fasteners, which is detrimental to its performance. The adhesive joint allows good load distribution; however, it leads to plastic deformation that is detrimental in the long run. The hybrid joint has better load bearing capacity when compared to the riveted or adhesive joints. Thus, the study indicates that a hybrid joint has better properties suitable for structural, automobile and aerospace applications.

Keywords: Hybrid joints, Riveted joints, Adhesive joints, Single-lap joint, Carbon composite.

1. Introduction

The process of combining different joining techniques and materials is called hybrid joining. Two or more joining operations are carried out consequent ly, leading to enhanced properties of the joint due to synergic load bearing interface. Hybrid joining can provide merits in terms of processability and load bearing capacity [1]. Irrespective of the merits related with hybrid materials, there is unwillingness to implement them for industrial usage. This unwillingness may be due to the hampered knowledge of joining techniques with hybrid materials. In 1985, L.J.H. Smith [2] studied the performance of bonded-bolted composite joints. The study provides an insight on bonded-bolted joints and concludes that it does provide exceptional strength compared to a better designed adhesive joint. In 2005, Gordon Kelly [3] studied the load transmission effect in adhesive bonded and bolted hybrid composite joints using 3-D analysis. It gives an insight that the performance of hybrid joining technique is enhanced in comparison to adhesive bonding. In 2008, Ryosuke Matsuzaki, Motoko Shibata [4] experimentally investigated the joint strength of aluminium alloy, glass-epoxy hybrid composites fabricated using bolted/adhesive joining method. It gives an insight that the glass fibers in the hybrid joints contribute to much higher fatigue strength than that of bolted joints. In 2010, H Ngoc and Eric [5] simulated the life of adhesive bonded and bolted joints. They suggested that the mechanical fasteners reinforced the hybrid structure in case the adhesive failed. In 1971, F. Erdogan and M. Ratwani [6] analyzed the distribution of stress in smoothly tapered and stepped joint plates. Here bonded plates with a smoothly tapered joint are compared with that of stepped joint. In 2015, S. Raviraja and L. Nafeez Ahmed [7] proposed a paper on the comparative study of bolted and hybrid joints, in epoxy/glass fiber composite laminates. Here modeling, analysis of 3D models and fabrication of the composite joints were carried out. In 2006, Kweon, Jung and Kim et al. [11] analyzed the performance of aluminium and carbon composite joints. They concluded that the usage of fasteners leads to a significant increment in weight of the part. In massive parts like ship and aircraft, the cutback in the number of fasteners used, lead to weight reduction of parts.
2009, Banea M D, Da Silva L F [12] proposed a review paper on composite materials joined by using adhesives. They concluded that bonded joints are light in weight, less expensive and damage resistant. Machining operations are not required for adhesive joints. Adhesive joints inhibit propagation of crack, leading to better performance and life of parts.

Holes drilled for mechanical fastening cause concentration of stresses which affects the strength and performance of the joint. However, for assembling parts, bolted joints are found to be more reliable and are used extensively for many engineering applications. Since the mode of failure is progressive, strength predictions in the bolted joints are easy and accurate. Mechanical fasteners have better shelf life in comparison to many adhesives.

Conventional bolted, riveted and welded joints are used for connecting various industrial parts. The reinforcement of adhesives to conventional joints enhances the strength of the joints without changing the existing design. The objective of the work is to evaluate the tensile strength of conventional and hybrid joints and decide on their suitability for making components for structural, aerospace, automobile and underwater applications.

2. Material and Methods

The materials used for the plates used for preparation of riveted, adhesive and hybrid (composite/metal) joints are Towpreg (T-700) (a composite with combination of carbon, basalt or fiberglass filament and a thermosetting resin as binder material) and Aluminum alloy. The properties of aluminium alloy and towpreg are given in Table 1 and Table 2. The adhesive used for preparing the joint is Araldite AW 106 / Hardener HV 953 U. Dimensions used for modeling the plate for analysis are given in Table 3.

