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Investigations on the joint properties of the friction welding of aluminium alloy tube to tube plate using an external tool

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ABSTRACT

Purpose: Aluminium and its alloys are frequently used in structural applications due to their good welding ability as well as their high strength and corrosion resistance. Several developments have been observed on the welding of aluminium in last decade. The manufacturing of heat exchangers, economizers and boilers is highly cost progress due to tube to tube plate welding's. The purpose of this study is investigation of friction weldability of tube to tube plate aluminium alloys using an external tools (FWTPET) which is a relatively newer solid state welding process used for joining tube to tube plate.

Design/methodology/approach: First, preliminary experiments were carried out to determining suitable the tool rotational speed, pressure load and temperature. An experimental setup has been designed and manufactured to keep the pressure load constant during the preliminary tests. Then, by changing the weld mouth on the plate, the gap between the tube and the plate, and the tube projection parameters, the effects of all parameters on shear strength values, micro hardness values and the formation of internal structure of the weld zone were investigated.

Findings: It was founded that aluminium tubes can successfully weld to tube plates with using an external tools. Also it is seen that vertical force between tool and sample, tube protection and temperature are very important parameters which are effect of welded joint properties.

Practical implications: FWTPET which is new welding method has been used in industrial field in last few years.

Originality/value: In the beginnings studies concentrate on non-ferrous metals such as Al, Cu, Mg etc. So this studies on FWTPET have remarkable importance.

Keywords: FWTPET; AA6063; AA6082; Tube to tube plate welding

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MANUFACTURING AND PROCESSING

1. Introduction

FWTPET (Friction welding of tube to tube plate using an external tool) is a welding method implemented in 2006 by Kumaran et al. and patented in 2008. The FWTPET method is a mixture of friction stir welding and friction welding methods. In this method, there is a tool composed of the shoulder and the pin in a way that of friction stir welding. This tool provides friction softening on the tube by different speeds and pressures. Unlike the friction stir welding, the pin does not mixing to softened metal, and it is not given to travelling for the tool or workpiece. This method allows different tube and plate materials to be joined together. The biggest disadvantage is that only small size work pieces can be combined .Tool rotational speed, the pressing load of the tool, the gap between the tube and the tool, tube projections, the time of the contact, the diameter of the tool shoulder and the temperature are affecting factors of weld quality in the FWTPET. The most important two of these parameters are tool rotational speed and the pressure load. These parameters directly affect the temperature and cause the metallurgical structure in the weld zone to change [2-11].

2. Materials and methods

During the experiments, EN AW-6082-T6 was used as plate samples and EN AW-6063-T5 aluminium alloys were used as tube samples. The chemical composition of these materials is shown in Table 1, and Table 2.

Table 1.
Chemical composition of EN AW-6082-T6 used as plate material, %

Fe	Si	Cu	Mn	Mg	Zn	Cr	Al
0.5	0.7-1.3	0.1	0.4-1.0	0.6-1.2	0.2	0.15	Bal.

Table 2.
Chemical composition of EN AW-6082-T6 used as tube material, %

Fe	Si	Cu	Mn	Mg	Zn	Cr	Zi	Al
0.35	0.2-0.6	0.1	0.1	0.45-0.9	0.1	0.1	0.15	Bal.

Mechanical properties of EN AW-6063 and EN AW-6082 aluminium alloys at different tempering treatments are given in Table 3.

