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Experimental Study of FRP Butt Joint between Two Commercial Aluminium Plates under Tensile Loading

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Abstract: Two 175 mm long commercial aluminum plates (adherends) of rectangular cross-section (38 mm × 3 mm) were joined together in butt configuration by bonding of FRP (fibre reinforced polymer) patches. FRP patches were applied symmetrically on both sides of adherends. The patch is made of load bearing unidirectional CFRP (carbon fibre reinforced polymer) plies and a separating thin ply of unidirectional GFRP (glass fibre reinforced polymer). Each CFRP ply is made by reinforcing epoxy with a unidirectional carbon fibre sheet of 160 gsm and thin separating GFRP ply is made by reinforcing epoxy with a unidirectional glass fibre sheet of 76 gsm where gsm is gram per square meter (gm/m^2). The surface of commercial aluminium adherends was prepared by rubbing it with emery paper of grade 50 followed by surface treatment with concentrated HCl (Hydrochloric acid) to increase the bonding between FRP patches and adherends. In this study the epoxy resin employed was Dobeckot 520 F (100 parts by weight) with hardener 758 (9% by weight of Epoxy) which cured the resin at room temperature. An adhesion promoter, aminopropyltriethoxysilane (0.5% by weight of Epoxy) was used. The patches were bonded using the vacuum bagging technique. Specimen kept in vacuum bagging setup for 15-18 Hrs at room temperature for curing and then placed in an oven for post curing for 5 hours at 80 ºC. Four types of joints were prepared with ply drop of 5mm in the patch configurations of: (i) one CFRP ply, (ii) two CFRP Plies, (iii) three CFRP plies, (iv) four CFRP Plies. The tensile strength of butt-joint was studied experimentally through the universal testing machine. A special clamping fixture was designed to eliminate induced bending moment in the specimen. The specimen was loaded in pure tensile load
Keywords: - CFRP, GFRP, Butt Joint, Commercial Aluminium Plates, Epoxy, Vacuum bagging

1.INTRODUCTION

In our day-to-day living, we come across the parts which are joined together. The joining of similar and dissimilar material is the requirement of the industries. Different types of joining methods are available to join two or more similar or dissimilar materials like fasteners, welding, adhesive bonding**,** and tying components together**,** gripping through elastic deformation (interference fit) etc. Each of these techniques has its own advantages and limitations. The welded joint has several advantages like they do not add much weight to the assembly, they have high strength, they are convenient to make, etc. However they have their limitations such as welded joints may induce residual stresses, due to high temperatures involved and the cooling, various kinds of cracks develop in the weldment as well as in heat affected zones. A skilled labor required carrying out welding, the inspection of welding is also specialized and costlier, and component cannot be recovered once the life of the product is over, extremely difficult to join components made of aluminium or of different materials. An adhesive joint is another technique to join two parts. Here the main advantage is that the adherends of two dissimilar materials can also be joined easily for example aluminum components can be joined with rubber components in automobile industry. Nowadays the use of adhesive joining is on increase substantially due to development of strong and tough adhesives that can withstand both static and dynamic loading. Though this method is economical and requires less skilled labor. It also has a limitation of detachment against fluctuating loads. In a recently developed method, a fibre reinforced polymer (FRP) composites are used to join two parts together. FRP is made of fibers (glass/ carbon) and a thermo set matrix (epoxy). Fibre is used to carry the load and matrix helps in bonding of fibre with adherends also it protect the fibre from abrasion and environmental attack. An FRP joint offers numerous advantages:-(i) the joining can be easily done at room temperature, as it is a cold working process, (ii) this method can be used to join similar or dissimilar materials, (iii) this overcomes the limitations of welding in which similar or certain pairs of materials can only be joined, (iv) directional properties can be obtained by varying the orientations of fibre in the composites, (v) this provides non-corrosive joint, (vi) the FRP joint offers high strength to weight ratio.

