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Optimal Selection for Dissimilar Materials using Adhesive Bonding and Mechanical Joining

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Abstract. In the present study, an investigation of double lap joints using two different joining methods was carried out. Carbon fiber and glass fiber reinforced materials were the composite materials that joined with the conventional steel and aluminium. Adhesive bonding joint and a combination of adhesive and mechanical fastener joints were used as a joining approach. It is found that adhesive bonding joint provided a better performance compared to the hybrid joint, where the holes created in the specimens for inserting mechanical fasteners caused a lower strength. It is observed that the adhesive joining of the glass fiber and steel obtained a maximum load of 35.5 KN, which is the highest strength among all other combinations examined in this study, while the similar combination joined using adhesive bonding and mechanical fastener showed a maximum load less than the adhesive joining by 21.4 %.

1. Introduction

Among many industrialization techniques, joining is the key technology that has been identified to enable innovative and sustainable manufacturing [1]. Joining is an important process in manufacturing a product to increase manufacturing process efficiency, where it seems possible to manufacture a product without using joining techniques. Nowadays, automobile industries concentrating on high performance and lightweight structure, and the direction of the integration of a growing number of functions in every part that can be met by joining different materials into hybrid structure [2]. Messler defines joining as the method that used to attaching parts of components together to create an integrated whole assembly [3]. Dissimilar materials are the materials that are hard to join due to the large difference in the physical properties or the chemical compositions of the materials need to join [4].

Joining dissimilar materials attained the performance needed for a product due to the different properties of each joined materials [1]. This combination of joining materials will need a methodical approach to select the materials, thus, to join the selected materials together may require a new method and a new manufacturing system. This involves the capability to improve the selection of materials and geometry [5].

2. Joining Processes for Dissimilar Materials

There are many techniques for joining of hybrid joints between metal and polymer workpiece. Mechanical fastening and adhesive bonding are the techniques that usually used in the hybrid joining. These techniques can be used in individual technique or in combination techniques to ensure a strong joint in the hybrid structure. However, the joining technique selected based on the application requirements [6].

2.1 Adhesive Bonding

The adhesive materials are used to bond joining surfaces. As shown in Figure 1, the adhesive material is usually applied to the adherend surfaces and keeps it for the solidification process in order to produce the bond. The major benefit of using adhesive joints that its effectiveness for joining dissimilar materials. Additionally, the adhesive joint has a less fabrication cost compared to mechanical fastening, as well as its improved the damage tolerance and has a lower structure weight. Using adhesive will avoid the cutting of the fiber where no holes required as what is usually happening when mechanical fastening is used for joining materials [7]. The technique of joining composite materials needs a pre-treatment in raising substantial adhesion between the adhesive and composite in order to improve the surface tension and wet ability of the composite material [8]. The aircraft Airbus A380 has faced an issue when the mechanical fastening used to join metal to composite in the development of the airplane wing. The composites in the Airbus were joined to the metal by bolting on aluminium brackets. While operating, some cracks showed in the aluminium brackets that might lead to failure in the whole component [9].

The disadvantages of cutting in the fiber that it may reduce structural safety by introducing a stress concentration. The flexibility of design and ease fabrication processes are the potential advantages of adhesive joints in addition to its strength to weight ratio [7]. Adhesive joints have some disadvantages such as the difficulties of disassembling, difficulties to get a good surface; there is no confidence in engineering design compared with mechanical fasteners. Generally, using adhesive joints led to difficulties in predicting bond failure [10, 11].

