# Friction Welding of MgAz31Alloy Tube to MgAz91 Plate Configuration by using Zinc Interlayer

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***Abstract* — Friction welding is one of the most efficient welding processes used for joining of metals and alloys. This paper deals about MgAZ31 and MgAZ91 alloy weld ability and process parameters are analysed. It is very useful technique for manufacturing aerospace applications and other commercial applications like aluminium absorber for solar heating application. Different welding zones like thermo-mechanically affected zone, heat affected zone, welding zones are analysed at different welding speeds. The process parameters such as speed and plunge depth of the external tool are varied and micro-macro structures of the welded joints has been analysed. Finally the optimum speed and plunge depth has been observed and analysed in friction welding process by interlayer method. Micro structural study confirms the phase transformations occur to joints, its refines grain structure, XRD pattern shows that the crystallinity crystalline peak level of alloy content. This method of joint shows that to produce the leak proof welding.**

***Keywords*— Friction welding, Microstructure**

## I. Introduction

Friction-Stir Welding (FSW) is a solid-state, hot-shear joining process [1-4]. The process utilizes a bar-like tool in a wear-resistant material (generally tool steel for aluminium) with a shoulder and terminating in a threaded pin. This tool moves along the butting surfaces of two rigidly clamped plates placed on a backing plate. The shoulder makes a contact with the top surface of the plates to be welded. The heat generated by friction at the shoulder and to a lesser extent at the pin surface and it softens the material being welded. Severe plastic deformation and flow of this plasticised metal occurs as the tool is translated along the welding direction. The material is transported from the front of the tool to the trailing edge where it is forged into a joint. Fig.1. shows a schematic representation of FSW.

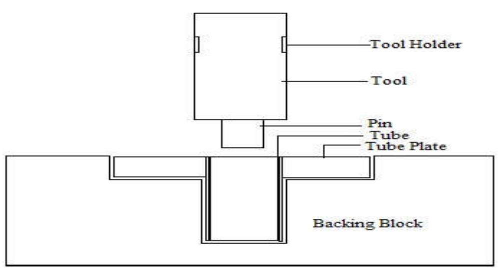


Fig.1. Schematic diagram of FWTPET

There are two principal parameters in FSW: tool rotation rate (ω, rpm) in clockwise or counter clockwise direction and the tool traverse speed (v, mm/min) along the line of joint. The rotation of the tool results in stirring and mixing of material around the rotating pin and the translation of the tool moves the stirred material from the front to the back of the pin and finishes welding process. A suitable tilt of the spindle towards trailing direction ensures that the shoulder of the tool holds the stirred material by threaded pin and move material efficiently from the front to the back of the pin. The heat generation rate, temperature field, cooling rate, x-direction force, torque and power are totally depended of the welding speed, the tool rotation speed, the vertical pressure on the tool, etc. FSW enables long lengths of weld to be made without any melting taking place. This provides some important metallurgical advantages compared with fusion welding, i.e. no melting means that solidification and liquation cracking are eliminated; the stirring and forcing action produces a fine-grain structure. However, one disadvantage is that the keyhole (exit hole) remains when the tool is retracted at the end of the joint. Several alloys have been welded by FSW, they included the following aluminium alloys: 5083, 5454, 6061, 6082, 2014, 2219 and 7075[5].

FWTPET process is one of the solid-state welding processes that produces weld joints due to friction heat generated by (tool and work piece) the combined effect of axial force and controlled rubbing of faying surfaces. 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. To overcome these problems by invented friction welding of tube to tube plate using an external tool (FWTPET) in the year of 2006 by Dr.S.Muthukumaran .

One of the interesting characteristics of FWTPET is that its capability to produce high quality leak proof joints [6-10]. Compared to with traditional tube to tube plate welding techniques, it is an energy efficient, environment friendly and versatile process [10-14]. Further, the slices made from the dissimilar tube to tube plate joint can be used as transition joints in electrical and electronics industries. . The potential application of FWTPET joints includes catch cans in automobile engines, box type heat exchangers, aerospace, railways, automotive, and marine industries. Aluminium evaporator used in household air conditioners, and solar panel backing. The aim of present study is to obtain the high quality weld between Al-tube to Al- tube plate by FWTPET. In the present work FWTPET is used for welding Al-tube to Al-tube plate at different process parameters. Important process parameters of FWTPET process are found as tool rotation speed (in rpm) and plunge depth.