| Material | Property | Value |
|----------|----------|-------|
| Al alloy (HE-15) (Al-90%; Cu-5.00%; Si-0.9%; Mn-1.00%; Mg-0.80%; Fe-0.50%; Zn-0.25%; Ti-0.15%; others-1.4%) | E (MPa) | 70,000 |
| | υ | 0.33 |
| | UTS (MPa) | 470 |
| | ρ (kg/m³) | 2,700 |

Note: E-Young’s modulus; υ-Poisson ratio; UTS-Ultimate tensile strength; ρ-Density.

| Stiffness Property | Value |
|--------------------|-------|
| E₁ (Along fiber) | 1,32,000 MPa |
| E₂ (Across fiber) | 10300 MPa |
| G (Shear modulus) | 3000 MPa |
| υ | 0.3 |
| ρ | 1570 Kg/m³ |
| σ (Tensile) | 2100 MPa |
| σ (Compressive) | 1050 MPa |
| τ (Shear stress) | 90 MPa |
Table 3. Dimensions of the plate

| S.No. | Parameter            | Dimension (mm) |
|-------|----------------------|----------------|
| 1     | Length of plate      | 100            |
| 2     | Width of plate       | 25             |
| 3     | Thickness of plate   | 10             |
| 4     | Overlapping length   | 40             |
| 5     | Adhesive Thickness   | 0.1            |

2.1. Preparation and testing of Adhesive Joint
The carbon fiber composite and the Aluminium plates prepared and tested as per ASTM D638-02a standard. They are bonded together using adhesive as shown in Figure 1. A layer of 0.1 mm thick adhesive applied in between the plates.

![Carbon composite and Aluminium plates joined using adhesive](image1)

Figure 1. Carbon composite and Aluminium plates joined using adhesive

2.2. Preparation of Riveted Joint
The composite and the aluminium plates prepared as per ASTM D638-02a standard. Holes of 4.5 mm drilled on the composite and aluminium plates as per requirement. Both the plates are fastened together using a suitable fastener as shown in Figures 2a and 2b.

![Carbon composite and Aluminium plates joined using rivet](image2)

Figures 2a and 2b. Carbon composite and Aluminium plates joined using fastener.
2.3. Preparation of Hybrid Joint
The composite and aluminium plates prepared as per ASTM D638-02a standard. Holes drilled on the composite and aluminium plates as per requirement. Then the adhesive applied on the plates. Both the plates after bonded together by adhesive are fastened together using a rivet to form hybrid joint as shown in Figure 3.

![Figure 3. Carbon composite and Aluminium plates joined using adhesive and rivet](image)

2.4. Experimental testing of Joints
A standard UTM used for performing tensile test on the specimens (plates). A load of 1000N is applied on one end of the specimen and on other end it is fixed. INSTRON 4505 machine of 10 T capacities was used for tensile testing. The test was conducted three times for each case and the mean of the three test results taken as the final value. A sample experimental setup for the test is shown in Figure 4. A failed riveted joint after testing is shown in Figure 5.

![Figure 4. Experimental setup for tensile testing](image)  ![Figure 5. Riveted joint plates after testing](image)

3. Results and Discussion
The function of any joint is to produce an effective and defectless bond between the plates and transmit loads efficiently and uniformly. In the adhesive bonded joints, joint failures are generally nonexistent as they possess exceptional dissemination of loads over a broader area when compared to mechanical joints. The combination of adhesive and riveted joints as hybrid joint provides excellent load distribution and required mechanical strength to the joint [10, 13].

The tensile test conducted on the adhesive, riveted and hybrid single-lap joints gave the results as shown by the Force-Displacement curves as plotted in Figures 6-8. The Force-Displacement curves are plotted considering eight displacement values (0-0.8 mm) for different load conditions and the
maximum load before failure evaluated. At 0.7 mm displacement, the plates bonded by adhesive and hybrid combination indicated that the joints could withstand maximum loads of 6.28 KN, and 9.48 KN respectively. While, the riveted joint could withstand a maximum load of 8.40 KN at 0.6 mm displacement and it failed well before it reached 0.7 mm. The study reveals that the hybrid joint (rivet and adhesive) has better load bearing capability when compared to the other two joints. The summary of ultimate tensile loads and tensile stresses taken by the joints before failure is shown in Table 4. The failure of the carbon composite plate due to tearing of the plate at the edge is shown in Figure 5. This is due to tension stress failure in the plate, with slight deformation of the rivet.

