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Strength analysis of single lap dissimilar materials bolted joint

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Abstract

Presently, lot of emphasis is given on joining of dissimilar materials. Around 60-70% of the structures are failing at the joints. Therefore, it is critical to investigate the failure load and failure mode of dissimilar materials joint. The present work investigates the failure of single lap single bolted joints mainly on shear and bending strength. Two material combination joints such as Mild Steel - Aluminum and Mild Steel - Glass fiber reinforced polyesters bolted joints are analyzed using experimental and finite element methods. Present investigation shows that the Mild Steel - Glass fiber reinforced polyesters has better shear strength and bending strength than the Mild Steel - Aluminum material joint.

1 Introduction

Mechanically fastened joints are often used to join composite materials in aircraft structures. It has an advantage over adhesive joints in regard to joining of thick structures which are difficult to bond. They can be detached without damaging the structural members, making repair possible. However, mechanical joints have disadvantages, the main one being that bolt holes cause stress concentrations which reduce the resistance of the joint construction to applied loads, and thus its efficiency[1]. Loading conditions, such as type of loading and load configuration, are one of the most important factors in designing a joint in a structure. Most published papers deal with the influence of geometry parameters, material system, and joint configuration on the strength and fatigue performance of composite joints [2]. Presently, in case of upper class vehicle doors, a large drawing depth is required for the inner panels. Using standard stamping procedures, the consistent realization of such high drawing depths presents some problems with the available standard car body aluminum alloys in mass production. The fabrication of aluminum inner door panels with larger drawing depths is possible, but asks for more complex and closely controlled stamping procedures, which increases the cost.

Ricardo de Medeiros et, al [2] has investigated on the mechanical behavior of single lap single bolted joints for titanium and composite structure using experimental and finite element method. They have concluded that the new experimental method can help the engineers to design similar metal-composite joints and also possible to study the different design parameters such as strength, limit stress and modulus of elasticity for metal-composite joints. Esmaeil Ghanbari et. al [3] have investigated strength of bolted joints for different tightening torque in tension load and four point bending load. They have



concluded that the both tensile and bending strength of joint increases with increase in E/D ratio and tightening torque value. Hilton Ahmad et.al [4] have investigated the effect of stress distribution around the hole for different materials and plate thickness, such as steel-CFRP and CFRP-CFRP materials joints. They have concluded that, due to secondary bending, the stress distribution through the CFRP woven fabric system single-lap joint changes significantly and the stress distribution increases with increase in thickness.

The present study aims to determine the shear and bending strength of the metal to metal and metal to composite bolted materials joint using experimental and finite element method. Finally, the results obtained from the two methods are compared.

2 Methodology

The present design and material data are obtained or collected from various journals. The specimens were manufactured as per the ASTM standards for experimental analysis. From the test ultimate load for different joints were obtained and same load was used to determine the shear and bending strength using empirical formulae. The same experimental data are used to generate a 3D model for finite element analysis using Cero3.0 and simulation is carried out using Ansys workbench17.0. The same ultimate load obtained from test has been used in simulation and strength was analyzed. Finally, the results are compared with each other.

The existing car door is made using Mild Steel with Aluminum bolted materials joints. On account of the ductility behavior aluminum is preferred as interior panel or bumper materials for the automobile vehicle. In the present competitive market, fuel efficiency and high strength to weight ratio place an important role. By considering these points existing materials fails to meet the requirement. Therefore, the other structural based material has been selected and comparative study of different materials joint is carried out. Here, a randomly oriented chopped glass fiber with polyester is selected in place of aluminum due to high strength to weight ratio and randomly oriented fibers exhibit isotropic property in planar condition.

3 Experimental analyses

3.1 Shear test: In most bolted connection, the bolts are subjected to shear and bolts can fail in shear or in tension. So it is necessary to know the strength of the joint under the shear conditions. As there are no such specific standard methods for determining the shear strength of the dissimilar materials single bolted joint, ASTM D5961 [5] provides a methodology to determine the shear strength of the composite-composite material joint. Figure 1 shows the image of test specimen used to determine the shear strength of the joint.



Figure 1. Image of MS-GFRP and MS-AL for shear test

The test was performed in the universal testing machine as per ASTM D5961 standard for both the Mild Steel-Aluminum and Mild Steel-GFRP joints for two samples each. The test has been performed till the samples break. The Figure 2 shows experimental load value at different cross head travel for MS-AL and MS-GFRP materials joint in shear test. The ultimate load of the MS-AL and MS-GFRP is 6950N and 7450N respectively.

