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Experimental And Numerical Analysis Of FRP Butt Joint Between Aluminium And Steel Pipes Using Glass Fiber Matrix Under Tensile Loading.

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ABSTRACT

A GFRP butt-joint was developed between adherends of an aluminum pipe and steel pipe by placing two layers of 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 was failed due to failure of the GFRP sleeve at the 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 using ANSYS was carried out to explain experimental results.

Keywords- **FRP joint, butt-joint, GFRP sleeve**

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I. Introduction

In our day-to-day living, we come across the parts which are joined together and the joining of similar and dissimilar material is the requirement of the industries. When the parts take up the load, often the joint becomes the weaker link. This means that the strength of the joint is less than that of the parent components. A good joint means that the strength of the joint is higher than that of the parent components.Butt joining of pipes is the regular requirement of the industries. The butt joining of the ends of two pipes is difficult. Many techniques have been evolved to meet the requirements. Still, investigators are working in exploring new ways of butt-joining the pipes.It is difficult to attach the end face of pipe to the end of other pipe because the cross-sectional area is limited. Some technique such as frictional welding, electro-magnetic welding etc. have been evolved which can join the end face of a pipe to the end face of another pipe. These techniques are quite sophisticated and are not suitable for in-field operation.The fastening of the ends of two pipes is either carried out through flange or unions [Alvse et al. (2014)]. The flanged joints are usually employed for relatively larger diameter pipes. A flange is usually welded on the end of a pipe and the holes are provided close to the circumference of the flange so that two flange ends are fastened together using appropriate bolts.Welding the two end faces of thin walled pipes is usually not feasible. In these pipes, making of proper V-groove to fill material is not convenient and thus conventional butt-welding of the pipe is usually avoided. Also it is difficult to have a high strength welded butt joint between thin walled tubes [Gourd (1986)]. Welded joints between components of dissimilar materials through the conventional methods are either not possible or difficult to achieve. Direct joining of end faces is possible through flash welding. In flash butt welding, the arc produced at the tube ends, gives rise to local heating and, material softening [ASM (1993)]. The flash butt welded joint is produced when the tubes are brought into contact by an axial compression force. The technique thus allows the welding of the end faces of dissimilar material, but it is more difficult to achieve. Another way to join the end faces of pipe is done through friction welding. The friction welding is solid state welding process that utilizes non consumable welding tool to generate frictional heat at the rubbing surfaces to raise the temperature at the interface higher enough to cause two surfaces to be forged together under high pressure [Kimura et al. (2012)]. The principle advantage of frictional welding, being a solid state process of low distortion, is the absence of melt related defect. The joint is possible between different materials and different thickness. But the joining becomes difficult with decreasing pipe thickness due to load buckling.Rombaut et al. (2011)focused on thedifficulties faced while joining the dissimilar material steel to ceramic by friction welding. Brazed / soldered joints are good alternative to welded joints in case of thin-walled tubes. They are produced by placing a filler metal with a melting temperature below that of the tubes between the counter facing surfaces of the tubes. [Miller (2003)]. The most important advantages of brazed/soldered joints is that they can be automated and effectively used to connect tubes made from dissimilar materials or exhibiting significant differences in wall thickness. Adhesive joints are alternative to welded and brazed joints in situations where temperature cannot be applied or in applications involving dissimilar materials (e.g. metals and polymers). Mattas et al. (2010) formed a simple butt joint of rods by placing a thin layer of adhesion between end faces of rod. They performed a study on the influence of adhesive layer thickness on the mechanical strength of axially loaded Aluminum-epoxy butt joint. Shim et al. (2011) explained magnetic pulse welding processes which use cylindrical material such as pipe, tube, dissimilar metal joining by repulsive force on account of the interaction between magnetic part of the working coil and current induced in an outer pipe. In magnetic pulse welding (MPW), electromagnetic forces are used to impact two materials against each other at high speed.The lap joint between the two pipes can be formed by crimping method. Crimped joints make use of beads or dimples produced by reduction or swaging forming [Zhang et al. (2014)]. Alves et al. (2014) introduced a new cold forming process for the end-to-end joining of tubes. Two metal tubes were joined by performing their ends in one stroke and making use of tube expansion to put the mating surface of the two tubes in correct position for subsequent locking by means of plastic instability and simultaneous compression locking. The process was performed in one stroke and employed two sequential forming stages. Haysmans et al. (1997)introduced prepregs for the bonding of two composite pipe sections. The prepreg tape was wrapped around the aligned pipe extremities. The prepreg based joining concept is illustrated in simplified way. Kumar et al. (2007) and Kumar and Kumar (2008) developed FRP T-joints between two pipes by winding a tow, wetted in epoxy and made of strong and stiff glass fibers, to form a tight enclosure around the joint after curing for 24 hours. Three kinds of appropriate windings, diagonal, straight and circular were used. The 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.Ramkumar et al. (2007) developed GFRP butt joints between two similar and dissimilar pipes by wrapping a balanced glass fabric in varying orientation. The glass fabric was wetted with controlled quantity of resin, wound circumferentially at the place of joining and letting it to get cured. The strength of the cold butt joints was determined by flexural bend test, fatigue test and internal pressure leak test. However, the tensile strength of the joint was not determined. Tsiafis et al. (2008) determined mechanical properties of epoxy resin by an experimental-computational procedure in tension. Tensile tests were carried out with standard aluminum tension specimens glued with epoxy resins. The stress-strain curve of the epoxy resin was determined.From the literature survey, it was realized that the butt-welding of thin tubes is difficult as there is not enough thickness available to prepare a V-groove for an efficient joining. The other methods, friction welding, magnetic pulse welding etc.require sophisticated equipment and are not suitable for a field work. Thus, it was realized that new methods should be developed to butt-join the ends of the pipes, which is simple and practical for field work. The method should also join thin tubes, no matter how thin they are. Also, the method should be able to join two dissimilar materials of very different kinds such as a metal to a polymer, a ceramic to a metal. The high stiffness and very high strength of fibers like glass and carbon should be exploited to have effective joints.The objective of this work is to develop a butt-joint between two dissimilar materials aluminum and steel pipe by placing two layers of unidirectional glass fiber at ±10°, wetted in epoxy resin, and letting it cured to form a GFRP sleeve. The butt-joint was tested for tensile strength. The schematic diagram of the specimen is shown in Figure 1.

