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Friction welding of Cu-tube to Al-tube plate using an external tool

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Abstract

In the present study, friction welding of tube to tube plate using an external tool (FWTPET) was used to weld copper tubes with aluminum plates. Tubes were prepared with holes along the faying surfaces of tubes and cleaned before welding. The weld microstructure shows line of stir zone (SZ), a narrow thermo mechanically affected zone and heat affected zone (HAZ). The welded samples were found to have satisfactory joint strength and the XRD study showed the presence of AlCu intermetallic in the weld zone. The hardness survey revealed that there was a slight increase in hardness adjacent to the weld interface due to grain refinement. Better weld joints were achieved when the tool rotation speed and interference are 1500 rpm and 0.8 mm respectively. The present study confirms that a high quality copper tube to aluminium tube plate joint can be achieved by FWPET process.

1. Introduction

Friction welding is solid-state welding process i.e. material that is being welded does not melt and recast. Due to friction intensive heat generated at the interface, the material reaches the softened or plasticized state which interacts with each other and produces a good quality weld. However, friction welding is not suitable for welding of tube to tube plate. The process of friction welding of tube to tube plate using an external tool (FWTPET) was invented in the year 2006, by one of the present author [1]. One of the interesting characteristics of FWTPET is that its capability to produce high quality leak proof joints [1-3]. Compared to with traditional tube to tube plate welding techniques, it is an energy efficient, environment friendly and versatile process [3-6]. In the present work FWTPET is used for welding Cu-tube to Al-tube plate at different process parameters. Important process parameters of FWTPET process are found as tool rotation speed (in rpm), tool shoulder diameter and interference between the tool pin and the tube.

Copper and aluminum are widely used in industries due to their excellent electric conductivity, heat conductivity and corrosion resistance. The joining of dissimilar metals is generally more challenging than that of similar metals because of difference in the physical, mechanical, thermal and metallurgical properties of the parent metals. In order to take full advantage of the properties of different metals it is necessary to produce high quality joints between them [6-8].

Joining of Cu-tube with Al-plate by fusion is not feasible due to a large difference in melting point (nearly 400p C) and it also may lead to formation of complex intermetallics. Also, aluminum is easily oxidized at elevated temperature and prone for cracks during fusion welding [8-10]. Literatures on welding of Cu tube to Al tube plate are scant. The aim of present study is to obtain the high quality weld between Cu-tube to Al- tube plate by FWTPET. Further, the slices made from the dissimilar tube to tube plate joint can be used as transition joints in electrical and electronics industries.

2. Experimental setup

2.1 FWTPET process

An in-house developed FWTPET arrangement used in the present study is shown in Fig. 1. The FWTPET machine configuration consists of a motor, spindle, tool holder, table and supporting structure. FWTPET tool consists of body,

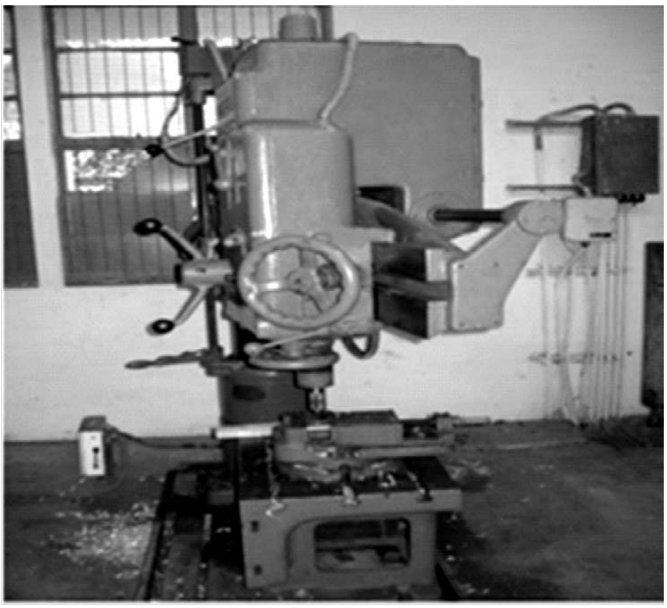


Fig. 1 : FWTPET machine (Developed in-house)