1.1. Literature Survey

Kumar et al.[1] (2007) developed FRP T-joints between two components by winding strong and stiff glass fibres wetted with an epoxy over the joint. They developed two kinds of joint: (i) between similar materials and (ii) between dissimilar materials. The strength of the T-joints was tested under four loading conditions: (i) tensile, (ii) in- plane bending, (iii) bending under a transverse load, and (iv) torsion-cum-bending. The results obtained were compared with weld joints of similar configuration. The strength of FRP-joint between two mild steel tubes was found to be comparable with the strength of welded joints. Welding between steel and aluminium is not possible but in FRP joints two dissimilar metals can be joined and marginally higher joint strength was observed than that of joint between similar materials. **Kumar et al.[2] (2008)** developed FRP T-joints by joining of pipes using FRP. Experimental study with high strength and high stiffness glass fibres. The joint was made by wetting a glass fibre tow with pipes was selected as a specimen. Three kinds of appropriate windings loops, diagonal, straight and circular were used. Strength of the T joint was determined under four loading conditions: (i) tensile, (ii) in-plane bending, (iii) bending under a transverse load and (iv) torsion-cum-bending. The strength of FRP joint between mild steel pipes for an appropriately chosen winding configuration was found to be higher than the strength of welded joints. **Ladhwe et al.[3] (2014a)** characterized the FRP butt joint between two aluminum pipes by winding a wetted roving of carbon fibre and glass fibre at $\pm 45^0$ angle. The butt-joint was studied through two kinds of tests: tensile and bending. The specimens were of two types: thin and thick GFRP sleeve. In tension tests, the thin sleeve specimens failed due to the failure of the GFRP sleeve at the joint plane as the axial stress developed in the GFRP sleeve exceeded its ultimate strength. However, the thick sleeve specimens resisted higher load but one of the two adherends slipped out of the sleeve. In bending experiments they found that the failure in specimens with a thin GFRP sleeve occurred due to the breakage of the sleeve at the joint plane. However the specimens of thick GFRP sleeve did not fail within the sleeve. Numerical analysis using ANSYS was carried out to explain the experimental results. **Ladhwe et al.[4] (2014b)** formed a butt-joint between two pipes of dissimilar materials, steel and aluminum, by winding a wetted roving of carbon fiber with epoxy at ±45° angle. On the curing of the epoxy, a tight carbon fiber reinforced polymer (CFRP) sleeve was formed, joining the ends of the pipes. The CFRP butt-joint was characterized for two kinds of loads: tensile and bending. Based on the joint strength performance, the specimens were categorized into two groups, thin and thick CFRP sleeved specimens. In the tensile testing, the thin sleeved specimen failed through the breakage of the CFRP sleeve at the joint plane because the axial stress developed in CFRP sleeve exceeded the ultimate strength of the CFRP. However, the thick sleeved specimens resisted the axial load in the sleeve and the weaker adherend, the aluminum pipe, slipped out of the CFRP sleeve. In the flexural testing, the thin CFRP sleeved specimens also failed by failure of the CFRP sleeve at the joint plane while the specimens of thick CFRP sleeve failed by the formation of a plastic hinge near the edge of the CFRP sleeve. **Ladhwe et al.[5] (2015)** developed GFRP butt-joint between an adherends of an aluminum pipe and steel pipe with unidirectional glass fiber at ±10°. The butt-joint was studied through two kinds of test: tensile and leak. The specimens were of two types: single layer and double layer GFRP sleeve. In tension test, the single layer sleeve specimens were failed due to failure of GFRP sleeve at joint plane as axial stress developed in GFRP sleeve exceeded the ultimate strength of GFRP. However, double layer sleeve specimens resisted higher load but one of the two adherends slipped out of the GFRP sleeve. Numerical analysis was carried out to explain results. **Battulwar [6](2016)** carried out experiment work on a CFRP butt joint between two metal adherends aluminum and steel. Three types of specimens two, three and four ply were tested under tensile loading. In each case unidirectional CFRP ply at $\pm 10^0$ angle were used. He observed that as the number of layers FRP patches increases the strength of joint increases with change in the mode of failure. In two ply specimens CFRP patches failed at the joint plane whereas in four ply specimens sleeve is slipping out from the adherends. The strength obtained in three and four ply specimens were more than the yielding strength of aluminium adherends. Most of the works on FRP butt joints were carried out on pipe joint. There was very limited works were carried out on bars or plates. It was necessary to investigate whether FRP joint will work on flats specimens or not.

