

The Effect of Dry and Wet Condition on the Mechanical Properties of Hybrid Single Lap

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Abstract. The aim of this study is to investigate the strength and mechanical behaviour of similar and dissimilar materials AA7075/E-glass single lap joint. The specimen radially in stack with Araldite epoxy adhesive and mechanical fasteners of Huck bolt with the bondline length of 64 mm for different joint configurations; bolted, bonded and hybrid. The investigation was conducted under two different conditions of dry and wet of 55°C for long water immersion of 120 days. The effect of moisture was defined in hybrid joints as combination of adherend and bonding materials. The tensile test with a speed rate of 1 mm/min was conducted for both condition using 100 kN load cell until total failure of specimen. The experimental results were plotted into load displacement and stress strain curve for each environment. In addition, failure mechanism of the specimens was detected in which occurred at adhesive and Huck bolt.

1. Introduction

The joint designs are key to exploit maximum capacity of composite materials, which are as a rule progressively utilized as a part of aircraft structures. The bolted joints were preferred for joining the structures which suffer from low joint efficiencies. Ordinarily, a composite joint accomplishes a joint productivity of 40–50% contrasted with 60% for metals [1]. The time and cost effective maintenance had been resolved by introduce mechanical fasteners of screw, rivet, and bolts which are regularly utilized on the grounds. This allow taking into an action for non-destructive and simply reassembly of structures. The hybrid technology is a combination of adhesive and fasteners as bonding and bolting parameters which prove the best properties and performance for individual stiffness in each load path [2]. Andure M W reported that the fuel consumption in transportation parts can be reduced by achieving the high strength in components by hybrid joint [3]. Fu and Hoang-Ngoc demonstrated the load sharing using low modulus of adhesive and found that the bolt does not participate initially in sharing the load until the adhesive has completely yielded [4, 5].

The utilization of plastic materials in engineering structures has increased due to their low weight, high specific strength, high specific modulus, design flexibility, reduced manufacturing cost, excellent corrosion, solvent and environmental resistance, thermal and electrical insulation and durability [6]. Rather than that, environmental effect of heat and humidity at long period can be avoid as corrosion preventative measures are taken into fasteners for being insensitivity. The water may diffuse into metal adherend in joints by: (a) diffusion through the adhesive, (b) transport along the interface, and (c) capillary action through cracks and crazes in the adhesive.

In the present study, the effect of dry and wet condition on mechanical properties of single lap joint were investigated. Three different joint configuration: bolted, bonded, and hybrid were used to evaluate the mechanical properties under dry condition. Meanwhile, only hybrid single lap joint was



exposed in wet condition with a long period of water immersion of 120 days. The hybrid joints purposely exposing the adhesive layer to moisture and drilling holes at the center to accelerate the temperature. Thus, the experiment continues by comparing the mechanical behaviour for dry and wet environment through tensile test.

2. Materials and specimen preparations

2.1. Materials Selection

Aluminium alloy AA7075 and [0/90°] laminates of E-glass were used in this experiment with the dimension of (160 x 40 x 3) mm as shown in figure 1. The composites were laminates with 17 plies and 1:3 ratios of hardener and epoxy. The composite was examined in preliminary tensile test of E-glass dog bone shape design shown in figure 2 accordance with standard ASTM D3039. The extensometer with gauge length of 50 mm was attached on the specimen. The composite properties were examined to calculate and define the bonding area. The function of joining or overlap or bondline length in bolted, bonded and hybrid were defined the length by which the adherends will attached one another. These design parameter was applied as one of the most important factors affecting the joint rotation, stress distribution and ultimate tensile strength of single lap joint. The attachment area was calculated using formula determined by in Eq. 1 as shown. The mechanical properties of aluminium and glass fiber are tabulated in table 1. The bonding area was set to 64 mm. In part, table 2 show adhesive properties of Araldite at elevated temperature, contribute to 55°C in this experiment with elastic modulus of 0.426 GPa.