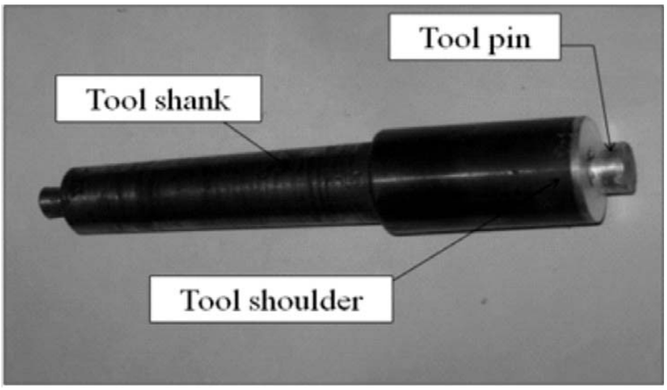


Fig. 2 : Tool used for FWTPET process

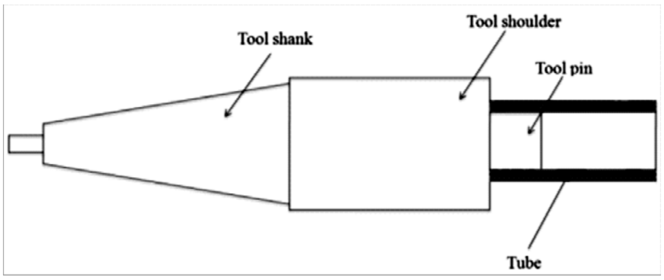


Fig. 3 : Tool inserted inside the Cu-tube

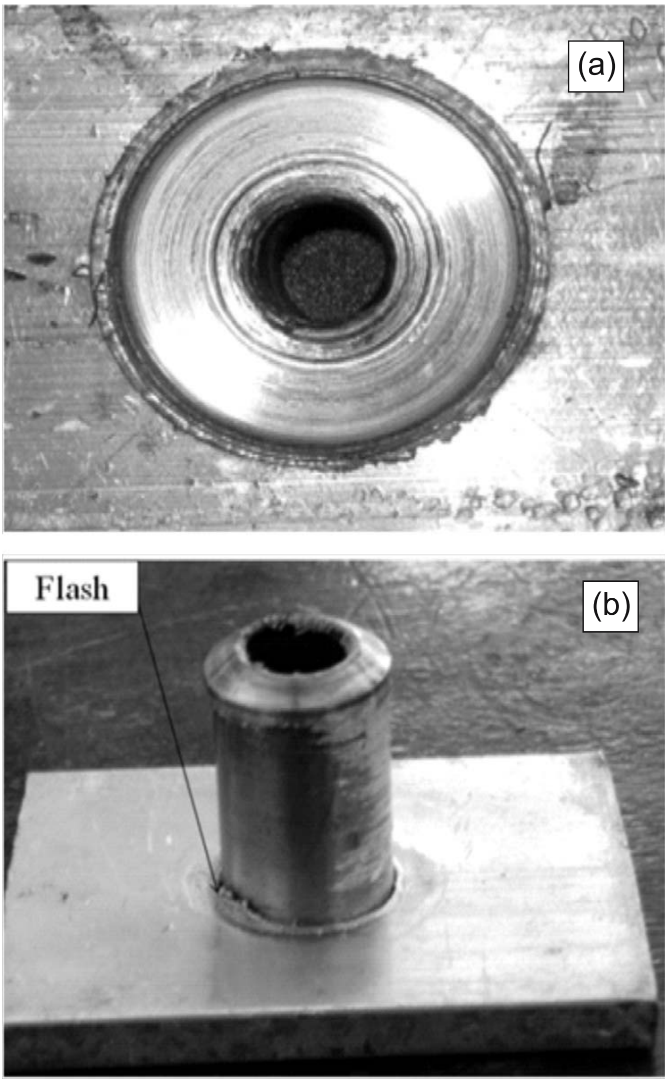


Fig. 4 : Cu tube to Al tube plate joint obtained by FWPET process. (a) Bottom view ; (b) Side view