2 FRP BUTT-JOINT PREPARATION (SPECIMEN PREPARATION)

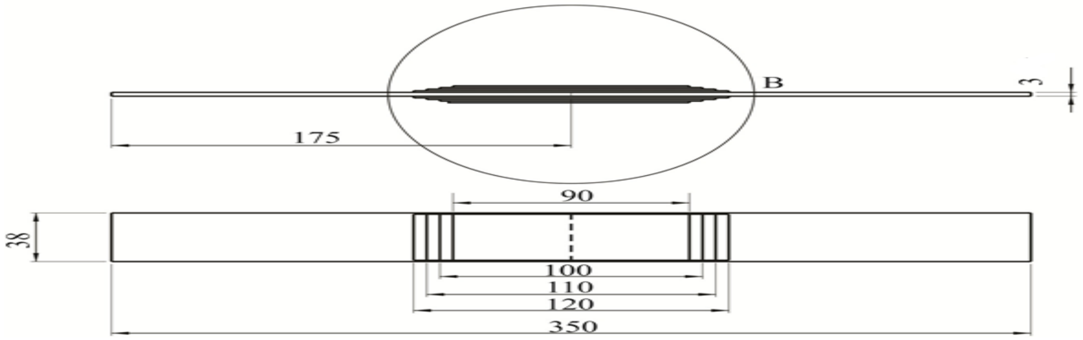
2.1 Basic Geometry Of Specimen

A carbon fibre reinforced polymer (CFRP) butt joint was formed between two commercial aluminium adherends by wetting the reinforcement plies of UD CFRP and GFRP (glass fibre reinforced polymer) in epoxy resin and stacking them on the surface of adherends. FRP patches were applied symmetrically on both sides of adherends. The Patch configurations for different specimens are shown in table 1.

Table 1: Patch configuration

No. of CFRP Plies on each side of adherends	Length of GFRP Ply 'G' , (mm)	Length of CFRP plies 'C' , (mm)			
		1st Ply	2nd Ply	3rd Ply	4th Ply
1 Ply	120	110	-	-	-
2 Plies	120	110	100	-	-
3 Plies	120	110	100	90	-
4 Plies	120	110	100	90	80

Four types of specimens were prepared using varying configuration of CFRP plies: (i) one CFRP ply on each side of adherends, (ii) two CFRP plies on each side of adherends, (iii) three CFRP plies on each side of adherends, (iv) four CFRP plies on each side of adherends



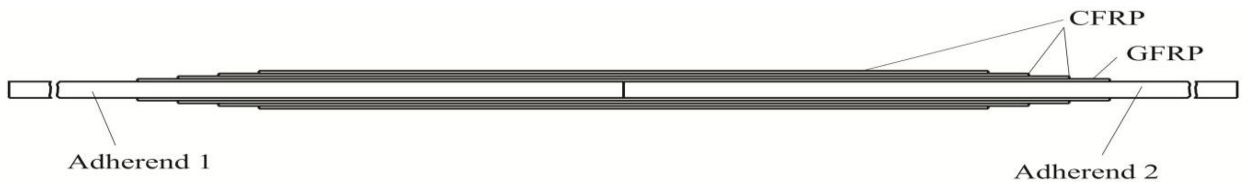


Figure 1: Basic geometry of CFRP butt joint specimen and detailed view of the joint portion for the case of three plies specimen (All dimensions are in mm)

The basic geometry of the specimen of three CFRP plies on each side of adherends is shown in Figure 1. Two adherends plates of (38 mm ×3 mm) cross section were butt jointed. A thin separating GFRP ply was placed in between the commercial aluminium adherend skin and CFRP ply. The GFRP ply helps to prevent possible corrosion between aluminium adherends and CFRP ply. The width of FRP plies kept smaller (36 mm) than that of width of adherends (38 mm) to avoid any possible separation of patches at the edges of adherends.