## II. METHODOLOGY

### *2.1. Experimental procedures*

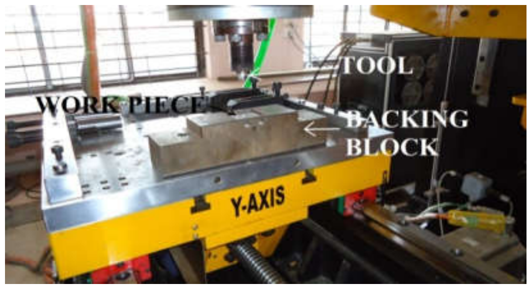


Fig. 2 FWTPET machine

The FWTPET machine is shown in Fig.2. Various steps involved in the process is given bellow.

Stage 1 : Tool Preparation
Stage 2 : Backing Block Preparation
Stage 3: Preparation Of Plate
Stage 4: Preparation Of Tube
Stage 5: Preparation Of Zinc Foil
Stage 6: Arrangement Of Tube And Plate With Interlayer
Stage 7: Cleaning The Surface With Alkaline Solution
Stage 8: FWTPET Welding Process
Stage 9: Preparation Of Destructive Testing
Stage 10 : Material Characterization

Backing block consist of three holes the outer two holes provided for clamping purpose and the centre hole is fit for the tube plate arrangement as shown in Fig.3. And work piece plate is prepared by 50 mmx50 mm and 6 mm thickness, tube length & thickness is 35 mm & 2 mm and outer diameter 19 mm.

Fig. 3 Backing Block Used For FWTPET

The bonding occurs between surfaces which are at higher pressure and temperature. The process variables considered in this research study are tool rotational speed, plunge depth. Both the tube and plate used in the present study are made of commercial grade pure aluminium whose chemical composition is shown using 6mm rolled plates of commercial grade pure aluminium and cut into the required sizes (50mm×50mm) by means of a power hacksaw. Similarly, tubes of 19mm external diameter have been cut into required size (35mm height). This is followed by drilling of 19mm diameter holes in the rolled plate. Then the tubes are fixed in their respective place position. Tools made of tungsten material are used to fabricate FWTPET joints in the present study. The assembled work piece is clamped on to the machine table and the tool has been fixed to the spindle of the machine. On completion of welding, the tube to tube plate joints are sliced for macro-structural observation.

Table.1. Tool material chemical composition

| Elements | W | Ni | Fe | Mo | Co | $O_2$ |
|---|---|---|---|---|---|---|
| Wt % | 90.56 | 5.79 | 3.23 | 0.22 | 0.12 | 0.07 |

Table.2. Work material chemical composition

| Elements | Al | Si | Fe | Cu | Mg | Mn | Ti | Zn |
|---|---|---|---|---|---|---|---|---|
| Wt % | Bal | 0.0006 | 0.0007 | 0.0013 | 0.0021 | 0.0001 | 0.0001 | 0.0002 |

## III. Results and Discussions

### *3.1. Macro structure*

The macro structure initially starts with zero mm plunge depth, there is no deformation occurs in this stage on the tube plate because the tool touches top surface of the plate. i.e. no feed is given to the tool. But in the case of 1 mm and 1.5 mm plunge depth the tube gets deformed along the tool axis. At the same time 2 & 2.5 mm plunge depths create some cracks due to high feed given to the tool.

Macro structure is revealed from the optical macro scope by the help of etching process (tucker reagent). The macro structure for different plunge depths as shown in Fig.9.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 has been performed using alumina and diamond paste by employing a disc polishing machine. This is followed by etching the macro-structure using tucker's reagent (composition: 4.5 ml HNO3, 2.5 ml H2O, 1.5 ml HCl, 1.5 ml HF). Then the sample has been washed, dried and observed using a macro scope. The integrity of joints has been analyzed through the micrographs at the weld zone, heat affected zone and thermo mechanically affected zone. The Keller's etchant has been used for micro structural studies (composition: 2 ml HF, 3 ml HCl, 5ml HNO3, 190 ml distilled water). Similarly material prepared for different plunge depth starts from 0mm,0.5mm, 1.0mm, 1.5mm, 2.0mm, 2.5mm are to be welded. Macro structures of the samples are shown in the Fig.4.