shoulder and pin as shown in Fig. 2. In the present study commercially pure Cu-tube is welded with commercially pure Al-tube plate by FWTPET process. The thickness of the Al-tube plate and the Cu-tube inner diameter are 6 mm and 15 mm respectively. The tool pin is inserted inside the tube before welding by shrink fit method as shown in Fig. 3. The shoulder diameter of the tool is chosen as 30 mm for all the experiments.

The tubes are then cleaned and washed with acetone and holes are drilled along the faying surfaces of the tube. A hole is drilled using a drill bit (before inserting the pin) and the plate is fixed in the machine table by using fixtures to restrict its movement. Tool with the tube assembly is fixed with tool holder and properly aligned with the drilled hole of the plate. The tool is lowered while in rotation and the shoulder is made to touch the plate surface. The arrangement is kept for few minutes and the tool is withdrawn. The tube rotates with the tool and heat is generated along the faying surfaces due to friction. The rotation ceases when the braking force offered by the plate exceeds the force due to hoop stress between the pin and the tube. The impurities come out as a flash and bonding between fresh surfaces takes place. The welded plate is removed and the above steps are repeated with different combination of process parameters. A joint obtained is shown in Fig. 4. The above steps are repeated at different process parameters and the process parameters adopted are given in Table 1.

Table 1 : Different welding conditions for FWTPET process.

Welding condition	*Process Parameters*		
	Tool rotation speed(in rpm)	*Pin diameter (in mm)*	*Interference (in mm)*
1	1500	15.8	0.8
2	1030	15.8	0.8
3	1500	15.6	0.6
4	1030	15.6	0.6
5	1500	15.4	0.4
6	1030	15.4	0.4

2.2.1 Analysis of hoop stress and pressure developed on the wall of tube after inserting the tool pin inside the tube.

Formula used:-

Hoop strain (ε) = change in dimension of tube / actual dimension of tube

Hoop stress (δ_h) = E x ε

Also, Hoop stress (δ_h) = $(P \text{ x } d)/2t$

So, Pressure developed (P) = $(\delta_h \text{ x } 2t)/d$

Calculated values of hoop strain, hoop stress and pressure developed is tabulate in Table 2.

The maximum hoop stress is developed or induced in tube wall with S.No. 3 (i.e. condition 1 & 2).

The welded samples are cut into small pieces for macrostructural and micro structural studies. The rough scratches are polished using a belt grinder. Fine scratches

Table 2 : Hoop stress and pressure developed at different interference fit conditions.

S.No.	*Interference (in mm)*	*Hoop strain due to interference*	*Pressure developed (p) between tube and pin (in MPa)*	*Hoop stress (σ) developed in tube wall (MPa)*
1	0.4	0.027	2.7×10^3	0.72×10^3
2	0.6	0.040	4×10^3	1.07×10^3
3	0.8	0.053	5.3×10^3	1.42×10^3

are then removed by using different grades of emery sheets. Further polishing is done on disc polishing machine using alumina powder followed by diamond paste. The prepared surface is etched by Tucker's reagent (composition: 4.5 ml HNO_3, 2.5 ml H_20, 1.5 ml HCl, 1.5 ml HF) for macrostructural analysis. Joint strengths are found out by using a tensometer and the setup is shown in the Fig.5.

