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TECHNICAL ARTICLE

Suitability of Friction Welding of Tube to Tube Plate Using an External Tool Process for Different Tube Diameters—A Study

S. Senthil Kumaran, S. Muthukumaran, and C. Chandrasekhar Reddy

Department of Metallurgical and Materials Engineering, National Institute of Technology, Tiruchirappalli, Tamil Nadu, India

Keywords
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Correspondence
S. Muthukumaran,
Department of Metallurgical and Materials Engineering,
National Institute of Technology,
Tiruchirappalli 620015, Tamil Nadu,
India
Email: smuthu@nitt.edu

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Abstract

During the past few decades, the field of welding technology has been witnessing tremendous challenges. Welding is an important metal fabrication process that has high potential for industrial applications. Friction welding is a vital solid state joining process that has gained popularity in welding non-weldable alloys. Friction welding of tube to tube plate using an external tool (FWTPET) is an innovative friction welding process that has been invented in the year 2006. FWTPET is capable of welding tube to tube plate of similar or dissimilar metals and is capable of producing good-quality leak-proof weld joints. In this work, four different tube diameter conditions in FWTPET welding have been studied. Macrostructural and microstructural studies have been conducted and they reveal the weld configuration that is susceptible to defect formation. Hardness and tensile strength of four different tube diameter preparations have been analyzed. The present study leads to the production of defect-free weld joints which have numerous industrial applications.

Introduction

In the past few decades, the field of materials processing technology has been witnessing tremendous improvements. Welding is an important metal-joining process that has varied applications across several industrial sectors. Friction welding is a solid state welding process that produces weld under the action of compressive forces, contact of rotating work pieces moving relative to one another so as to produce heat by means of controlled rubbing of faying surfaces. Friction welding has gained popularity because of several advantages and one among which is to weld alloys that cannot be welded otherwise. The unique feature of friction welding process is that the material that is being welded does not melt and recast. Due to the intensive heat generated at the interface, the material reaches the softened state which interacts with each other and produces good-quality weld.[1] To produce good-quality weld joint, it is vital to set proper welding process parameters. Generally, the welding process is a multi-input and multi-output process in which there exists a close relationship between the quality of joints and the welding parameters. This process of identification of suitable combination of input process parameters so as to produce the desired output parameters necessitates several experiments to be conducted which is a time-consuming task and consumes significant amount of cost. Several efforts have been taken to understand the effect of process parameters on material flow behavior, microstructural formation, and mechanical properties of friction welded joints.[2,3] As a milestone in the field of friction welding, 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 authors and a patent was granted in the year 2008.[4] This process is capable of welding tube to tube plate of similar or dissimilar metals. Major advantages of this process include capability to join dissimilar metals that can take any dimension. However, in the case of friction welding, only shorter work pieces can be joined. Joints made by FWTPET process exhibit enhanced mechanical, metallurgical properties with lesser energy consumption. Important process parameters of FWTPET include tool rotational speed, shoulder diameter, and clearance between pin and tube. In this research work, tube is prepared with four different diameter conditions and FWTPET welding process has been carried out. The macrostructural and microstructural studies have been conducted for four different tube diameter weld joints, followed by the measurements of hardness and tensile strength.

Experimental Procedure

FWTPET process

The FWTPET machine developed in-house is shown in Fig. 1. The external tool consists of a shoulder and pin which is shown in Fig. 2. The tube to be welded is cleaned and holes or slots are prepared along the faying surface of the tube. A suitable hole is drilled in a plate and the tube is fitted and assembled in FWTPET machine table. The FWTPET machine consists of tool holder, spindle, table, and supporting structure. The tool is lowered while in rotation and heat is generated due to friction when the shoulder touches the plate. The plastic flow of metal takes place toward the center of the tool axis. The metal flows through the holes in the tube and occupies the gap between pin and inner diameter of the tube. The tool is withdrawn after predetermined time. The material movement is restricted by the cylindrical pin, and forging of metal takes place between the tube and the plate.[5–7] Due to the combined effects of high pressure and temperature between the faying surfaces of tube to tube plate, a good metallurgical bond is occurred.[6–9] Both the tube and plate used in the present study are made of commercially pure aluminum and their chemical composition is shown in Table 1. Commercially pure rolled aluminum plates of 6 mm thickness are cut into the required size (50 mm × 70 mm) using a power hacksaw and suitable external diameter tubes have been cut into required sizes. Then suitable diameter holes according to the tube condition are drilled in the center of the plates. Tool used in the present study is made of tool steel for fabricating FWTPET joints. The backing block employed in FWTPET process is shown in Fig. 3. The assembled work piece is fixed on the machine table with the fixtures and the tool has been fixed to the spindle.