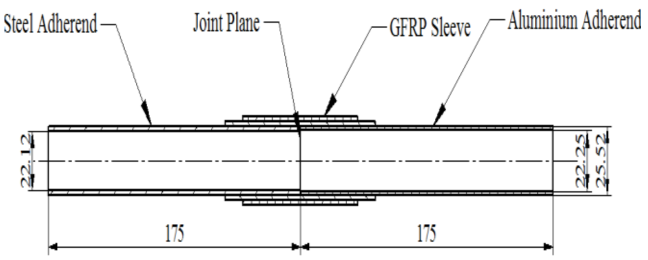

Figure 1 Tension test specimen

2. Experimental Technique

2.1 Materials

Commercially available aluminum and steel pipes were used as the adherends in this study, whose properties were: aluminum- modulus=69 GPa, Poisson's ratio=0.33, yield stress=152MPa and steel- modulus=210 GPa, Poisson's ratio=0.30, yield stress = 330 MPa.Aluminumadherend member was of 25.52 mm outside diameter, 22.25 mm inside diameter and 175 mm length, while steel adherend was of 25.52 mm outside diameter, 22.12 mm inside diameter and 175 mm length. The unidirectional glass fiber used was of 473 gsmand was purchased from Owens Corning India Limited, Raigad, India. The epoxy resin employed was Dobeckot 520F (100 parts by weight) with hardener Beck 758 (9 parts by weight) which cured the resin at room temperature. The mixture of epoxy and hardener has processing time of 25-30 minutes and it gets cured in 25-30 hours at room temperature.

2.2 FRP patch method

The butt-joint was made by placing the ends of the pipes face to face and applying patches of unidirectional glass fiber, wetted with controlled amount of epoxy at an angle ±10° along the longitudinal direction. Before winding, the surface of adherends was made rough by filing it in θ-direction (normal to the length direction) and then it was degreased by wiping the surface with acetone. A thin layer of resin hardener mixture was applied on adherend surfaces before starting the process. Two layers of unidirectional glass fiber with three patches at ±10° angle with patch on gap arrangement was used for preparing the specimens. Vacuum bagging technique which uses atmospheric pressure to hold the adhesive until it cures was used for two purposes: (i) to obtain stronger grip between FRP sleeve and adherends and (ii) to obtain higher fiber-to-resin ratios by removing excess epoxy. The FRP joint thus formed was cured for 24 hours at room temperature and further post cured for 5 hours at 80°C to ensure better polymerization.