Table 3.
Mechanical properties of EN AW-6063 and EN AW-6082 aluminium alloys in different tempering processes

	Tempering	R_m, MPa	A, %	HBW	Shear strength R_{mk}, MPa
EN AW-6063	O	130	18	25	R_{mk}=0.52 Rm 0.52x175= 90
	T4	130	14	50	
	T5	**175**	**8**	**65**	
	T6	215	10	75	
EN AW-6082	O	160	14	35	R_{mk}=0.52 Rm 0.52x290= 150
	T4	205	14	70	
	T5	270	8	90	
	T6	**290**	**8**	**95**	

a)

b)

c)

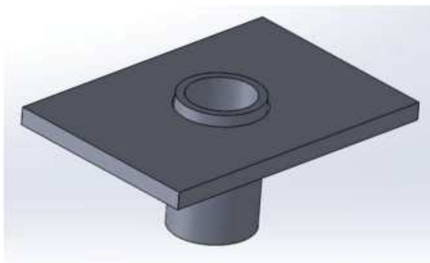

Fig. 1. The view of welded parts (a) plate, (b) tube, (c) assembled status

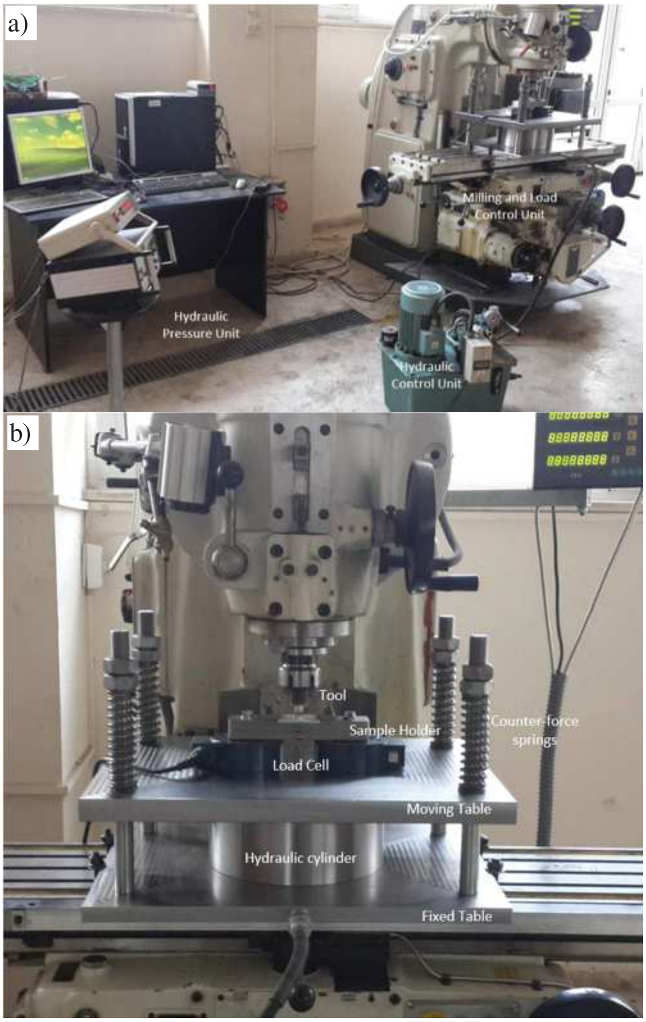

Fig. 2. The view of the experimental setup, a) (general), b) (fixing)

Plates to be welded are prepared in dimensions of 5 x 50 x 70 mm and tubes in the dimensions of Ø20 x 2 mm. The tubes were cut at 35 mm, 36 mm and 37 mm with tube projections of 1 mm, 2 mm and 3 mm (Fig. 1).

An experimental setup has been manufactured to control the pressure load applied during the experiments. The experimental setup consists of milling machine, load control unit, hydraulic control unit, hydraulic pressure adjustment unit and pressure force instrument panel. The desired pressure load can be adjusted during welding by means of hydraulic control and pressure adjustment unit.

In the FWTPET method, keeping the applied load constant during welding is one of the most important parameters. It is difficult to keep this load constant in conventional counterpart. During welding the workpiece is stationary, while the rotating tool is moved vertically downwards to perform the welding operation. During this process, the pressure force is equal to the force applied manually by the person using the mill. This causes different pressures to appear during each welding. Therefore, it was used a special hydraulic system to keep the pressure force constant. With this system, during welding, the top plate to which the part is attached will move upwards in the vertical direction to the milling table. The tool will rotate at a fixed number of revolutions in the fixed position. In this case, the pressure force can remain approximately constant during each welding operation. This makes it easier to compare welding operations [1].