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AQ1 **Figure 1** FWTPET machine (developed in-house).

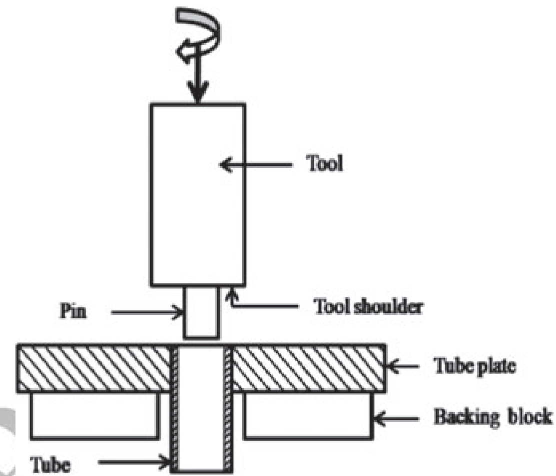


Figure 2 FWTPET set up.

Experimental investigation of four different tube diameter conditions

Four different tube conditions used in the present investigation are shown in Table 2. The above four types of different diameter tube preparations are

Table 1 Chemical composition of parent metal

	Element									
	Al	Si	Fe	Cu	Mg	Mn	Ti	Zn	Cr	V
Wt%	Bal	0.0006	0.0007	0.0013	0.0021	0.0001	0.0001	0.0002	0.0001	0.0001

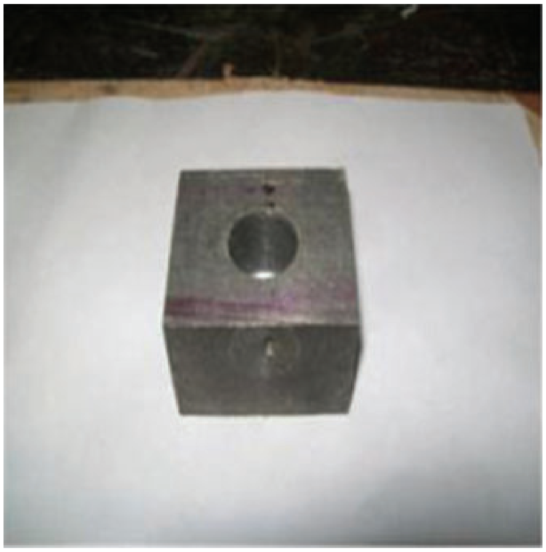


Figure 3 Backing block used in FWTPET process.

Table 2 Tube diameter values

S.no	Tube Conditions	Tube projection values
1	Condition 1	Tube external and internal diameters of 19 and 15.5 mm ($t = 1.75$ mm)
2	Condition 2	Tube external and internal diameters of 16 and 14 mm ($t = 1$ mm)
3	Condition 3	Tube external and internal diameters of 11.61 and 10.5 mm ($t = 0.55$ mm)
4	Condition 4	Tube external and internal diameters of 9.15 and 7.5 mm ($t = 0.82$ mm)

shown in Fig. 4. The assembly of all four tubes and plates before welding and insertion of four tubes into four plates are shown in Fig. 5. The four types of different tubes are cut into required sizes using a hack saw. To remove oxide film on the faying surfaces, both the tubes and tube plates are cleaned with wire brushes and washed in acetone solution before welding. The tubes are assembled into the tube plates and the process parameters used in the present investigation are tool rotational speed, shoulder diameter, feed rate, and pin clearance, whose values are 1030 rpm, 30 mm, 0.2 mm/min, and 1 mm, respectively. For all four tube diameter preparations, the welding has been carried out using the above-mentioned process parameters and FWTPET joints after welding are shown in Fig. 6. Joints are prepared for tensile test and the tests have been conducted using a tensometer. A tensile test specimen fixed in the tensometer is shown in Fig. 7.