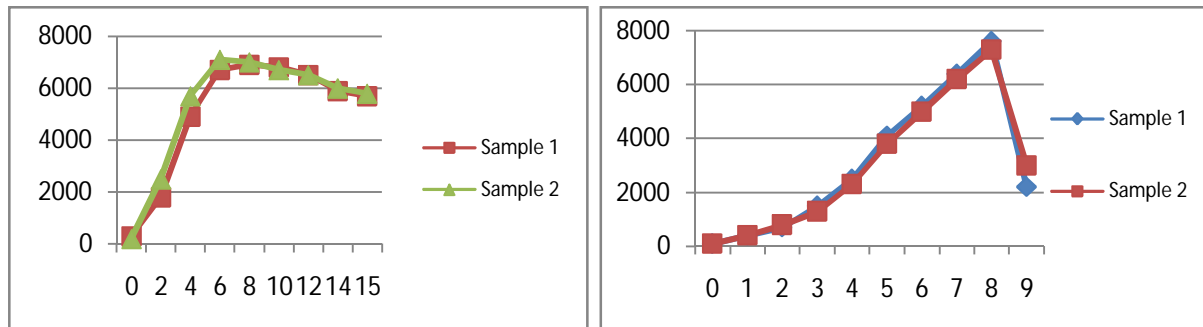


Figure 2. Loads (N) vs. cross head travel (mm) of MS-AL and MS-GFRP joint in shear

The Shear Strength of the joint is determined by using the formula, $S = F / A$ (MPa)

Where, F= Load (N),

$$A = \text{Area of hole (mm}^2\text{)} = (3.141/4) * d^2 = (3.141/4) * 6^2 = \mathbf{28.3 \text{ mm}^2}$$

Ultimate shear strength of MS-AL joint, $S_{ult} = (6950/28.3) = \mathbf{245.93 \text{ MPa}}$.

And, Ultimate shear strength of MS-GFRP joint, $S_{ult} = (7450/28.3) = \mathbf{263.6 \text{ MPa}}$.

From the analysis, it shows that the shear strength of the MS-GFRP joint is better than the MS-AL joint. The Figure 3 shows the image of the failed specimen. The failure mode of MS-AL is Shear out and of MS-GFRP is net tension failure.

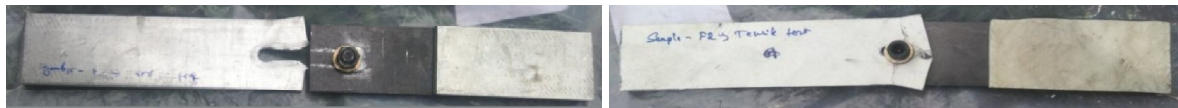


Figure 3. Failed Specimen of MS-AL and MS-GFRP in Shear test

3.2 Four-point bending test

The doors are subjected to bending load. Due to the closing of the doors, there will be generation of bending load on the door. So it is necessary to find the bending strength of the door. In this study, since we have concentrated at the joint, it is essential to find the bend strength of the joint. There is no standard procedure to find the bending strength of the dissimilar joint, ASTM E-855[6] standard is used to determine the bending strength of the joint. Figure 4 shows the image the bending test specimen.



Figure 4. Image of Bending test specimen for MS-GFRP and MS-AL

The test has been carried out on universal testing machine using four bending fixtures for both MS-AL and MS-GFRP joints and the test as been performed for two specimens of each combination. Figure 5 show experimental load value at different cross head travel for MS-AL and MS-GFRP joint in bending test. The ultimate bending load obtained from the test is 7669N and of MS-AL and MS-GFRP joints.

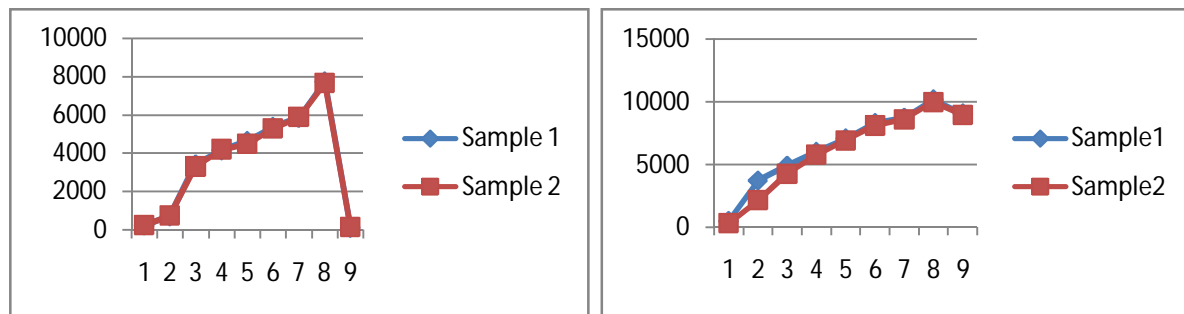


Figure 5. Loads (N) vs. cross head travel (mm) of MS-AL joint in bending

Bending Strength of the joint is determined by using the formula, $S_b = 3Wa / bh^2$ (MPa).