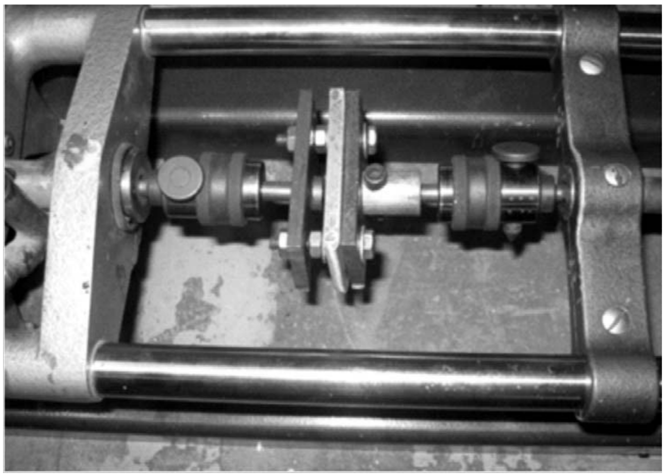


Fig. 5 : Specimen loaded in a tensometer.

The hardness is measured from plate to tube through the transition boundary (TA). A specimen is prepared along the interface and XRD analysis is performed. Vickers micro-hardness measurements are performed on both the cross- and longitudinal sections of the welds using a micro-hardness tester at a 500-g load and a 15-s dwell time. Micro hardness is measured at different location across the bond interface. Samples are prepared for the XRD analysis and the phase structures of dissimilar (aluminum /copper) welds are studied using the XRD system with 40-Kv operating voltage and Cu K_α radiation. A scanning program with a step scanning rate of 0.04^o mm^{-1} was employed to determine the peak positions of different phases in the range of $10^o<2\theta<100^o$.

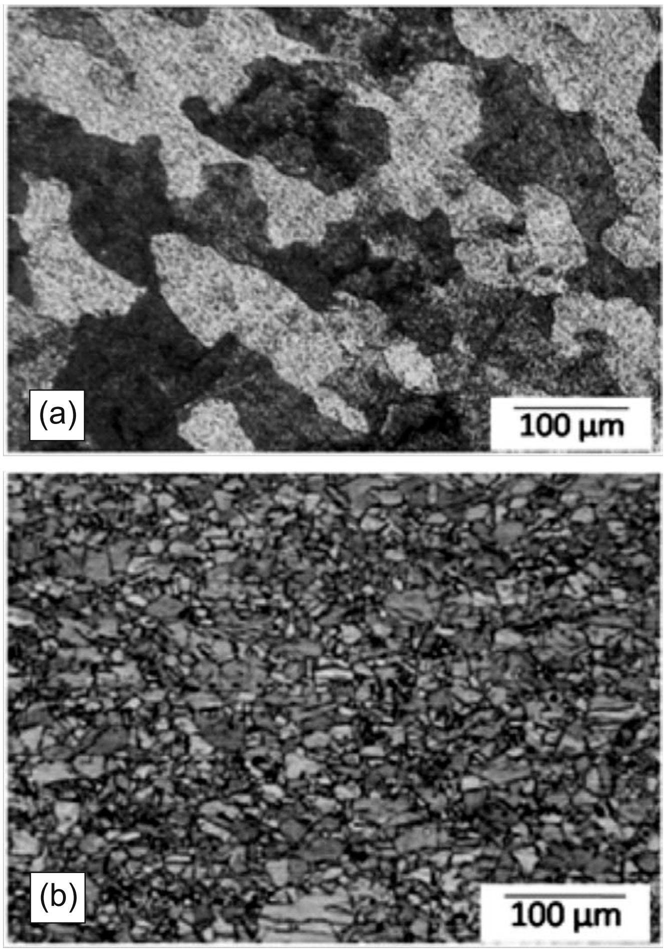


Fig. 6 : (a) Aluminum plate microstructure; (b) Copper tube microstructure.