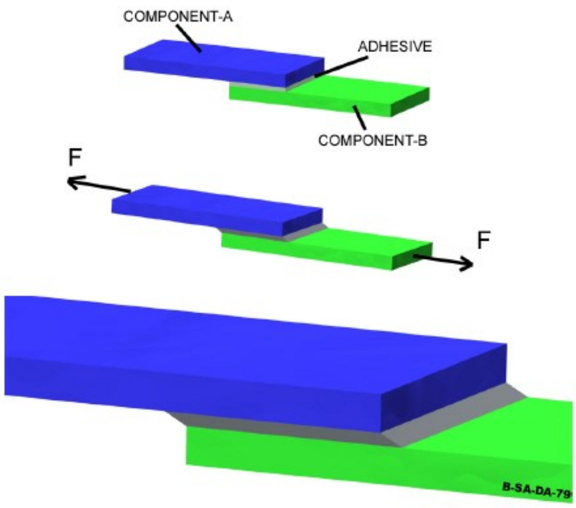

Figure 1. Single lap joint under tension (F) [12].

2.2 Mechanical Fasteners

Threaded fasteners joining have been in use for a long time. Different forms of bolts can be applied in one-side joining when the entrance of the components from the other side is limited. Therefore, a combination of the bolt and nut is used when the entrance is exiting from both sides of the joined components. The major advantage of threaded fasteners is when the disassembly is required where unscrewing does not produce demolition of the components.

A bolted joint is an easy way to connect two components together, which is also, allows disconnecting the components for maintenance or repairs or remanufacturing without damaging the components [13].

3. Experiment Detail

3.1 Materials Selection

Material selection is very important in the engineering structure design with considering manufacturing, joining and assembling processes that involved. The decision to selection base materials for this study was made due to the market requirement with respect to cost and availability. In the current study, two types of metal; aluminium 1050 and low mild steel were investigated. In the other side, carbon fiber and glass fiber reinforced polymer materials were chosen as composite materials for this study. These selected materials were based on most of the engineering applications.

3.2 Fabrication Processes

A high strength extruded sheets of steel and aluminium were used to produce the adherend metal specimens. The steel and aluminium materials specimens were produced from large sheets that have a dimension 317 mm x 244 mm each. Based on the dimensions of the available metal sheets, the specimens were manufactured using the specified dimensions.

3.2.1 Adhesive Joining Process. The adhesive process is a solid state bonding technique that depends on the formation of the forces between molecules between the workpiece and the polymeric adhesives themselves to form the joint [7]. It involves the use of a polymer adhesive that subjected to chemical or physical reactions to form the joint [14].

Hand layup process used to prepare the composite material panels in the present study. The adherend areas where the composite should be bonded for double lap joint were cleaned. The cut woven carbon and glass fiber fabrics were placed over the resin (UN 3082 Ultimeg 2020 with UN2735 Ultimeg 2020 hardener). The adhesive materials were squeezed on the adherend surface using a resin-wetted brush. The first composite material layer was placed on the metal; therefore, subsequent layers are placed in a similar way. This method was repeated until the necessary layers have been built up as Figure 2, shows the top view of the final glass fiber and steel specimen which they adhesively joined. The original thickness of the women carbon and glass fiber cloth was 0.1 mm each, thus, ten layers of the composite were required to place in 1 mm area. The specimens were subjected to external pressure in order to cure and then they left at room temperature to solidify. In this study, aluminium material joined adhesively once with carbon fiber and once with glass fiber, while steel material joined also with carbon fiber and again with glass fiber using the adhesive joining technique.