2.2 Material Properties

In these study commercial aluminum plates of rectangular cross-section (38 mm × 3 mm) was taken as adherends and is purchased from Oswal Metalica, Pune. The length of each adherends was 175 mm. To determine the properties of as purchased commercial aluminium plates (adherends), a tension test was carried out on 240 mm long bare commercial aluminium plate. Universal Testing Machine (UTM) of 100 kN capacities was used to conduct the tests. The results of tension test (average of 5 readings) on the commercial aluminum adherends are yield stress $\sigma_{ys} = 202 \pm 4$ MPa, ultimate tensile strength $\sigma_{uts} = 235 \pm 3$ MPa, elastic modulus of aluminium adherend $E_a = 68.6 \pm 6$ GPa, density $\rho_a = 2700\ \mathrm{kg/m^3}$. Two types of reinforcement were used in this study for specimen preparation. A unidirectional (UD) carbon fiber fabric of 160 gsm where gsm is gram per square meter (gm/m^2). They were purchased from Hindustan Mills, Mumbai. A UD glass fiber fabric of 76 gsm was also purchased from Hindustan Mills, Mumbai. The properties of the UD carbon fiber as obtained from the supplier-fiber modulus $E_c = 231$ GPa, poisson's ratio $\nu_c = 0.2$, density $\rho_c = 1860\ \mathrm{kg}/m^3$ And that of UD glass fiber as: fiber modulus $E_g = 72.4$ GPa, poisson's ratio $\nu_g = 0.22$, density $\rho_c = 2540\ \mathrm{kg}/m^3$. In this study the epoxy resin employed was Dobeckot 520F (100 parts by weight) with hardener 758 (9 parts by weight) which cured the resin at room temperature. The mixture of the epoxy and the hardener has a pot life of 25-30 minutes. The mechanical properties of epoxy as obtained from supplier [Elantas beck India Ltd.]: modulus $E_e = 3.8$ GPa, poisson's ratio $\nu_e = 0.4$, density $\rho_e = 1200\ \mathrm{kg}/m^3$. Amino Silane was used as an adhesion promoter. It improves the chemical bonding of resin with the reinforcement. Although as supplied carbon and glass fibres are coated with an appropriate saline; amino silane was added in this investigation to improve adhesion between epoxy and aluminum adherend. In this study 3-aminopropyltriethoxysilane was used in 0.5 % amount of epoxy resin.Properties of 3- aminopropyltriethoxysilane are color-pale yellow, viscosity (at 25°C)=1.6 cPs , flash point = 96 $^\circ$C , purity = 98.66 %, specific gravity = 0.946. [Test certificate – Doc no. F – QAD-04, silicons H 55 MIDC Waluj, Aurangabad].

2.3 Strength of CFRP Lamina:

To determine the strength of UD CFRP specimen and characterize the failure pattern a tension tests were carried out. Two kinds of tension specimens with configuration 5 ply $[0]_5$ UD carbon fibre and 5 ply [10/-10/10/-10/10] UD carbon fibre were prepared using vacuum bagging technique (discussed in next section). The geometry of tension test specimen of CFRP is shown in figure 2. Ultimate tensile strength (UTS) obtained for UTS of 5 ply [10/-10/10/-10/10] UD carbon fibre lamina is 721.0 ±29.8 MPa (avg. of 5 readings) and UTS of 5 ply $[0]_5$ UD carbon fibre lamina is 1109 ±125 MPa (avg. of 5 readings).

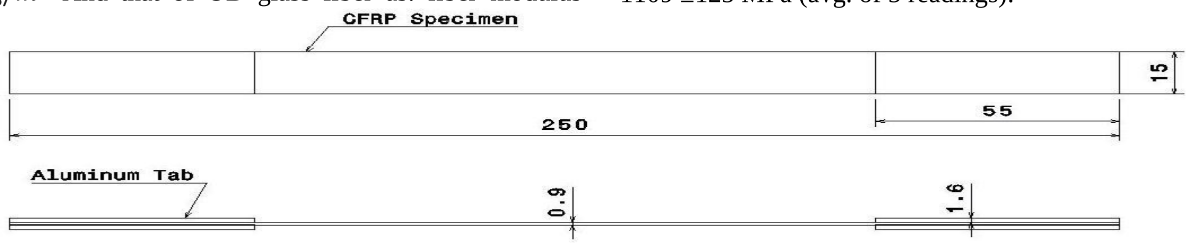


Figure 2: Tension test specimen to determine strength of CFRP Lamina (all dimension are in mm)