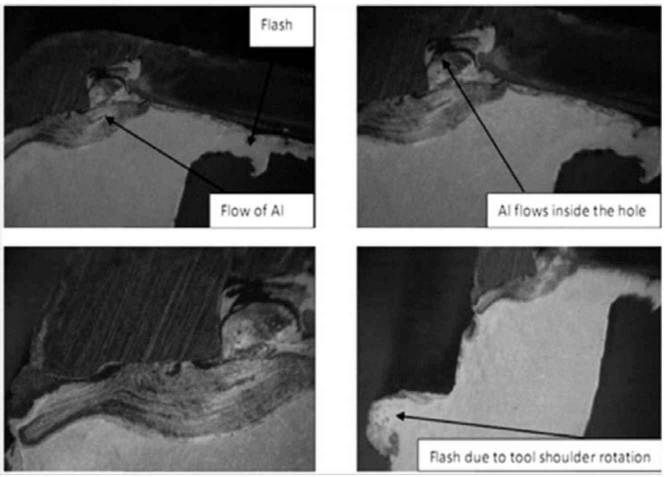


Fig. 7. Macrostructures of weld.

3. Result and discussion

The sample prepared for macro structural studies are washed, dried and observed under a metallurgical microscope. Al-tube plate microstructure and Cu- tube microstructure are shown in Fig. 6 (a) and (b) respectively. The bond interface is found to be defect free and macrostructures are as shown in Fig.7. The metal flow pattern and flash formation are clearly seen in the macrostructure. The aluminium occupies the holes in the copper and provides mechanical inter locking as shown in Fig. 8(a). The weld interface is shown in Fig. 8 (b) in which aluminium and copper sides are clearly seen. The FWPET weld consists of a narrow stir zone (SZ) followed by narrow thermo-mechanically affected zone (TMAZ) and heat affected zone (HAZ) as shown in Fig.9 (a) and (b). Metal flow pattern and elongated grains along the direction of rotation are observed in the TMZ.

The different zones have been observed in the dissimilar FWTPET process. When compared to base metal, the TMAZ and HAZ are found to have fine grains due to severe plastic deformation during FWTPET process.

A mixed zone is formed at the interface during dissimilar FWTPET process at some locations as shown in Fig. 9. It is clear that at the interface refined mixing of aluminium and