Where, W= Load (N), b= Width of the specimen (mm), h= Thickness of the specimen (mm), a= distance from the support to the load applicator (mm).

Ultimate Bending strength of MS-AL, $S_{bult} = [(3 \times 7669 \times 16) / (24 \times 6^2)] = 426.1$ MPa.

And, Ultimate Bending strength of MS-GFRP, $S_{ult} = [(3 \times 10083 \times 16) / (24 \times 6^2)] = 560.2$ MPa.

From this analysis, it shows that the bending strength of the MS-GFRP joint is better than the MS-AL joint. The Figure 6 shows the image of the specimens failed under bending.



Figure 6. MS-AL and MS-GFRP combination specimen failed in bending test

4 Finite element analyses

The finite element analysis is carried out using average load from the experimental data and the bolted joint specimen is designed as per standards used in experimental method for different analysis. The simulation is carried using the analysis software Ansys 17.0.

4.1 Shear strength analysis

In meshing, a quadrilateral type of mesh is used for both types of material joint. The number of elements and nodes obtained are 3121 and 12612 respectively. The boundary conditions are applied as per experimental condition. Here, the Mild Steel end of joint model is fixed in all the three direction and the tensile load is applied at the AL or GFRP end of the joint model, which has free displacement in x direction. The Figure 7 shows the boundary conditions for materials joints under shear.

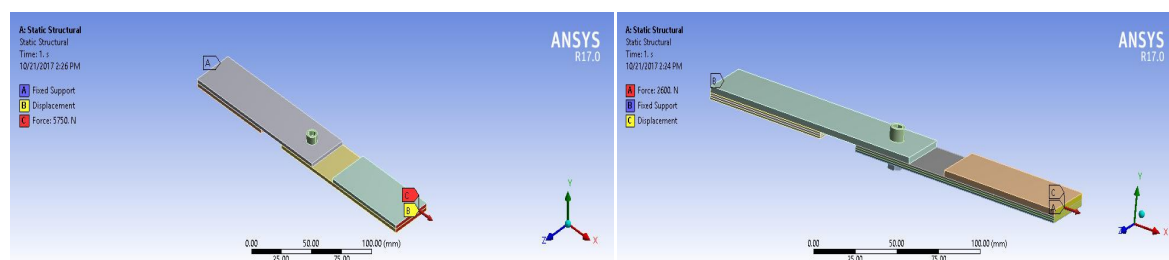


Figure 7. Boundary condition of MS-AL and MS-GFRP joint for shear

The finite element analysis has been carried out for ultimate load which is obtained from experimental verification for both types of joint. The Figure 8 shows the shear strength value for ultimate load of

6950N and 7450N for MS-AL and MS-GFRP materials joint respectively. The results obtained are 245.9 and 426.1Mpa for MS-AL and MS-GFRP materials joint respectively.

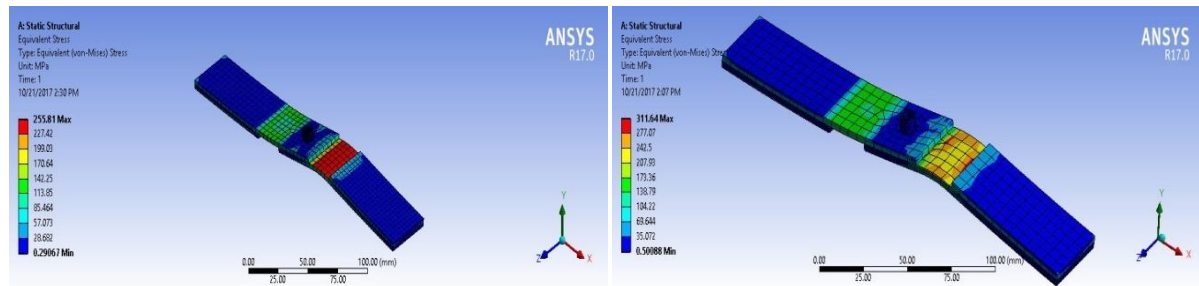


Figure 8. Shear stress of MS-AL and MS-GFRP materials joint for ultimate load

From this analysis, it shows that the Shear Strength of MS-AL joint as higher strength than the MS-GFRP joint.