2.4 Specimen Preparation

The surfaces of both the adherends were made rough by rubbing them with an emery paper of grade 50 for proper bonding of FRP patches. The emery papers were rubbed in the width direction as shown in Figure 3. To improve the adhesion, aluminium surface was treated with concentrated hydrochloric acid (HCl) solution. It was applied on one side of adherends and kept it undisturbed for twenty minutes. After that it was applied on the other side. The surfaces were cleaned with tap water followed by acetone. Figure 4 shows the surface treatment of adherends with HCl and a paint brush was used to apply the solutions to avoid any direct contact with person's skin. Figure 5 shows the adherends surface after the treatment with HCl visible as dark colour.

Figure 3: Roughened surfaces of adherend plates

Figure 4: Surface treatment with HCl

Figure 5: Adherend surface after HCl treatment visible as dark colour

2.5 Vacuum Bagging

A UD carbon and UD glass fiber sheet reinforcement, wetted with a resin, are placed on both sides of the adherends. The assembly is placed within a vacuum bag which did the functions: (i) applied about 1 atmospheric pressure on the specimen being used, (ii) removes excess resin from the stack, (iii) decrease the entrapped air in the epoxy resin. In the vacuum bag several disposable material are used: (i) glass fibre fabric reinforced teflon sheet of 100 micron thickness, (ii) peel sheet, made by making perforators in the glass fibre reinforced teflon cloth, (iii) breather, a spongy material which absorbs the excess epoxy resin and facilitates the process of taking air out from the inside of the bag, (iv) bagging sheet made up of a thin polymer which does not adhere to epoxy, (v) double sticking tape. A glass plate of 500 mm ×300 mm ×20 mm, with a very smooth top surface was employed as a base plate shown in Figure 6. A double sticking tape of 3 mm thickness and 20 mm width was placed all around the edges of the glass plate as shown in Figure 7. Then a glass fibre reinforced Teflon cloth was placed inside the double stick tape area. The purpose of putting this Teflon cloth was to prevent the bonding of epoxy with the glass plate. Then two layers of breather fabric of a thickness of 2 mm each were placed on the Teflon cloth. This breather absorbed the excess resin. Above this breather a peel sheet with equally spaced (8 mm × 8 mm) holes in the square pattern was laid up as shown in Figure 8.

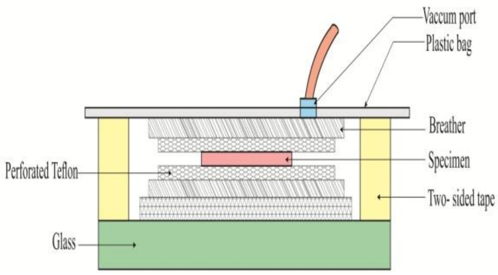


Figure 6: Sectional view of vacuum bagging setup, magnified in the thickness direction