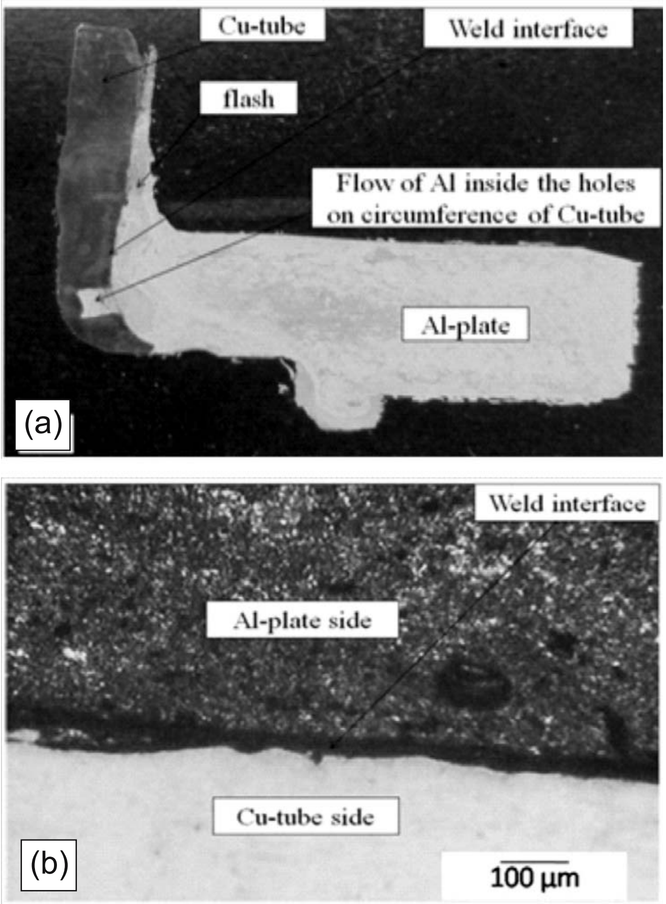
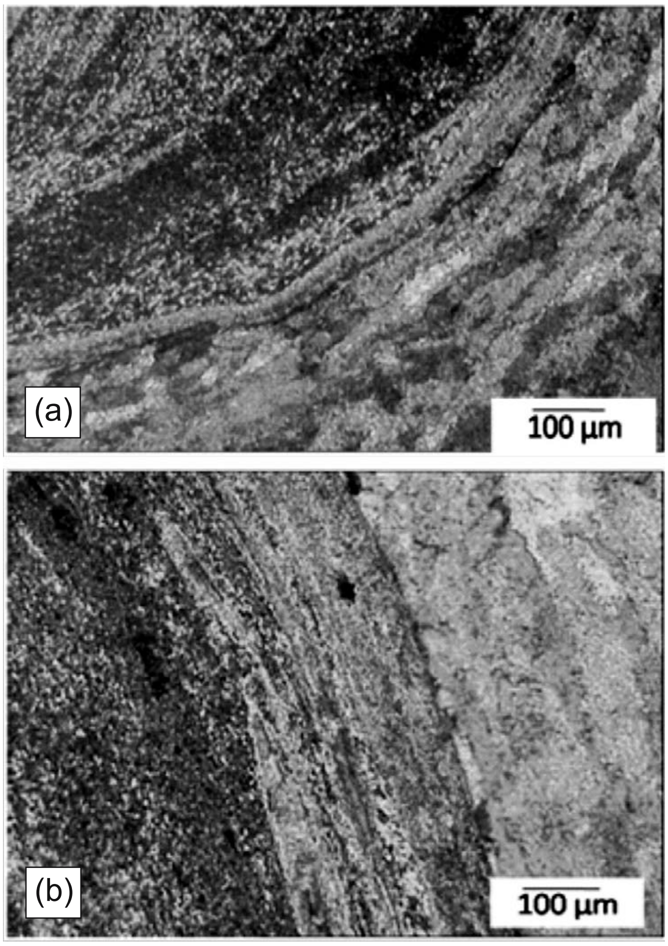


Fig. 8 : (a) FWPET Macrostructure; (b) Weld interface.