4.2 FOUR POINT BEND ANALYSIS:

In meshing, a quadrilateral type of mesh is used for both the types material joint. The number of elements and nodes are 1690 and 7906 respectively. The Figure 9 shows the boundary condition for MS-AL and MS-GFRP materials joint. In this, the load is applied on Mild Steel upper face or on the loader, and support is fixed in all the direction. The specimen is fixed in x and z direction and free displacement in y direction. The boundary conditions are applied on the basis of experimental setup.

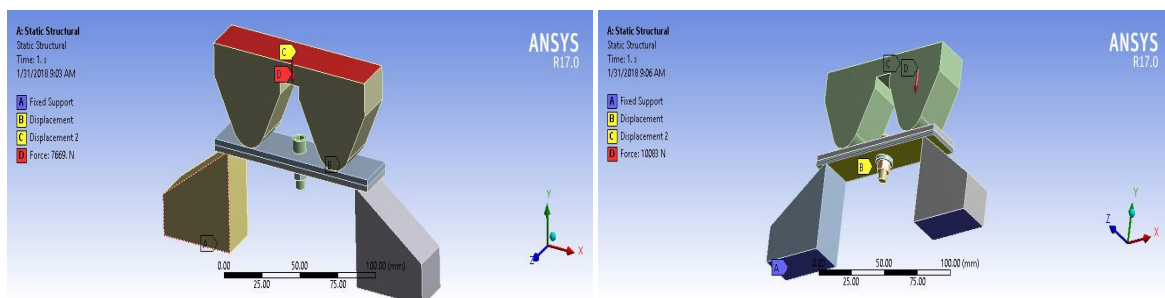


Figure 9. Boundary condition of MS – AL & MS-GFRP joints for Bending

The finite element analysis has been carried out for ultimate load which is obtained from experimental verification for both types of joint. The Figure shows the shear strength value for ultimate load of 7669N and 10083N for MS-AL and MS-GFRP materials joint respectively. The results obtained are 311.6 and 637 Mpa for MS-AL and MS-GFRP materials joint respectively

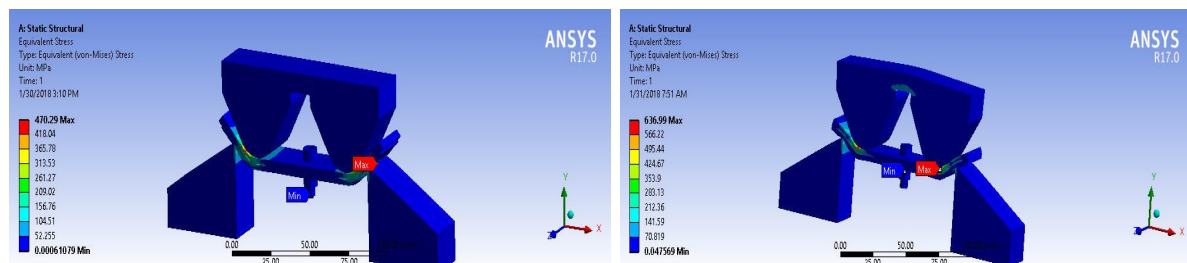


Figure 10. Equivalent stresses for MS – AL and MS-GFRP joints for ultimate load for Bending

From this analysis, it shows that the Bending strength of MS-AL joint as lower strength than the MS-GFRP joint.

The table 1 shows the comparative study between FEA and Experimental analysis for ultimate load under shear and bending test.

Table 1. Comparison between experimental and FE method

Types of materials joint	Ultimate shear Strength (Mpa)		Ultimate Bending Strength (Mpa)	
	Experimental	FEA	Experimental	FEA
MS-AL	245.9	255.8	426.1	470
MS-GFRP	263.9	311.6	560.2	637

5 Conclusion

In this present work, the MS-AL and MS-GFRP materials single bolted single lap joint has been analyzed. The shear and bending strength of both the joints have been analyzed using experimental and finite element method. In experimental analysis, a two set sample were prepared as per ASTM standards and carried out the shear and bending test were carried out. The average load obtained from the test has been used in empirical formulae to determine the shear and bending strength. In case of FE analysis, the models are generated as per ASTM standards which are used in experimental work using Creo3.0 and the simulation was carried out using Ansys package. In simulation, average load obtained from the experimental work has been applied on the model to verify the shear and bending strength. Finally the results of joints of dissimilar materials were compared and concluded as follows:

- MS-GFRP materials single bolted joint has better strength compared to MS-AL materials single bolted joint under Shear and Bending loading.
- Experimental analysis has good agreement with Finite Element analysis with minimal difference.
- Finally, MS-GFRP joint has better properties compare to MS-AL joint.

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