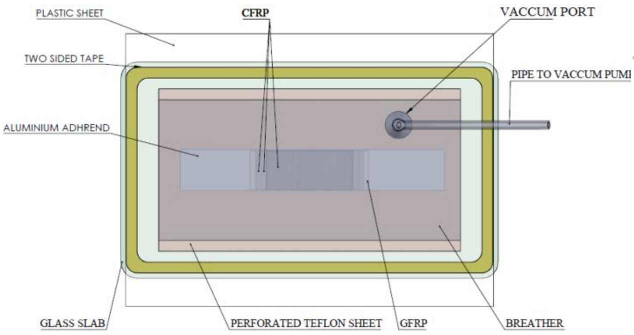


Figure 7: Top view of the setup of vacuum bagging technique

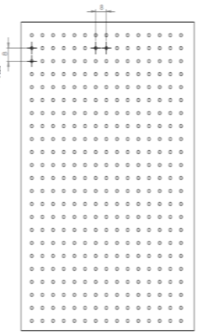


Figure 8: Square cell patterns on the peel sheet

Over the long perforated peel sheet UD carbon sheets, wetted with epoxy resin were placed in the proper sequence as shown in Figure 9. Then a steel roller of 25.4 mm diameter with very polished surface was rolled over the FRP sheet to remove the excess resin and to make a uniform distribution of resin throughout the ply surface shown in Figure 10. Then a wetted UD glass sheet was placed over the wetted carbon sheets and excess resin was rolled out. Once the glass sheet was stacked, an aluminium adherends were placed touching each other in butting configuration. Similar stacking of FRP sheets were carried out at the top of the adherends. Again perforated peel sheet and breathers were placed over the specimen to absorb excess epoxy and other contaminants. Then the entire assembly was covered with a vacuum bagging sheet. A vacuum port was inserted on the bagging sheet to create a vacuum as shown in the Figure 11. After this the vacuum pump was started and the pressure was maintained at 720 mm of Hg vacuum (i.e. -720 mm of Mercury column). The vacuum pump removed the entrapped air and excess resin. The vacuum pump was operated for the duration of about 4.5-5 hours at a constant pressure of 720 mm Hg vacuum. And then it was kept within the bag for 15-18 hours for curing at room temperature.

Figure 9: Application of resin on FRP sheets

Figure 10: Rolling of roller over FRP sheets

Figure 11: Photograph of vacuum bagging of set up

The vacuum bagging technique ensured uniform pressure on the composite FRP sheets during the curing of the epoxy. Because of uniform pressure, a thickness of an FRP patch was found to be constant on the entire patch area. Also, it took most of the entrapped air bubbles and excess resin out under the vacuum pressure, thus enhancing the quality of adhesion between the FRP patches and the aluminium skin. After curing, the specimen was separated out of the vacuum bag and was placed in an oven for post curing for 5 hours at 80 ºC as per the specifications of the epoxy supplier (Elantas Beck India Ltd).

3 EXPERIMENTAL TECHNIQUES

A universal joint was developed for the universal testing machine. It applies pure tensile load on the specimen as the fixture clamps the specimen in such a way that the specimen becomes a two-force member. The specimen was loaded in machine with the help of upper and lower jaws of universal fixture. The FRP butt joint specimens were loaded in the Universal Testing Machine (UTM) as shown in Figure 12. The upper jaw of fixture is attached to the cross head of machine with the help of universal bar (UB) and movable hub (attached to the load cell). Similarly, the lower jaw is attached to the lower universal bar through a hinge and the UB is attached to the fixed hub through another hinge joint whose rotational direction is normal to that of the other hinge. These two pin joints at each ends eliminate any possible induced bending moments and load the specimen in pure tension as a two-force member. Also, these hinge pins will transfer the tensile force from the machine to universal bar and to the specimen. The specimen was held between the two clamping plates of a jaw as shown in Figure 13. The displacement was applied to the cross-head at the rate 0.5-1 mm/min until the failure of joint failed or the adherend failed in the bare portion of the specimen. The load applied was measured by means of a load cell of 100 kN and the mode of failure was observed.