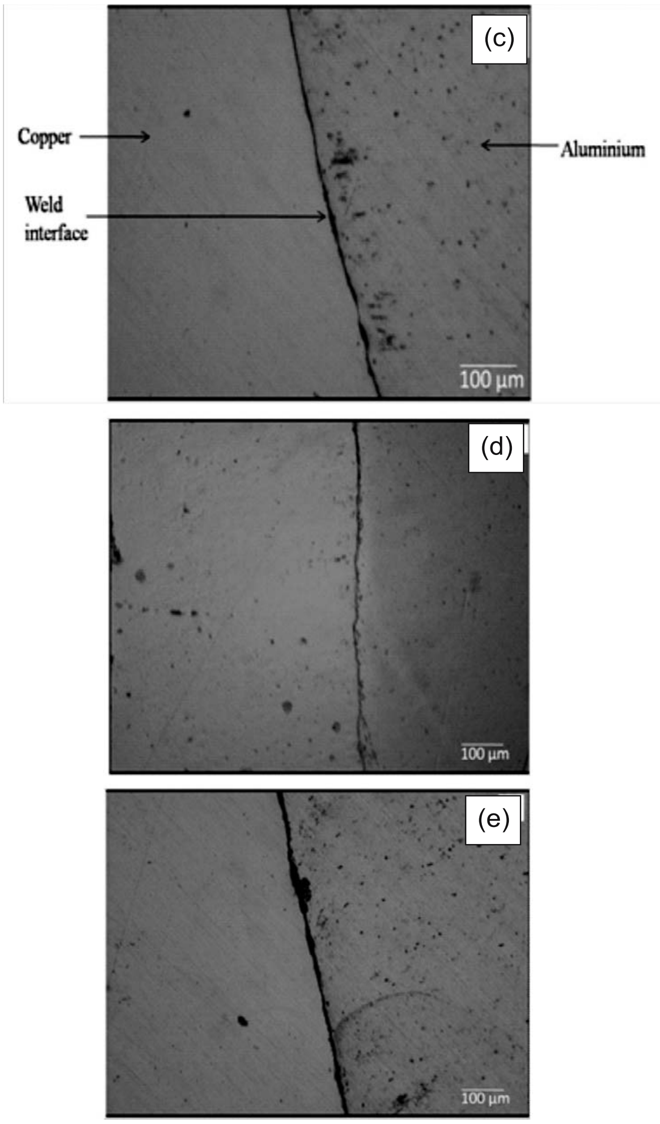


Fig. 9 : Weld interface microstructure at different locations.

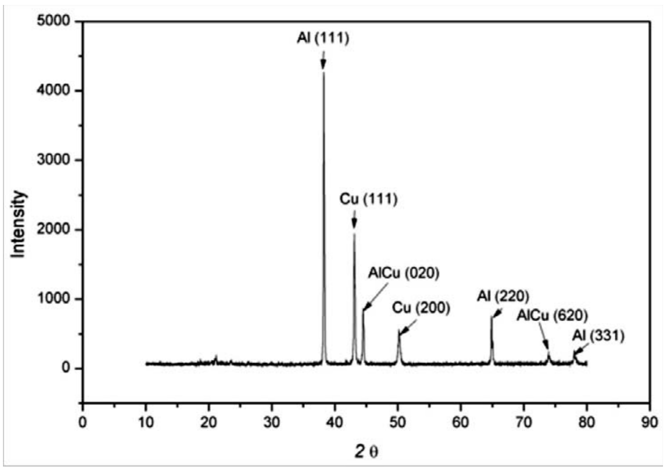


Fig. 10 : XRD plot for weld interface zone

copper during FWTPET process. However, the weld interface is found to have both aluminium and copper compound after FWTPET process. The intermetallic compounds have been identified by XRD analysis.

A XRD sample is prepared along the weld interface and the test result confirms the presence of AlCu intermetallic along the interface in addition to parent metals (Fig. 10). The experiment is repeated and the formation of AlCu is confirmed along the bond interface. The XRD patterns clearly indicate the formation of AlCu intermetallic during dissimilar welding of FWTPET process. The area of the highest AlCu intensity peak is calculated to find the volume fraction based on schirerr formula. The amount of volume fraction actually formed in AlCu, Al and Cu is 15.66%, 51.34% and 32.99% respectively.

Table 3 : Joint strength results for all different welding conditions.

S. No.	*Conditions*	*Joint strength (in MPa)*
1.	1	148
2.	2	138
3.	3	134
4.	4	133
5.	5	129
6.	6	115

Three samples are prepared in each condition and the average joint strength results are tabulated in Table.3 and curve plotted for joint strength for welding condition with 1030 rpm and 1500 rpm tool rotation at different interferences are shown in Fig.11 (a) & (b) respectively. The strength is found to increase with the increase in tool rotational speed. The results show that the maximum strength is achieved at the higher interference in all the three cases. At higher interference, a higher pressure is induced and this causes maximum frictional force and hence, a better flow of plasticized metal is possible. However, interference more that 0.8 mm could not be achieved due to machine constrain. A maximum value of joint strength is observed with Condition 1(i.e. 1500 rpm, 0.8mm interference and 30 mm shoulder diameter).