$$L = \sigma_y t / \tau \quad (1)$$

Where,

σ_y = Yield strength of GFRP composites

t = Thickness of the adhesive

τ = 50 % of the shear strength of adhesive

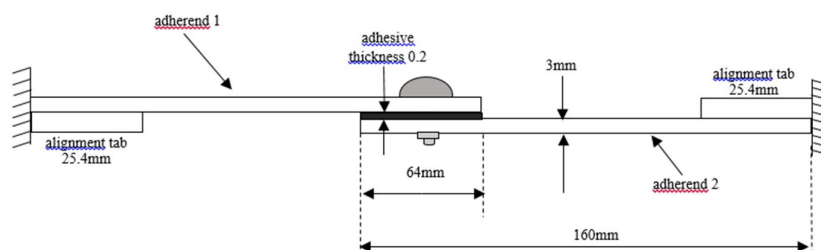


Figure 1. Hybrid single lap joint dimension.

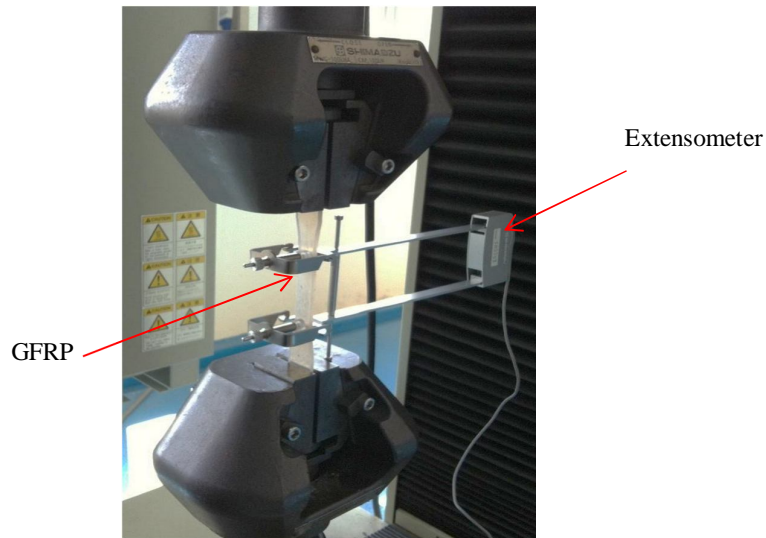


Figure 2. Dog bone shape preliminary tensile test.

Table 1. Mechanical properties of adherends.

Material	Tensile Strength, [MPa]	Poisson ratio, ν	Elongation, (%)
Aluminium alloy AA7075	228	0.33	1.7
E-glass	157.052	0.19	2.3

Table 2. Araldite epoxy adhesive properties.

Temperature, °C	Elastic Modulus, GPa	Poisson ratio, ν
Room Temperature	1.392	0.380
55	0.426	0.463

2.2. Specimen preparations

The similar and dissimilar adherends of metallic alloy and composite were combined into bolted, bonded, and hybrid single lap joint for dry condition. Thus, mechanical joint strength obtained was compared with the wet condition on dissimilar hybrid single lap joint. According to figure 3, the flow of both condition was illustrated. In joining manufacturing, the jig was prepared and aluminium alloy was placed on the top as the bottom plate for the joint in first step. The jig was manufactured using black thermos material with the required shape for placing five specimens at one time. In the second step, the Araldite epoxy was applied on the top of aluminium along the bondline length of 64 mm and 0.2 mm thickness. The glass fiber plate was inserted on the top of adhesive. A small alignment tabs (25mm x 25mm) were inserted at the both end of adherends to assure a correct alignment and get symmetry during the test [7]. The specimens were then being rested for 24 hours. Properly, the Huck bolt types C6L Lockbolts was inserted using hydraulic installer at the centre of bond length with diameter hole of 6.4 mm in final step. The steps were repeated for bolted and bonded joint as shown in figure 4.