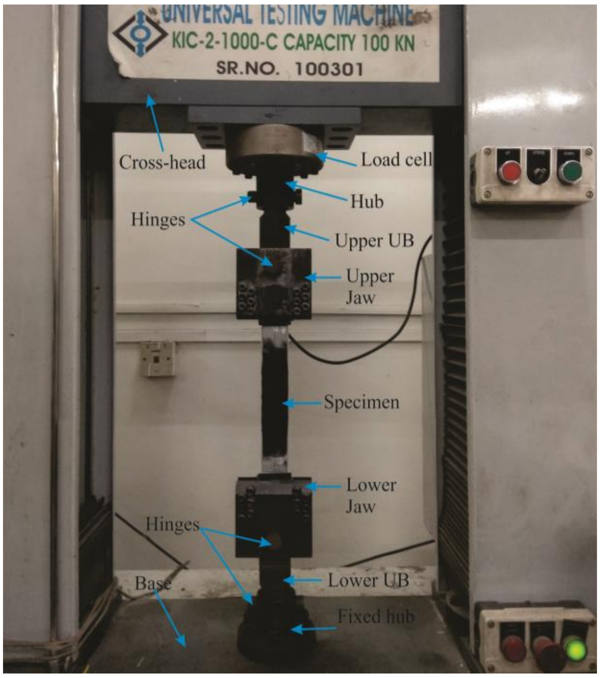


Figure 12: Specimen loaded in UTM

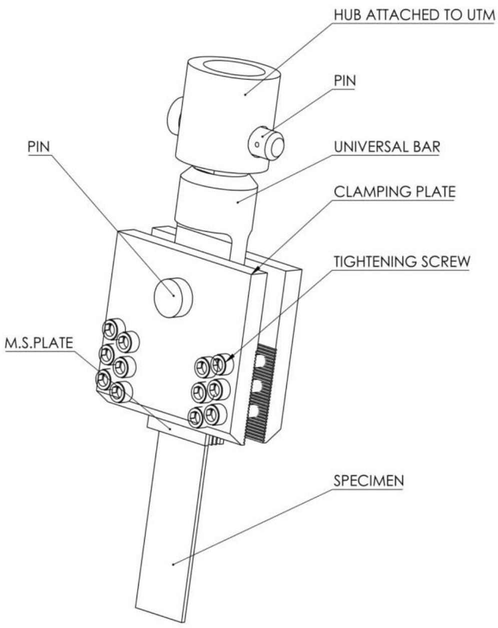


Figure 13: Isometric view of a universal tensile clamping fixture assembly

4 RESULTS & DISCUSSION

The volume fraction obtained for GFRP ply was close to 35 % whereas the volume fraction obtained for CFRP plies was close to 50 %. The elastic modulus along longitudinal direction for GFRP and CFRP plies were found out using rule of mixtures. The elastic modulus along the longitudinal direction obtained for GFRP and CFRP plies were 117.4 GPa and 28.0 GPa respectively. The FRP patch thickness (patches on both side included) obtained in each configuration is given Table 2. At the leading edge the where only the GFRP was presents; its thickness obtained was 0.18mm and stiffness ratio S obtained for same GFRP ply was 0.03, where stiffness ratio S is given as,

$$S = \frac{E_p T_p}{E_a T_a}$$

where, $\mathbf{E_p}$ and $\mathbf{E_a}$ are modulus of patch and adherends respectively (GPa).

$\mathbf{T_p}$ and $\mathbf{T_a}$ are thicknesses of patch and adherends respectively (mm).

The tensile strength of FRP bonded butt joint ($\boldsymbol{\sigma_f}$) was compared with the yield stress ($\sigma_{ys} = 202 \pm 4$ MPa) (tensile) of commercial aluminium adherend and ultimate tensile strength ($\sigma_{uts} = 235 \pm 3$ MPa) of commercial aluminium adherend and results were obtained are shown in Table 2.

Table 2 –Detailed results of 1,2,3,4 CFRP plies specimens

No. of CFRP plies on each side of adherend	**Patch Thickness T_p , (mm)**	**Tensile strength Of FRP bonded butt joint σ_f, (MPa)**	**Stresses in CFRP at joint Plane , (MPa)**	$\frac{\sigma_f}{\sigma_{ys}}$	$\frac{\sigma_f}{\sigma_{uts}}$
1 Ply	0.27	148 ±6	1170 ±30	0.733	0.630
2 Plies	0.42	215 ±13	946 ±59	1.064	0.915
3 Plies	0.57	223 ±8	687 ±24	1.104	0.949
4 Plies	0.72	218 ±7	517 ±16	1.080	0.928