### *3.2. Micro structure*

Micro structure is revealed from the optical micro scopy by the help of etching process (keller reagent). The micro structure for different plunge depth as shown in Fig.10. The main reason for decrease in strength and hardness with higher plunge depth is due to higher feed given to the tool and tube plate. As the tool shoulder touches more tube area, large quantity of heat is generated only along the tube side. During the same time, the tool contact has been more focused on tube surface, and also tube bending occurs slightly during welding. The friction-welded joints have been sectioned perpendicular to the bond line and observed using optical microscope. Typical micrographs showing different morphology of microstructures at different zones of the friction-welded joints have been presented and analyzed. Compared to base metal, the changes in microstructures are observed obviously at weld zone interface. The grains at base metal (plate and tube) are relatively coarser. Fine grain structure has been observed in the weld zone interface. In solid state welding, especially in friction welding, due to severe deformation, the refined grain structure is observed at the weld zone which resulted in improved properties. Micro structures of the samples are shown in the Fig.5.

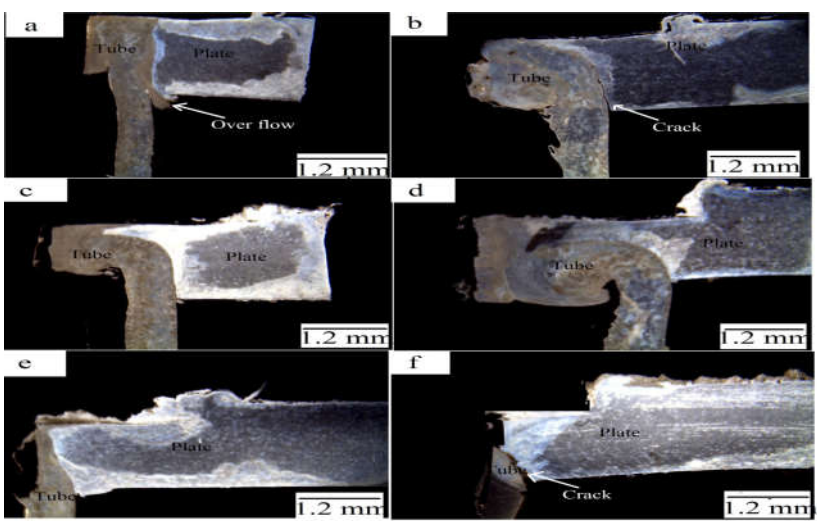


Fig.4. Macro Structure Samples

a. (0-mm plunge depth). b. (0.5-mm plunge depth). c. (1-mm plunge depth).
d. (1.5-mm plunge depth). e. (2-mm plunge depth). f. (2.5-mm plunge depth)

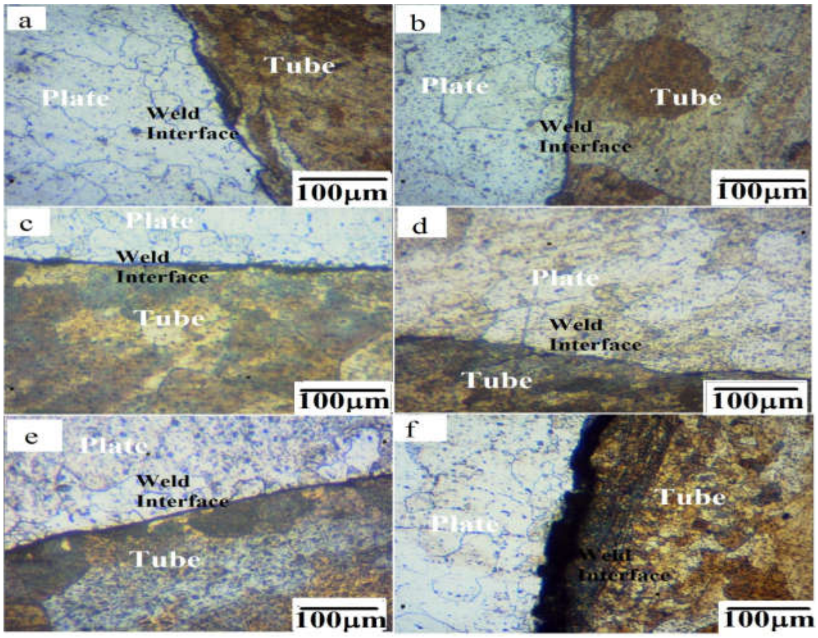


Fig.5. Micro structure sample
a. (0-mm plunge depth). b. (0.5-mm plunge depth). c. (1-mm plunge depth).
d. (1.5-mm plunge depth) e. (2-mm plunge depth). f. (2.5-mm plunge depth)

### *3.3. Micro Hardness Test*

The Micro hardness has been measured for the welds obtained with six different welding plunge depths using Vickers hardness tester. The hardness 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. 6. One of the commonly used micro hardness tests are tests that also can be applied with heavier loads as macro indentation tests:

Vickers hardness test (HV): There is some disagreement in the literature regarding the load range applicable to micro hardness testing. ASTM Specification E384, for example, states that the load range for micro hardness testing is 1 to 1000 gf. For loads of 1 kgf and below, the Vickers hardness (HV) is calculated with an equation, wherein load (L) is in grams force and the mean of two diagonals (d) is in millimetres:

$$HV=0.0018544 \,´\, L/d2$$

Micro hardness value tested from the computerized Vickers hardness test machine. The various welded zones having different hardness strength are listed in table. There are 5 different readings taken in each region the average value is taken for consideration.