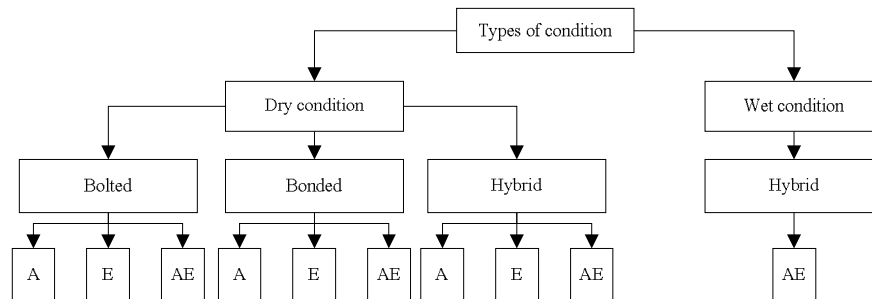


Figure 3. Flow chart of dry and wet condition: A (similar aluminium alloy), E (similar E-glass composite), AE (combination of aluminium and E-glass).

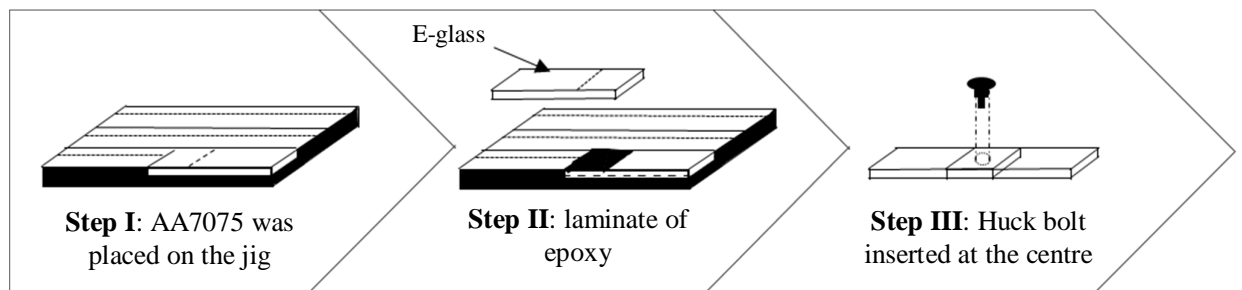


Figure 4. Manufacturing steps for hybrid joint.

3. Experimental Procedure

Figure 5 shows the 100 kN load cell used during tensile testing to determine the elastic-plastic mechanical properties of each joint configurations. Five specimens for each joining and conditions were experimentally conducted at speed rate set up to 1 mm/min with the gauge length of 206 mm. The composite specimen was placed on top as recommended for dissimilar materials joining testing. Furthermore, the head of Huck C6L lockbolt should be placed on the composite surface as lock tail on metal surface.