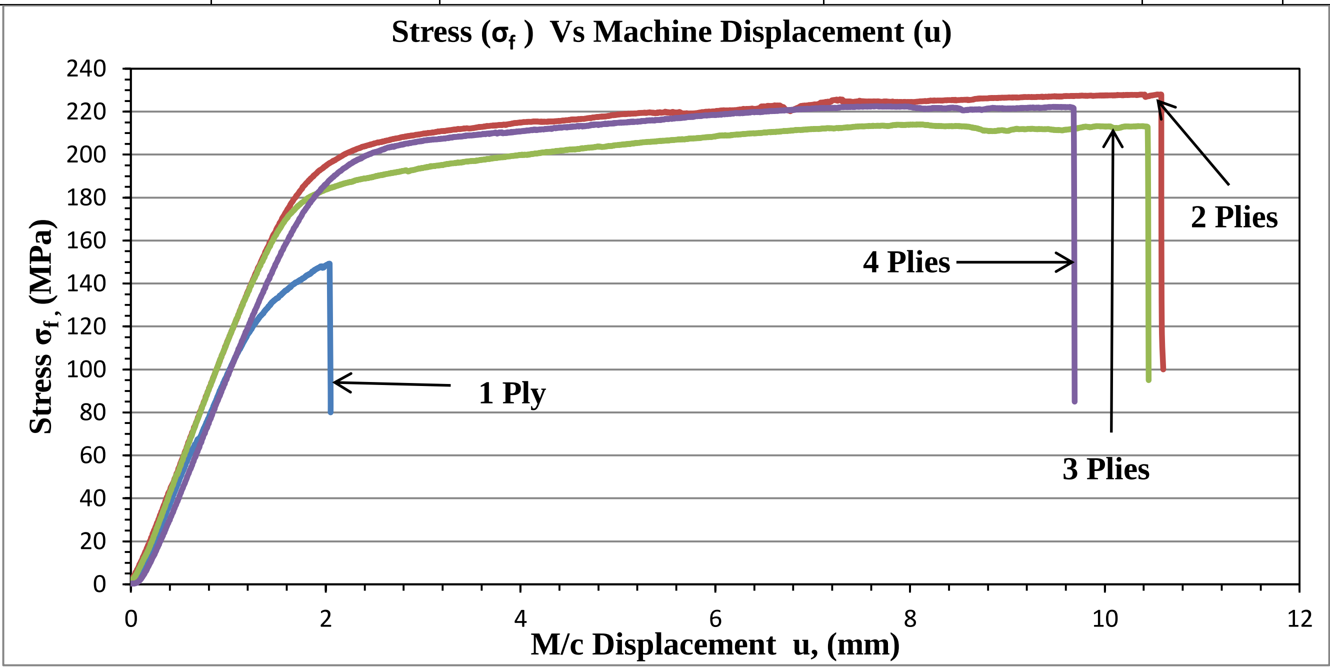


Figure 14: Far field stress σ_f v/s machine displacements for 1,2,3,4 ply specimen

Figure 14 shows the stress-m/c displacement behavior of specimens with different configuration. In one CFRP ply specimens, FRP patches failed at the joint plane and strength of joint obtained was 148±5 MPa. In specimens with two CFRP plies, specimens failed due to the separation of one patch from adherends and failure of another patch at the joint plane. The separation of patch occurred because of yielding of adherends material as material flows and separation of patch initiated at the leading edge and grows over entire face. The strength obtained for this configuration was 215±12 MPa; which more than the yield strength of adherend (202±3 MPa). It makes the interface weak as the aluminum material flows; consequently a separation initiated which then grows to the entire face. The stresses induced in an FRP patches in two ply specimens were less than the stresses induced in one ply specimens. The strength of joints obtained in three and four CFRP plies specimens were 223±7 MPa and 218±6 MPa respectively.

5 CONCLUSIONS

Two 175 mm long commercial aluminum plates (adherends) of rectangular cross-section (38 mm × 3 mm) were joined together in butt configuration by bonding of FRP (fibre reinforced polymer) patches. FRP patches were applied symmetrically on both sides of adherends. The patches were bonded using the vacuum bagging technique. Adhesive joints between two commercial aluminium plates were reinforced with high strength and high stiffness carbon fibres. Strength of joints for three plies and four plies specimens shows marginal improvement when it compared with two CFRP plies specimens. Marginal improvement in the strength leads to separation of both patches from the adherends. Two CFRP plies on each side of adherends provide sufficient strength (more than the yield strength of adherends) to joint under static loading condition.

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