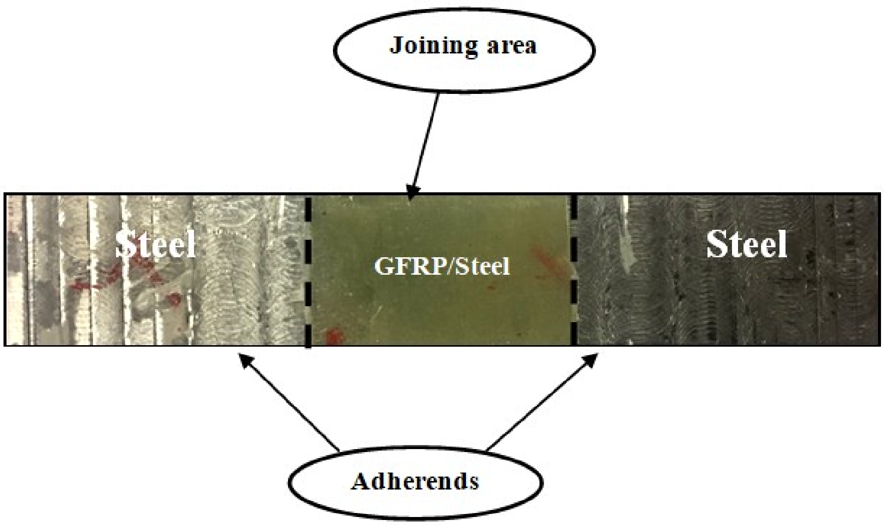

Figure 2. Adhesively bonded lap joint specimen.

3.2.2 Hybrid Joining. In this study, rivet fastener joining combined with adhesive joining to bond metal to polymer materials in order to investigate the strength of the joint. Hundreds of several types of rivets are available these days. An aluminium blind rivet that has 3.1 mm diameter was used in this joining. After the composite materials joined with metal materials adhesively, the drill machine used to create two holes in the joining area through the composite and metal materials. A 3.1 mm diameter drill bit used to create the holes, whilst, the distance between two holes is 10 mm. The blind rivet then inserted in the rivet gun and then penetrated through the two created holes, the rivet gun helped to squeeze the rivet pin in the right locations. Figure 3, shows the top view of the hybrid joint of steel and glass fiber specimen used in this study.

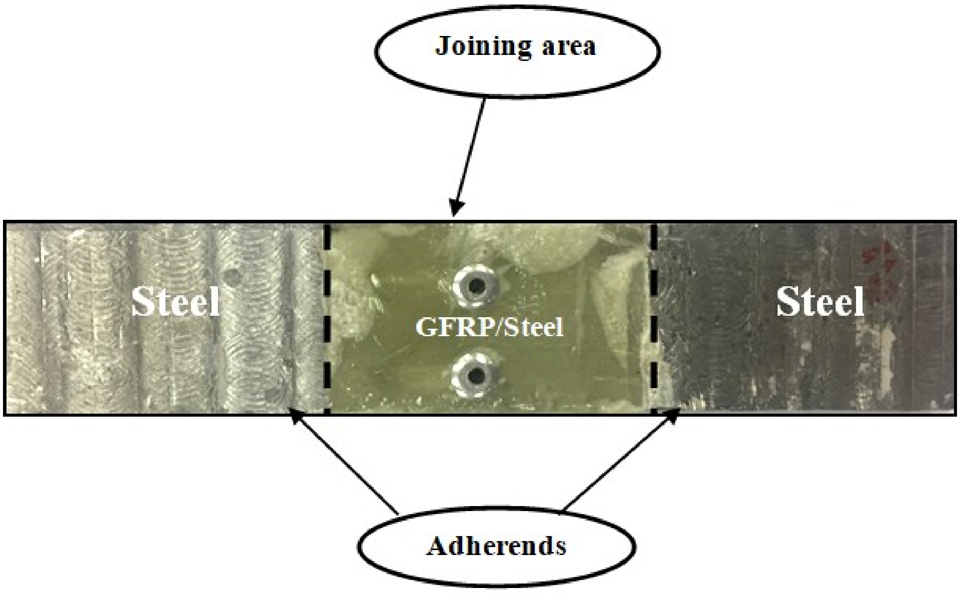

Figure 3. Hybrid joints of adhesive and mechanical fastening (rivet).

3.2.3 Mechanical Testing. The tensile tests for all specimens were carried out on - LLOYD - LR50K Plus universal testing machine in order to test the joints strength. The tensile test was displacement-controlled with a crosshead velocity of 5 mm/min at room temperature. The rectangular flat specimens were gripped vertically from the metal part areas with a crosshead distance of 40mm. The total specimen's length is 120mm with 25mm width, while the gauge length was 40mm. The machine load capacity can reach up to the 50KN load cell; therefore, the general purpose of the tensile test was to pull to break setup.