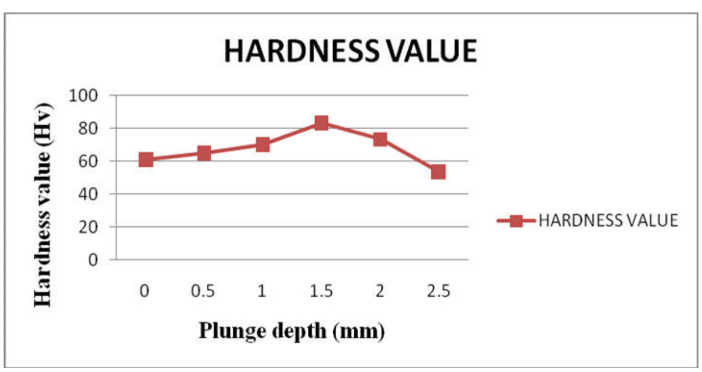


Fig.6. Plunge depth vs. Micro Hardness

### *3.4 Shear Test*

Shear test was conducted by the help of Universal Testing Machine (UTM). The same backing block used in welding process is used for shear test. The external tool is used for push the tube. Shear test was conducted by partial hollow tube is used full tube length 30mm, inner diameter 14mm outer diameter 19mm, in that 15mm is hollow 15mm length is solid, the tube and plate (50X50) mm, thickness 6 mm as shown in Fig.7 and the samples vs the shear force diagram is shown in Fig.8.

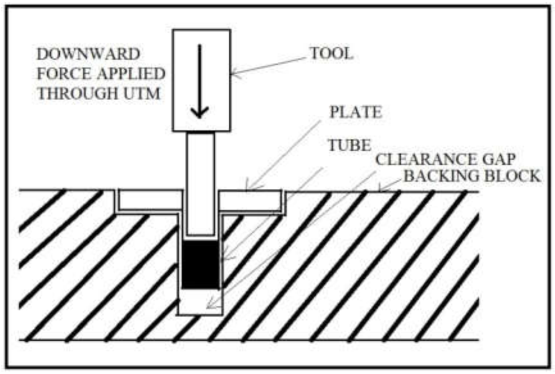


Fig.7.shear test setup

Some of the specimens have fractured away from the joints and the maximum tensile strength has been achieved by the FWTPET process. Table 3 shows pull strength for six different weld conditions.

Table.3. Shear Test

| S.No | Plunge depth (mm) | Break Point (kN) |
|---|---|---|
| 1 | 0 | 11.9 |
| 2 | 0.5 | 10.1 |
| 3 | 1.0 | 10.4 |
| 4 | 1.5 | 11.3 |
| 5 | 2.0 | 12.2 |
| 6 | 2.5 | 10.7 |

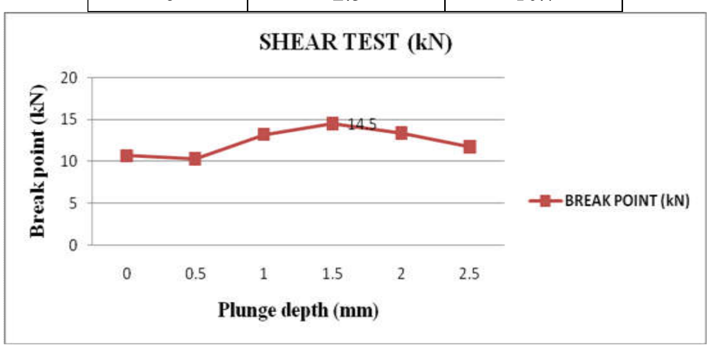


Fig.8. Samples vs. Shear Force

## IV. Conclusions

FWTPET process with clearance method is a novel solid state joining method to weld tube to tube plate. The micro and macro structure shows that clear interface between tube and 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 & Break point of the tube plate observed as graph is 84.4 kN& 14.4 kN with process parameter: plunge depth as, 1.5 mm.

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