![Figure 6. Force-displacement curve (adhesive joint)](image1)

![Figure 7. Force-displacement curve (rivet joint)](image2)

![Figure 8. Force-displacement curve (hybrid joint)](image3)

| Type of joint | Displacement (mm) | Ultimate tensile load (KN) | Tensile stress (N/mm²) |
|---------------|-------------------|---------------------------|------------------------|
| Adhesive joint | 0.7               | 6.28                      | 25.12                  |
| Rivet joint   | 0.6               | 8.40                      | 33.60                  |
| Hybrid joint  | 0.7               | 9.48                      | 37.92                  |
4. Conclusions
The tensile strength evaluation and comparison of adhesive joint, riveted joint and hybrid joint test results revealed the ensuing evidence.

1. Tensile test on aluminium and towpreg carbon composite joined plates bonded with adhesive indicated that it can withstand an ultimate tensile load of 6.28 KN and tensile stress of 25.12 N/mm² at 0.7 mm displacement. It failed due to interfacial bond failure.
2. Tensile test on aluminium and towpreg carbon composite joined plates bonded with single rivet indicated that it can withstand an ultimate tensile load of 8.40 KN and tensile stress of 33.60 N/mm² at 0.6 mm displacement and it had failed before 0.7 mm. It failed due to tearing of composite plate near the hole.
3. Tensile test on aluminium and towpreg carbon composite joined plates bonded with single rivet and adhesive (hybrid combination) indicated that it can withstand an ultimate tensile load of 9.48 KN and tensile stress of 37.92 N/mm² at 0.7 mm displacement. It also failed due to interfacial bond failure.
4. In comparison to adhesive joint, the hybrid joint indicated that it has 50.95% higher load bearing capacity.
5. In comparison to the riveted joint, the hybrid joint indicated that it has 12.85% higher load bearing capacity.
6. Experimental study revealed that the tensile strength of a hybrid joint is considerably superior to that of adhesive and riveted joints.
7. Experimental study also revealed that the better load transmission in hybrid joints can give improved structural performance in comparison to other joints as is also supported in literature [10].
8. Reinforcement of the adhesive joints with rivets gives the joint enhanced strength as is also supported in literature [13].

The study may pave the way for the development of light-weight materials suitable for making components for structural, aerospace, automobile and underwater applications.

Acknowledgements
The authors thank Aarshananano Composite Technologies Pvt. Ltd., Medikonduru, Guntur for providing technical assistance required for the work.

References
[1] Yadav P D and Patil M J 2014. Journal of Engineering Research and Technology 3 957
[2] Hart Smith L J 1985. Journal of Aircraft 22 993
[3] Gordon Kelly 2005. Composite Structures 69 35
[4] Ryosuke Matsuzaaki, Motoko Shibata and Akira Todoroki 2008. Composites Part A: Applied Science and Manufacturing 39 154
[5] Cat-Tan Hoang-Ngoc and Eric Parroissien 2010. International Journal of Adhesion and Adhesives 30 117
[6] F. Erdogan and M. Ratwani 1971. Journal of Composite Materials 5 378
[7] Raviraja S and Nafeez Ahmed L 2015. International Journal of Innovative Research in Science, Engineering and Technology 4 214
[8] Parthiban T, Subramanian G and Muthuraman K. 2017. Journal of Marine Science and Application 16 237
[9] Shukur A Hasan, Carlo Santulli, Mohd. Yazid B Yahya, Chong L Gang and Mohd. NFB Abu Bakar. 2018. FME Transactions 46 108
[10] Jeevi G, Sanjay Kumar Nayak and Abdul Kader M 2019. Journal of Adhesion Science and Technology 33 1497
[11] Kweon JH, Jung JW, Kim TH, et al. 2006. Composite Structures 75 192
[12] Banea MD and Da Silva LF. 2009. Proc IMECE 223 1
[13] Ezzine M C, Amiri A, Tarfaoui M and Madani K 2018. Advances in Aircraft and Spacecraft Science 5 595