Samples are prepared for the hardness measurement from the weld obtained of six different process parameters. The

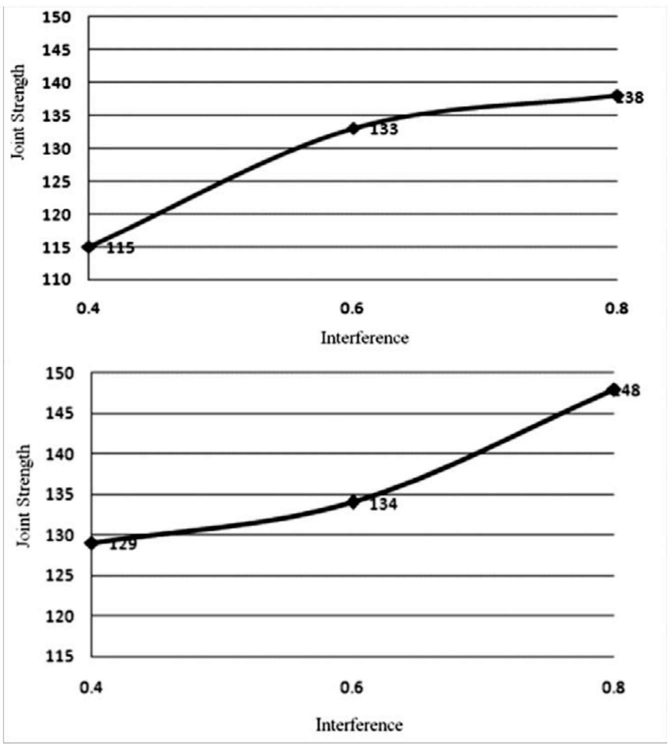


Fig. 11 : (a) Joint strength plot for welding condition with 1030 rpm tool rotation; (b) Joint strength plot for welding condition with 1500 rpm tool rotation.

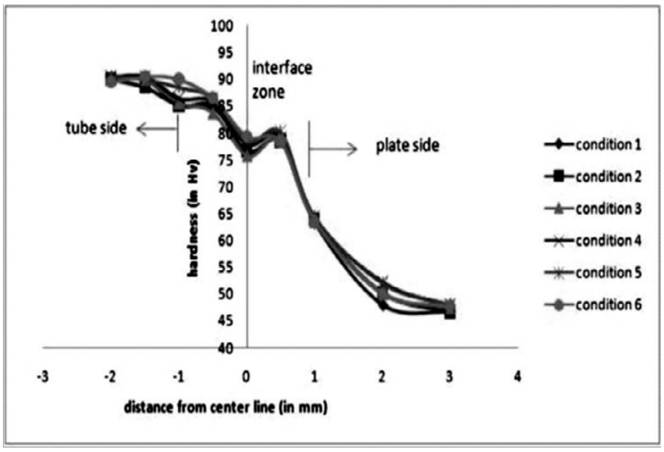


Fig. 12 : Vickers hardness plot for all welding conditions.

hardness values are measured transverse to the weld interface and the obtained values are plotted and shown in Fig. 12. All the welds shows more or less similar hardness plot irrespective of change in process parameters and there is slight increase in hardness adjacent to the weld interface. This increase in hardness is due to grain refinement in the HAZ.

4. Conclusion

FWTPET process with interference fit method is a novel solid state joining method to weld tube to tube plate. This process is capable of producing high quality tube to tube plate weld joint for dissimilar metals with enhanced mechanical and metallurgical properties. The maximum observed joint strength of Cu tube to Al tube plate joint is 148 MPa with process parameters; tool rotation, interference and shoulder diameter of 1500 rpm, 0.8mm and 30mm, respectively. It is also observed from joint strength results that the higher interference value and tool rotation speed produces the weld having better joint strength. From hardness profile it is clear that the hardness adjacent to the weld interface is slightly higher than at the interface for all weld condition. Formation of AlCu intermetallic compound is observed along the joint interface. The present study is a preliminary and a detailed studies need to be carried out to exploit the industrial potential of the FWPET process.

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