Macrostructure studies

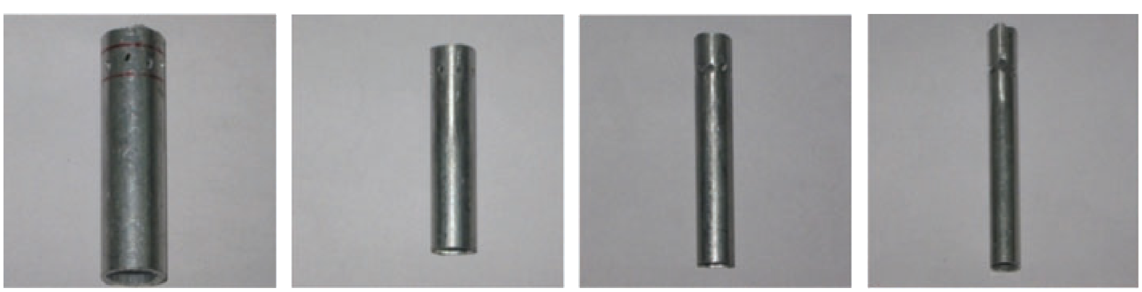
After the completion of welding, the tube to tube plate joints are sliced for macrostructural studies. The rough scratches on the surfaces have been removed using a belt grinder. The fine scratches have been removed using emery sheet of different grades and further polishing is done using alumina and diamond paste by using a disc polishing machine. This is followed by the etching using tucker's reagent (composition: 4.5 mL HNO_3, 2.5 mL H_2O, 1.5 mL HCl, 1.5 mL HF) in order to see the macrostructure. Then the samples are washed, dried, and observed in a microscope.

Microstructure studies

The microstructure aspects of the friction welded joints are studied through optical microscopy. The integrity of joints has been analyzed through the micrographs at the weld zone. The Keller's etchant has been used for microstructure studies (composition: 2 mL HF, 3 mL HCl, 5 mL HNO_3, 190 mL distilled water).

Results and Discussions

The hardness has been measured for the welds obtained with four different tube diameter preparations using Vicker's hardness tester. The hardness



(a) (b) (c) (d)

Figure 4 Photograph of tube corresponding to conditions 1–4.

(a) (b)

Figure 5 Assembly of tubes and plates before welding.

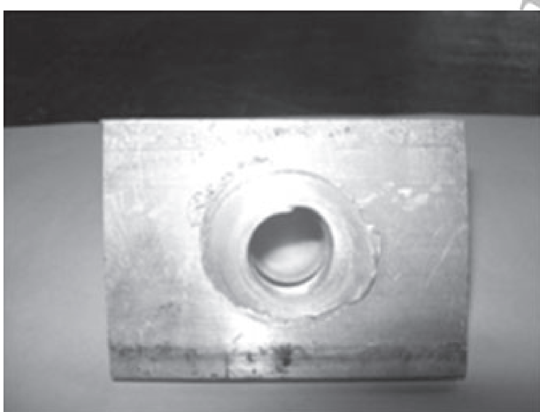


Figure 6 Bottom view of tube to tube plate weld joint.

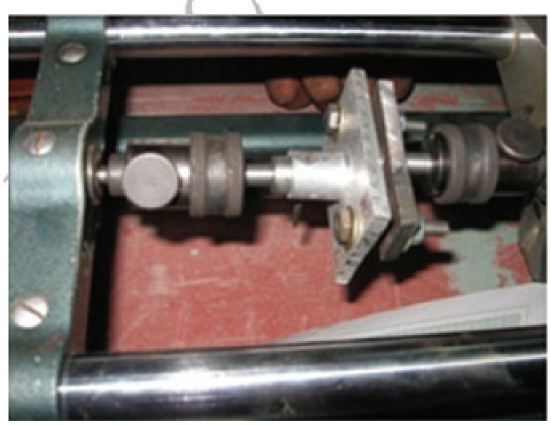


Figure 7 Tube to tube plate joint loaded in a tensometer.

has been measured at three different positions in tube, as well as in the tube plate and three different positions in weld interface area, and the results are shown in Fig. 8. Then the average of those values