An hardened cold work tool steel (X210Cr12) is used as tool material as seen in Figure 3.

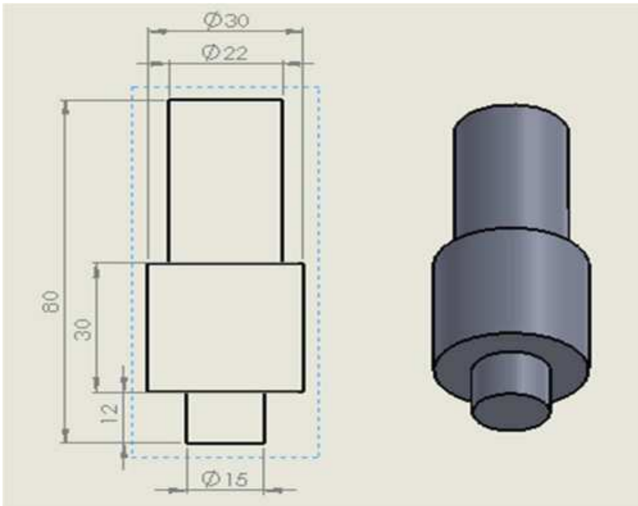

Fig. 3. The dimension of tool used for FWTPET

Compression test were carried out after the tests to find the shear strength values. An apparatus as shown in Fig. 4 has been used to fix the samples during the compression test. This apparatus fixes the welded tube-plate sample to prevent the welded part from deforming during the compression test. For the test results to be valid, it must be from the tube-plate junction point. For this purpose, the outer diameter of the pin part must be manufactured equal to the outer diameter of the welded tube part.

The parameters used during the experiments are given in Table 4. During welding, the temperature must reach 369-431°C, which is 0.6-0.7 times of the melting temperature of 616°C of EN AW-6063-T5 aluminium alloys. So the temperature value was selected as 400-450°C. The tool rotational speed was selected as 3 different values (950 rpm, 1180 rpm and 1500 rpm). Three different values were studied for tube projections (1 mm, 2 mm, 3 mm).

The vertical load value is fixed at a value between 250 kg and 300 kg.

a) b)

Fig. 4. The parts of cutting test apparatus (a), and picture from during cutting test (b)

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Table 4.
Welding parameters for FWTPET process

Welding number	Tool rotational speed, rpm	Tube projections, mm	Vertical load, kg	Temperature, °C
1	950	1		
2	1180	1		
3	1500	1		
4	950	2		
5	1180	2	250-300	400-450
6	1500	2		
7	950	3		
8	1180	3		
9	1500	3		

3. Results

The welded samples prepared for the internal structure analysis were cut for the purpose of making macro examinations. Samples prepared for internal structure analysis were kept in a 10% sodium hydroxide solution for 5 minutes. At the end of the time the parts were rinsed with ethyl alcohol and dried.

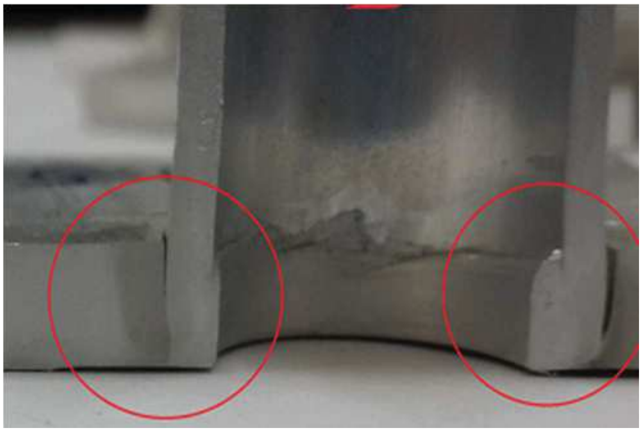

Fig. 5. The macro view of cross section of welded interface

It was observed that there were visible openings when the samples were examined and that the volume of the melt metal did not completely fill the gap between the tube and the plate. It also flows into the tube at a fraction of the volume of the melt metal as seen in Fig. 5.