2.3 Tensile Test

The GFRP butt-joint specimens were tested through a 10 ton UTM in which special crosshead fixtures were made to hold the adherends of 25.52 mm outer diameter. Also, to suppress the local buckling (flattening) of aluminum pipe inside the crosshead, solid cores of aluminumof diameter equal to the inner diameter of the adherend and the length of about 40 mm were inserted inside the upper and lower ends of the adherends. The specimen was loaded at a pulling rate of 0.2 mm/min till the specimen failed.

2.4 Experimental results

It was important to develop adequate adhesion between the adherends and the GFRP sleeve. After many alternative trial and errors, it was found that good adhesion was developed when two layers of unidirectional glass fiber with three patches at ±10° angle with patch on gap arrangement was employed.

The experimentally obtained result using UTM for one of the specimens is as shown in Figure 2.

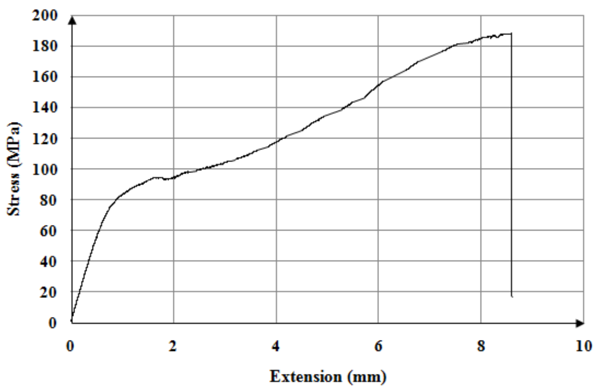

Figure 2 Stress vs extension graph

A peak stress of 190.56 MPa was taken by the specimen after that the specimen failed. Total 4 specimens were tested with an average value of peak stress was found to be 175 MPa. The failure of the specimen was such that aluminumadherend slipped out of the GFRP sleeve at the interface. A slipped specimen of tensile test is shown in Figure 3.

Figure 3 Slipped GFRP sleeve over aluminum adherend

3. Numerical techniques

3.1 Tension Test Specimen

For the numerical analysis the thickness of epoxy layer between the adherends and the sleeve was taken as 0.1 mm. The thickness of ±10º plies was 0.72 mm for the FRP joint. For the analysis of tension test specimen, one end of model was fixed and at the other end, critical tensile stress σ^{∞} was applied. For the simulation of a tensile test in ANSYS, plane183 element was used. It is a 2-Dimensional 8 noded higher order structural element. The 2D axisymmetric geometry model was then meshed, in which aluminum thickness was divided into 12 concentric layers, epoxy thickness in single layer and ±10° sleeve in 8 layers. Along the length of the specimen, 0.02 mm long elements were generated for 20 mm distance from the joint plane (JP) and beyond this distance 0.1 mm long elements were employed.

3.2 Results and Discussion

The applied load considered for the numerical study σ^{∞}, was 160 MPa which was more than the yield stress of weaker parent material, aluminum, 152 MPa. Elastic-plastic properties were used for aluminum and steel. In addition, highly non-linear stress-strain relation of epoxy was considered in the analysis. It was worth noting that epoxy fails at very high strain of 0.42 and, therefore, the failure of epoxy was unlikely.A part of axial stress σ^{∞}, applied to adherend ends, was transferred to the GFRP sleeve at its leading edge. It was carried out by a shear stress peak developed between the adherends and GFRP sleeve. The axial stresses in the adherend and the FRP sleeve were stabilized after a short distance. Similarly, axial stress in the adherend was completely transferred to the GFRP sleeve close to JP. However, in the middle portion of an adherend which was far away from the sleeve's end and JP, stabilized axial stresses in the adherend and the sleeve were attained. They were found by realizing that the adherend and the sleeve were elongated by the same strain.

The analysis near the joint plane was found to be more complex. As the GFRP sleeve was only on one side, neutral plane locally was no longer at the middle thickness of the pipe, but it moved out towards the sleeve. At the joint plane, the entire force was taken by GFRP portion of the strip. Consequently, a bending moment acted on the GFRP portion. The stresses developed due to bending moment were imposed on direct axial stress. Thus, the tensile stress was highest at the interior surface of GFRP material and lowest at the outermost region of GFRP sleeve.