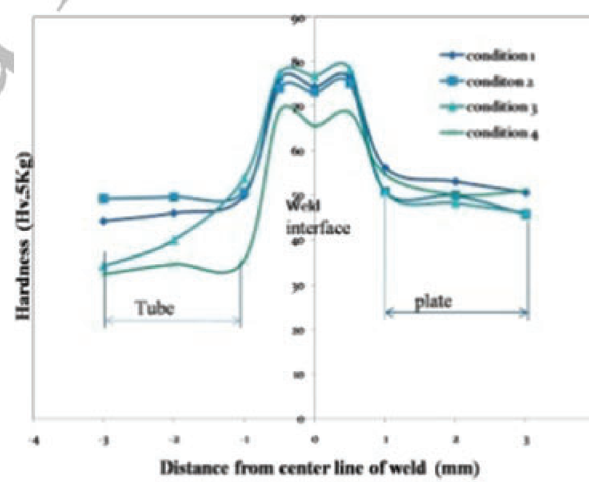


Figure 8 Graph drawn between hardness and distance from centreline of the weld.

has been taken and presented in Table 3. The tensile test sample (prepared from condition 1) before and after testing are shown in Figs. 9 and 10, respectively. Some of the specimens have fractured away from the joint as shown in Fig. 10 and hence maximum tensile strength has been achieved by the FWTPET process. Table 4 shows tensile strength for four different weld conditions. The macrostructural observation

Table 3 Hardness measurement for different diameter tube weld conditions

S. no	Weld condition	Tube (H_v)	Base metal (H_v)	Interface (H_v)
1	Condition 1	50.60	50.70	73.22
2	Condition 2	42.95	50.87	74.48
3	Condition 3	47.27	50.46	76.88
4	Condition 4	34.17	51.0	65.48

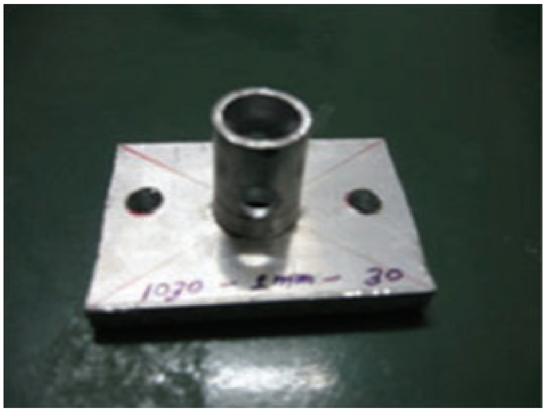


Figure 9 Tensile test sample.

Figure 10 Fractured tensile test sample.

Table 4 Values of tensile strength for different diameter tube weld conditions

S. no	Tube condition	Tensile strength (MPa)
1	Condition 1	78.61
2	Condition 2	81.18
3	Condition 3	99.24
4	Condition 4	50.01

pertaining to four different tube diameter weld conditions are shown in Figs. 11–14. Based on the macrostructural observation, it is found that the weld conditions 1, 2, and 3 can produce defect-free welds, whereas weld condition 4 is susceptible to defects as shown in Fig. 14. Weld condition 4 is more prone to defect when compared to other weld conditions due to insufficient bonding between tube and tube plate. The variation of hardness and tensile strength for four different weld conditions are shown in Fig. 15. Based on the inferences from Fig. 15, it has been found that

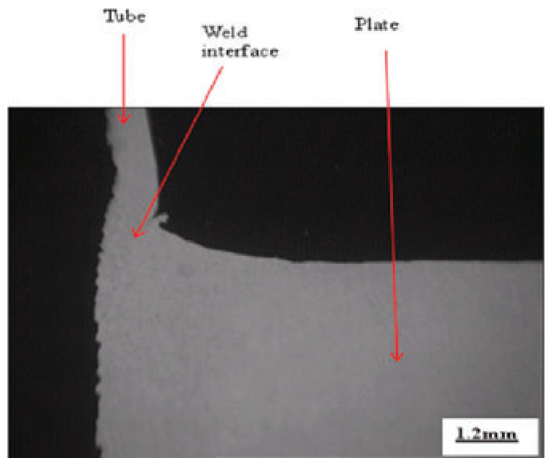


Figure 11 Condition 1.

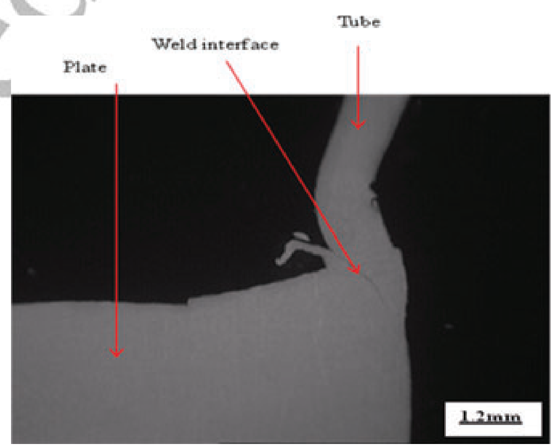


Figure 12 Condition 2.