4. Result and Discussion

The outstanding joints design not only stands the highest strength but also expects the accurate stress distributions in both adherend and adhesive. This is mainly based on the correct experimental procedure for evaluation of reliable mechanical properties, suitable failure criteria and rational fracture mechanisms for the adhesive material used. Metal and composite materials were successfully joined using adhesive bonding and hybrid joining techniques and prepared for the tensile test. The main purpose of the tensile experiment is to obtain a load-deflection curve of the joining in order to get the strength of the joining materials. A static loading has been performed for all specimens in order to establish a baseline for loading rate comparison. The ultimate failure loads and deflections were recorded after the tensile test completed. The data of the maximum loads and deflection of the specimens that joined adhesively were tabulated in Table 1.

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Table 1. Maximum loads and Deflection data joints bonded adhesively.

	Maximum Load (KN)	Maximum Deflection (mm)
CFRP/AL	10.9	10.2
CFRP/Steel	30.4	9.5
GFRP/AL	10.6	11.2
GFRP/Steel	35.5	19.8

The observed failure locations for all adhesive joints specimens are shown in Figure 4. In the joining between CFRP and steel shown in Figure 4 (a), the failure mode observed is an adhesive failure where the adhesive separated from the steel on one side. Therefore, Figure 4 (b) shows the failure observed location in the joining of CFRP and aluminium, where the failure occurred out the joining location, this failure considered as adherend failure due to adhesive did not experience any failure after tensile test conducted. This failure could be due to the weakness in the failure area; however, the test obtained a reasonable tensile load. A mixed failure took place in both glass fiber cases, once when it joined with steel in Figure 4 (c) and when it joined with aluminium in Figure 4 (d).

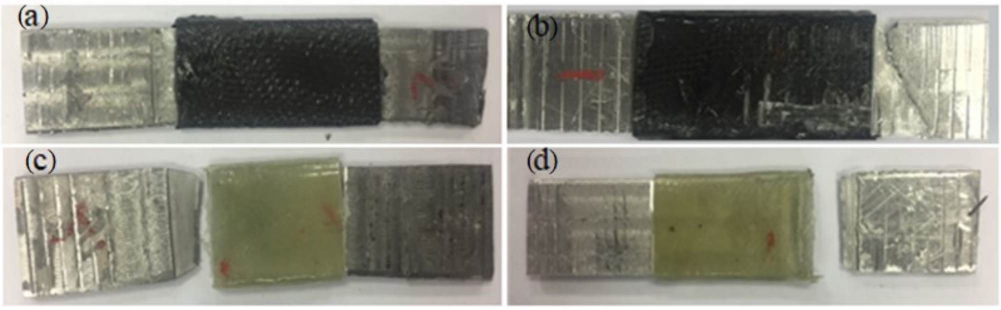

Figure 4. Failure locations of adhesive joints specimens (a) CFRP/Steel, (b) CFRP/Al, (c) GFRP/Steel, (d) GFRP/Al.

In the case of the hybrid joining, the tensile results that adhesive and fastening joining were used to join the dissimilar materials are presented in Table 2.

Table 2. Maximum loads and Deflections by using hybrid joints

	Maximum Load (KN)	Maximum Deflection (mm)
CFRP/AL	9.0	4.3
CFRP/Steel	29.2	16.4
GFRP/AL	8.8	8.2
GFRP/Steel	27.9	8.0

The hybrid joint specimens that made from adhesive and mechanical fastening failed very differently from the adhesive specimens. The rivets stayed firmly inserted in the metal during the tensile test. After reaching maximum load, the hybrid joints experienced drop off in load and considerable damages in the specimens. The failure modes observed in the combination of CFRP/Al and GFRP/Al shown in Figure 5 (b) and (d) respectively, are the net tension failures, while the combinations of CFRP/Steel and GFRP/Steel shown in Figure 5 (a) and (c) respectively, observed shear out failure mode. The carbon fiber joined with steel and joined with aluminium had observed an inter-laminar failure initiation in bonded joints.