The shear stress at the interface, exactly at the joint plane was found to be maximum, 34.6 MPa. The shear stress, developed at the interface was found prominent in the region of 15 mm from the joint plane in both, aluminum and steel pipe. Comparative curve showing development of shear stress at the interface in both aluminum and steel is shown in the Figure 4. Shear stress developed in both aluminum and steel was observed to be same at the joint plane as upper limit of shear stress was controlled by the flow stress in epoxy layer which deformed easily at high strain.

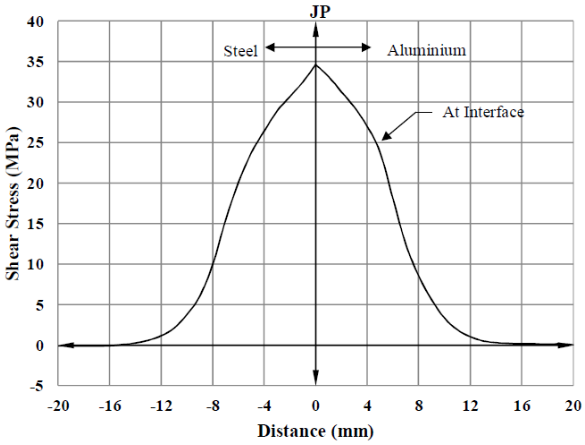

Figure 4 Shear stress (σ_{rz}) in aluminum and steel adherend at its outer surface near JP.

The axial stress developed in aluminum and steel pipe is shown in Figure 5. The compressive stress was developed in inner side of both aluminum and steel. The highest value of compressive stress in aluminum was -9.7 MPa at a distance of 1 mm from JP. Whereas, in steel pipe, it was -94.1MPa at a distance of 2.25 mm from JP. On the outermost surface of both aluminum and steel the tensile stress was developed. The maximum tensile stress developed in aluminum was 155.7 MPa which is higher than yield stress of aluminum, caused the plastic deformation in the outermost layer. The maximum value of tensile stress developed in steel pipe at outermost layer was 214.4 MPa, which is less than yield stress, 330MPa of steel pipe. At the joint plane, axial stress in both the pipe was reduced from maximum value to zero, being free ends.

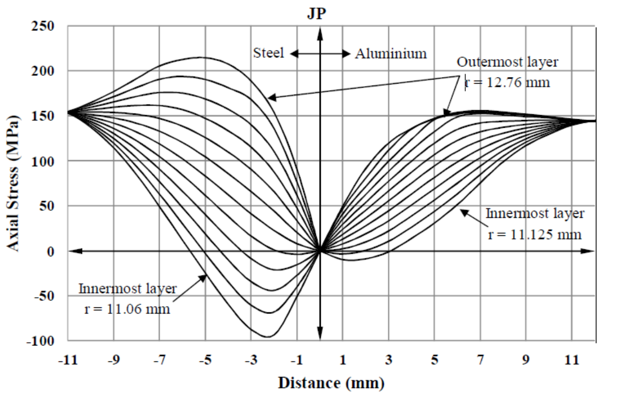

Figure 5 Axial stress (σ_{zz}) within the aluminum and steel adherend through the thickness of the specimen

Axial stress distribution in ±10° GFRP sleeve is shown in Figure 6. The maximum value of axial stress developed in the innermost layer at JP was 438.1 MPa which was less than the strength of GFRP sleeve. Thus GFRP sleeve did not break at JP. Instead of breaking of GFRP sleeve at JP, specimen was failed by slipping out of an aluminum pipe from GFRP sleeve, due to combine effect of high shear stress and high tensile radial stress at the interface.