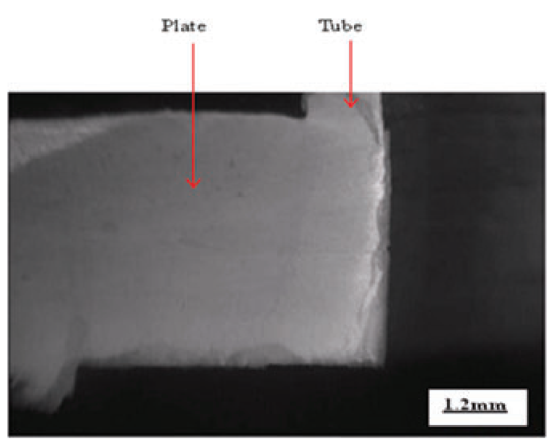


Figure 13 Condition 3.

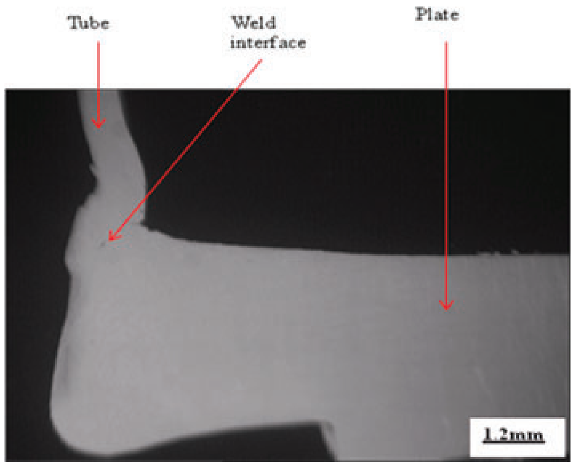


Figure 14 Condition 4.

weld condition 3 possesses both maximum hardness at the interface and maximum tensile strength.

As the tube wall thickness decreases, the tensile strength of the tube materials keeps on increasing. However, the weldability is poor as the inner diameter decreased below 7.5 mm. The above phenomenon is due to excessive thinning of the tube and decrease in load transmitting capacity. Hence, FWTPET is not suitable to achieve high-quality joint if the wall thickness is below some limiting value. Typical micrographs of different zones in the welded joint have been presented in Fig. 16. The friction welded joints have been sectioned perpendicular to the bond line and observed using optical microscope. Typical micrographs showing different morphology of microstructure at different zones of the friction welded joints have been presented. Compared to base metal, the changes in microstructures are observed at weld zone interface. The grains at base metal (plate and tube) are relatively coarser. Fine grain structure

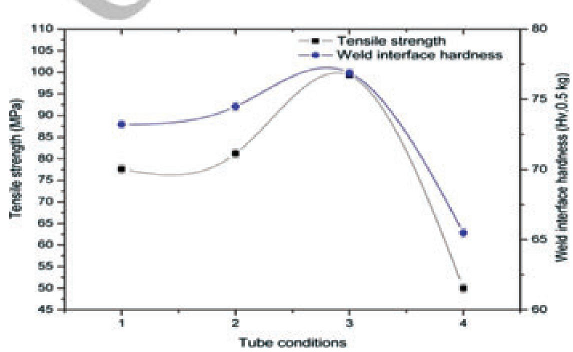


Figure 15 Tensile strength and hardness for four different tube diameter weld conditions.