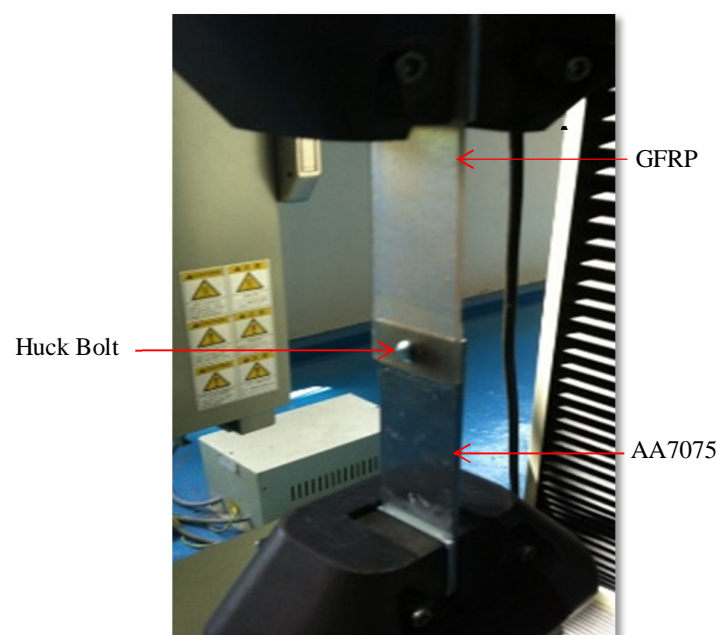


Figure 5. Tensile test

4. Results and Discussion

4.1. Loading Effect in Joint Configuration

The ultimate tensile failure load of bolted, bonded and hybrid joints were obtained from the test shown in figure 6. The average value of maximum load was plotted with similar and dissimilar materials for dry condition. It can be observed that, hybrid joining exhibits highest failure load followed by bonded and bolted joint for both similar and dissimilar materials. According to the error bars chart, dissimilar AA7075/E-glass demonstrates the highest strength with 18.34 ± 0.61 kN, reducing the strength with similar E-glass and AA7075. The differences rate is 13.2% with increasing of joint strength. However, the strength in similar AA7075 raised up in bolted joint rather than hybrid. Two failure was detected in hybrid joint as adhesive failed at initial and mechanically fastened of Huck bolt support the joint and failed as final failure. The stress distribution is uniform in bonded joint, while the crack and fracture occurred when stress concentration arisen at the drilling hole. The maximum load for each joining was tabulated in table 3.

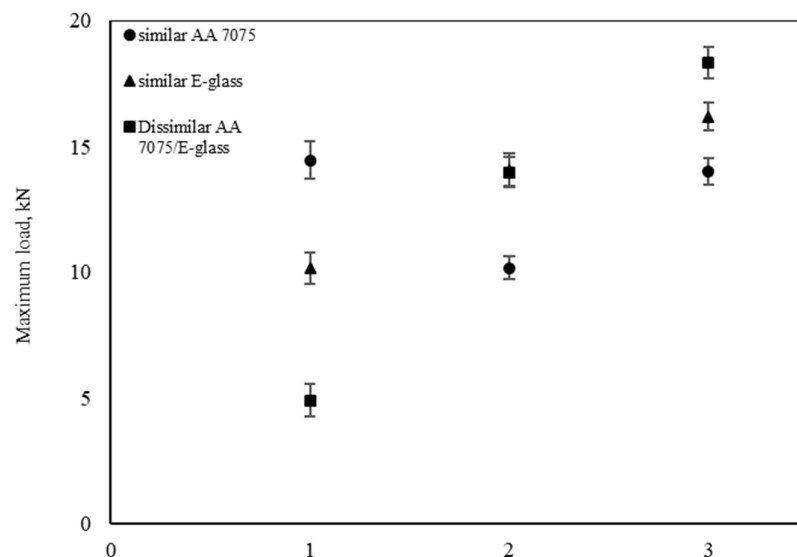


Figure 6. Maximum load in similar and dissimilar materials under dry condition for bolted (1), bonded (2) and hybrid (3) joints.

Table 3. Ultimate tensile failure load data.

Specimens	Ultimate Tensile Failure Load (kN)		
	Bolted	Bonded	Hybrid
Similar AA7075	14.47±0.73	10.16±0.44	14.02±0.51
Similar E-glass	10.14±0.63	14.08±0.65	16.20±0.53
Dissimilar AA7075/E-glass	4.90±0.65	13.99±0.611	18.34±0.61

4.2. Effect of Wet Environment On Hybrid Joint Strength

All the specimens prepared were conducted in tensile test to evaluate the strength performance with the load displacement and stress strain behaviour. The effect of dissimilar hybrid joint on wet condition was compared with dry condition as illustrated in figure 7. The plotting curved of the joints

are based $[0/90^\circ]$ laminates of composites and Araldite adhesive. This clearly indicates that the tensile strength of long water immersion affected the joint behaviour and the reduction about 62% compared with the dry environment. The adhesive and Huck bolt failed at first and second fracture, respectively. Meanwhile, it can be observed that the adhesive failure occurred at first fillet and structural was failed after second fillet once the Huck bolt was significantly damaged. Mostly, the structural failure was observed on the composite specimen at the edge of bolt holes. The increasing of second fillet was attributed to load sharing between adhesive and Huck bolt. The ultimate strength of dry and wet is calculated by 17.729 kN and 6.819 kN, respectively. Meanwhile, the tensile strength of hybrid joint decreased from 63 MPa under dry conditions to 24 MPa under wet conditions; representing a decrease of over 60%.