The recrystallization of the grains in the heat-affected zone was found to be finer than the grain size of the base metal as seen the Fig. 6. In addition, the grain size in the area with the appearance of onion rings have undergone recrystallization as well. Onion rings have an apparent grain size of less than 10 μm, while grain sizes in the HAZ region are below 20 μm.

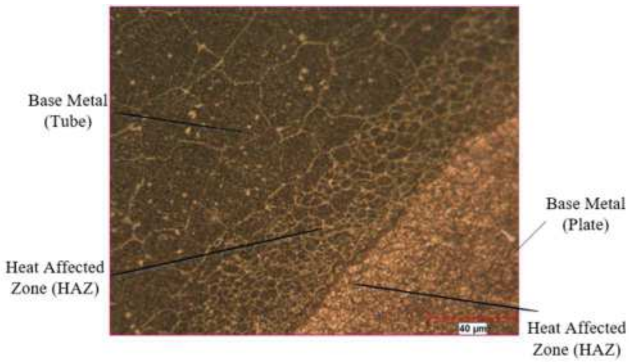

Fig. 6. The view of micro structure of welded zone

Three of the welded samples were used to measure the shear strength and the other two were used for internal structure analysis. The shear strength test results of the samples were compared. As seen in Table 5, the highest values were reached at welded in the parameters of 1180 rpm tool rotational speed and 3 mm tube projections.

Table 5.
FWTPET experimental test results

Sample name	Rotational speed, rpm	Tube projection, mm	Shear strength, R_{mk}, MPa	Shear strength average, R_{mk}	Vertical load, kg	Temperature, °C
S 1-1	950	3	28	30	345	417
S 1-2			26		315	428
S 1-3			38		285	431
S 2-1		2	49	48	305	450
S 2-2			45		295	421
S 2-3			48		295	414
S 3-1		1	42	36	300	374
S 3-2			35		270	414
S 3-3			32		290	401
S 4-1	**1180**	**3**	**47**	**49**	250	425
S 4-2			**47**		250	447
S 4-3			**53**		250	441
S 5-1		2	36	43	250	469
S 5-2			42		290	444
S 5-3			52		250	454
S 6-1		1	39	32	260	455
S 6-2			23		255	447
S 6-3			35		275	462
S 7-1	1500	3	31	34	250	427
S 7-2			37		260	410
S 7-3			36		250	446
S 8-1		2	45	45	305	446
S 8-2			43		250	433
S 8-3			48		275	418
S 9-1		1	38	38	265	440
S 9-2			39		250	433
S 9-3			35		300	420

4. Conclusions

When the tool rotational speed was selected respectively as 950 rpm, 1180 rpm, 1500 rpm, the highest shear strength values were obtained at 1180 rpm. In the case of the tool rotational speed being 1180 rpm, the highest shear strength values were reached with an average of 49 MPa in samples with tube projection value 3 mm. This strength value is about 10% to 20% above the strength values of the samples made at other speeds.

Healthy welding can be made when the temperature reaches the aluminium dough temperature during welding. This temperature value was measured at approximately 400°C.

As a result of the microstructure analysis, it is observed that the particles in the regions close to the source interface are refined as a result of recrystallization. The grain size of the base metal was measured as about 25 µm, while grain sizes decreased to 5 µm.

When the macrostructure analysis was examined, it was observed that a part of the volume of the melt metal migrated into the tube, and a part of the volume of the melt metal swept out through the plate. As a result, partial voids were observed that the melt metal did not completely fill the space between tube and the plate.

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