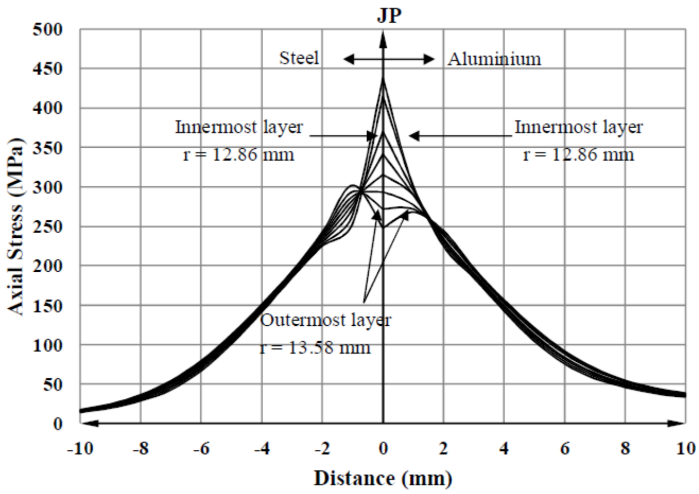

Figure 6 Axial stress (σ_{zz}) distribution within ±10º GFRP portion of a specimen

The comparative radial stress distribution in both the aluminum and steel pipe is shown in the Figure 7. The high radial stress 61.3 MPa and high shear stress of 34.6MPa were developed at the interface of aluminum and epoxy. At such high stresses, epoxy probably failed causing initiation of crack at the interface which propagated further and finally aluminum pipe slipped out. Beyond this any further increase in stiffness ratio was not affect the strength of the joint. The maximum radial stress developed at the interface in steel pipe was found comparatively less than in aluminum. Hence such type of separation was not observed in steel pipe. Instead compressive radial stress was developed, which holds the steel pipe and restricts the slipping out of steel pipe from the sleeve.

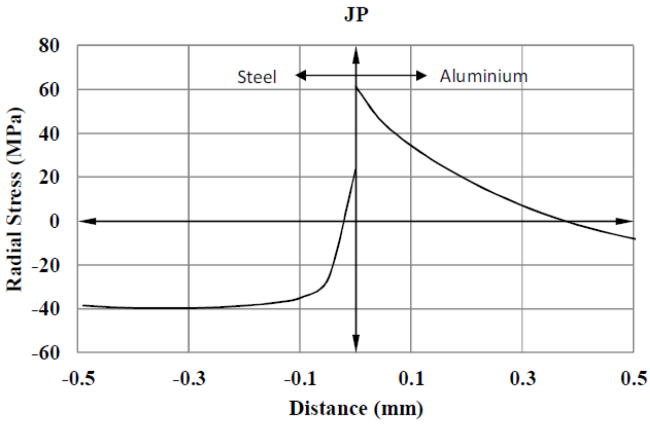

Figure 7 Radial stress (σ_{rr}) at the interface of the specimen near joint plane.

In numerical analysis, it also showed the generation of pinching effect near the joint plane. Due to pinching effect, inside surface of aluminum pipe moved in by 27.77 µm and outer surface of GFRP by 29.52 µm. This pinching effect supported the slipping out of aluminum from GFRP sleeve. The pinching effect was not prominent in case of steel pipe; hence did not support for slipping to that much extend as in aluminum.

4. Conclusion

A GFRP butt-joint was formed between two adherend,aluminum (outside diameter of 25.52 mm and inside diameter of 22.25 mm) and steel (outside diameter of 25.52 mm and inside diameter of 22.12 mm). The GFRP butt joint was prepared by placing the ends of the aluminum pipe and steel pipe face to face and applying two layers of unidirectional glass fiber at ±10° angle along the longitudinal length of adherends with controlled quantity of epoxy to obtain the GFRP sleeve around the joint plane and allowed it to get cured at room temperature for 24 hours. Thus, after curing, GFRP sleeve was formed over the both adherends which was further kept for post curing at a controlled temperature of 80°C for 4-5 hours. For the characterization of GFRP butt-joint, this joint was subjected to tensile test. With double layer patch on gap configuration at ± 10°, the maximum axial stress in the bare portion of aluminumadherend was found to be 190.6 MPa, higher than yield stress of aluminum.The axial stress developed in steel adherend was found to be less than the yield stress of steel adherend, 330 MPa.The specimen with double layer GFRP sleeve was found to be failed through the slipping out of aluminumadherend from GFRP sleeve when tensile load was applied. Failure of the specimen took place due to combine action of high tensile radial stress and high shear stress at the interface. Afterwards, any further increase in number of layer will not be found useful as stress developed in aluminumadherend was found to be higher than the yield stress of one of the parent material, aluminum, 152 MPa. Thus the joint with double layer GFRP sleeve was quite strong.

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