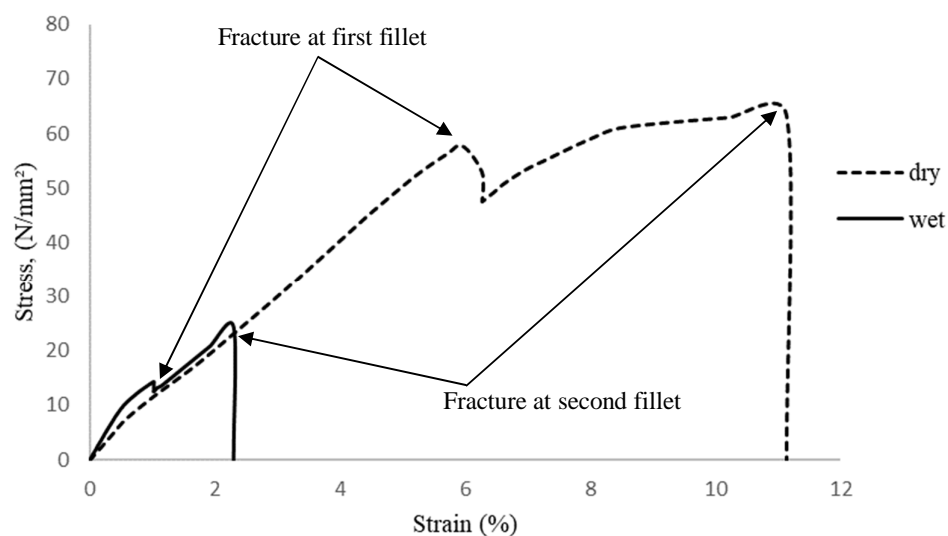


Figure 7. Stress strain behaviour.

4.3. Analysis of Failure Types

The adhesion and structural failure was identified in the study as in figure 8. The failed adhesive was stack on the lap side of both substrates. The failure was occurred by fiber tear in one of the substrates which can be described as adhesion failed. This was due to long moisture exposure with the water diffused in composite and adhesive. The bolt holes on composites were expanded before splitting and net tension until reach maximum loaded to fracture.

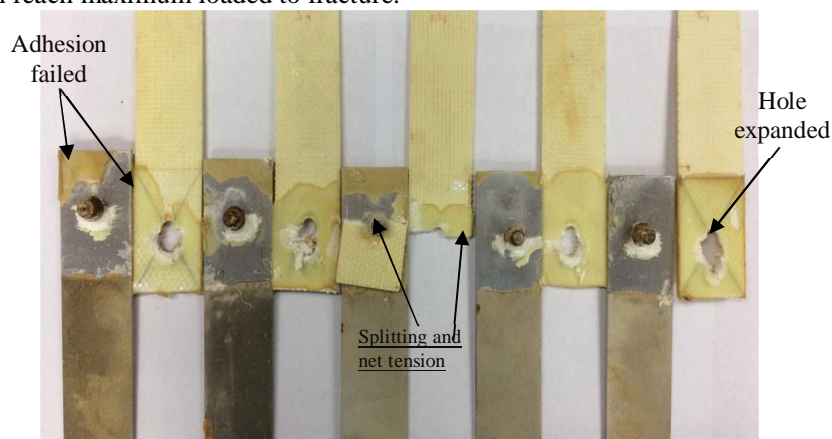


Figure 8. Failure specimen of wet hybrid joint.

5. Conclusion

The strength of hybrid joints under dry and wet environment had been investigated through experimental work. It can be concluded that, the water absorption at long exposure highly affects the strength of joint about 62% in wet condition. The highest failure mode for both conditions are 63 MPa and 24 MPa, for dry and wet, respectively. Also, the primary failure mode occurred in adhesive joint, and prevented by the presence of bolt as secondary failure before final separation.

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