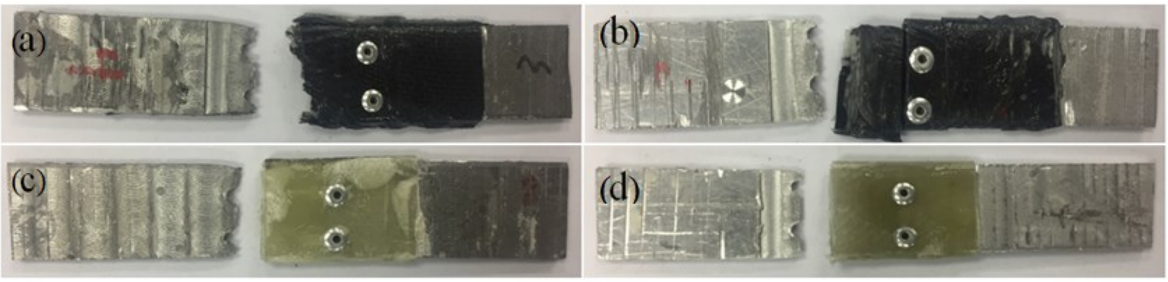

Figure 5. Failure locations of hybrid joints specimens (a) CFRP/Steel, (b) CFRP/Al, (c) GFRP/Steel, (d) GFRP/Al**.**

The joint strengths obtained for specimens joined adhesively were significantly higher than the specimens joined using the fastening and adhesive joints. The hybrid CFRP/Al specimen was about 18 % weaker the CFRP/Al specimen that bonded adhesively. Where maximum stress recorded were 8.0 MPa and 9.8 MPa respectively. From the observation, it found that the adhesive joining in CFRP/Al was stronger than in hybrid joining and that outcome a failure in the metal area compared with CFRP/Al hybrid joined which is failed in joining area where the rivets were fixed.

Obviously, low mild steel material is very strong than pure aluminium material. This fact appeared in the results obtained from the tensile test for the dissimilar materials joining. It can be seen that in the combinations of CFRP/Steel in both joinings techniques have the highest stress than those in the combinations of CFRP/Al. However, the adhesive joining of GFRP/Steel obtained the highest maximum stress among all other specimens, where the maximum stress recorded was 31.6 MPa compare with 24.8 MPa in the GFRP/Steel that joined adhesively and fastener.

Generally, the adhesive joints either experienced a ductile or brittle fracture. The joining specimens that involving steel showed a brittle fracture while the aluminium joining obtained ductile fracture and that due to the nature of both metal materials. Nevertheless, the maximum deflection for the CFRP/steel is almost twice that of the CFRP/Al. Ultimately, it can observe that the rivets involved in the hybrid joints that required predrilled to create holes were the cause of the failure when recorded lower mechanical properties compare with adhesive joints which only depend on the stiffness of the adhesive material.

5. Conclusion

Based on the result, glass fiber reinforced polymer gave a maximum load when it joined adhesively with conventional steel metal that recorded 35.5 KN. However, the combination of glass fiber and aluminum which joined adhesively showed more strength than the hybrid joint of glass fiber and aluminum that recorded 10.6 KN and 8.8 KN respectively. Consequently, the maximum stress observed in the combination of the glass fiber and steel joined adhesively that around 31.6 MPa, while in the hybrid joint, the same combination has a maximum stress of 24.8 MPa. The weakest combination observed in this study was in the combination of glass fiber and aluminum that joined using hybrid joints were the maximum load recorded was 8.8 KN and the maximum stress was 7.9 MPa.

The results show that the failure mechanism could be detected in the joining area, when the failures of adhesive joining were in the middle on the joining in the case of glass fiber combination with steel and aluminum, in the case of carbon fiber; the failures were in the adherend areas. For hybrid joining, all failures observed were due to the blind rivets area and that because of the holes that created to allow the rivet to penetrate. This study is a solid basis for developing and validating a model analytically and numerically which will be very useful to design.

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