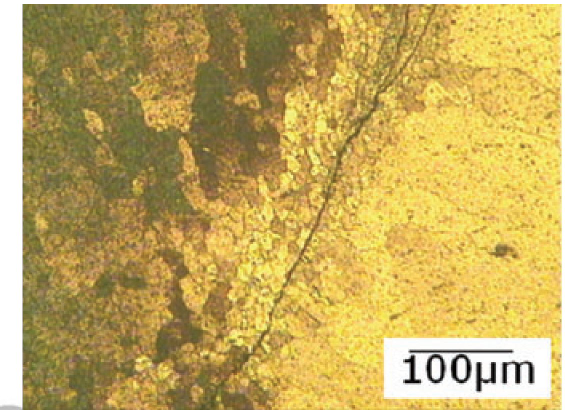


Figure 16 Condition 1.

has been observed in the weld zone interface. The microstructure variation with different tube diameters is depicted in Figs. 16–18. It has been found that

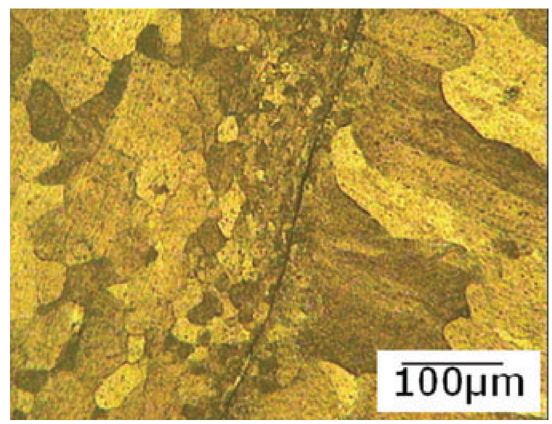


Figure 17 Condition 2.

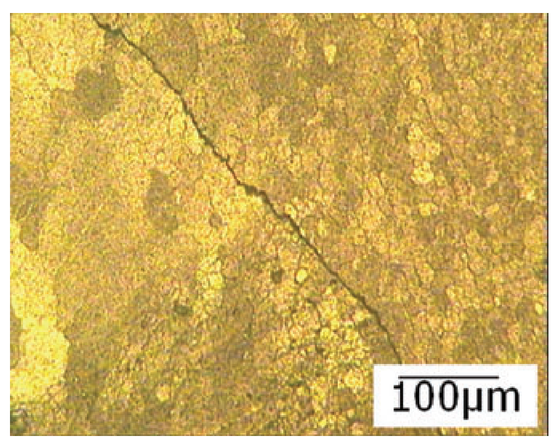


Figure 18 Condition 3.

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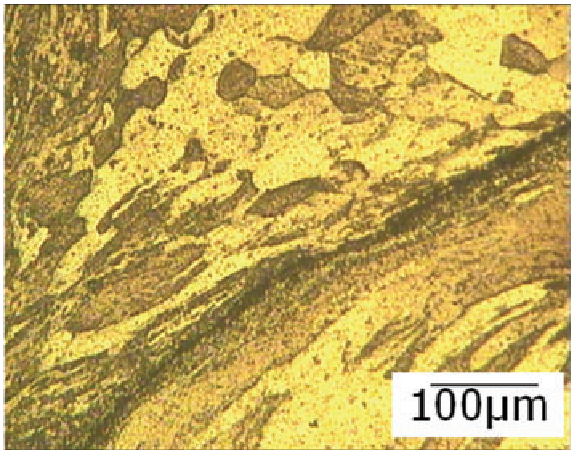

Figure 19 Condition 4.

conditions 1–3 possess better metallurgical bond at the weld interface. But in the case of condition 4, the cracks have been observed at the interface due to poor metallurgical bond between the tube to tube plate as shown in Fig. 19. The reason for crack formation at the interface is due to decrease in load transmitting capacity of the tube. For this reason, the crack got propagated at the interface and also more quantity of plate material gets occupied at the slot of the tube and also affects the strength of the FWTPET process. Hence, conditions 1–3 possess better weld strength between tube to tube plates.

Conclusions

In this study, FWTPET process has been used to join tube to tube plate which is a new process possessing wider applications. This process is capable of producing high-quality and defect-free weld joints. Also, this process is capable of producing joints with enhanced mechanical and metallurgical properties with lesser energy consumption. In this work, a study of four different tube diameter conditions has been subjected to FWTPET welding. The macro- and microstructural study indicates that welds obtained with tube inner diameter more than 7.5 mm are free from defects and better strengths are achieved. As the tube diameter is below 7.5 mm, defects are visible at the interface and hence a reduction in tensile strength is obtained. The above phenomenon is explained by the combined effect of decrease in load transmitting capacity and excessive thinning of the tube. The present study enables engineers to predict the kind of weld condition that is capable of producing high-quality weld joints which has tremendous applications in industries.

Acknowledgments

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