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Research Paper

FRICTION STIR WELDING STUDY ON ALUMINUM PIPE

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Friction stir welding, a solid state joining technique, is widely being used for joining Al alloys for aerospace, marine automotive and many other applications of commercial importance. FSW trials were carried out using a drilling machine on Al 6063 alloy. The tool rotational speeds 485, 710, 910, 1120 and 1400 rpm with a traverse speed 4 mm/min were applied. The Mechanical properties of welded joints were investigated using different mechanical tests including destructive test (tensile test, hardness and microstructure). Based on the stir welding experiments conducted in this The resultant microstructure was characterized using optical microscopy This paper presents the optimization of friction stir welding for pipe and also highlights the influence of microstructure and mechanical properties of FSW 6063 Al alloy.

Keywords: FSW, Al alloys, Mechanical properties, Microstructure

INTRODUCTION

solid-state welding is the process whereby coalescence is produced at temperatures below the melting point of the base metal without the use of any filler metal. Examples of solid-state welding processes include friction welding, Friction Stir Welding (FSW), ultrasonic welding, resistance welding, explosive welding and diffusion welding. There are fewer defects in solid-state welding because the metals do not reach their melting temperatures during the welding process. However, the base metals being joined retain their original properties, and the Heat Affected Zone (HAZ) is small when compared with the fusion welding techniques (O'Brien and Guzman, 2007). Friction Stir Welding is a variant of friction welding that produces a weld between two or more work pieces by the heating and plastic material displacement caused by a rapidly rotating tool that traverses the weld joint (Thomas *et al.*, 1991). The schematic diagram of the process is presented (http://www.twi.co.uk/content/fswintro.html). In FSW, the interrelationship between the process parameters is complex;

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the two most important welding parameters being the tool rotational speed in a clockwise or anti-clockwise direction, and the tool traverse speed along the joint line (Reynolds, 2003). The rotation of the tool results in the stirring and mixing of material around the rotating pin during the welding process which in turn affect the evolving properties of the weld. such, understanding the relationship between the process parameters and the resulting properties of the welds is Research studies on process-property relationship (Reynolds, 2003; Lim *et al.*, 2004; Abdollah *et al.*, 2008; and Akinlabi *et al.*, 2011) reported that the input process parameters are found to exert significant effect on the resulting joint integrities. In attempting to further understand the process-property relationship in FSW, statistical analyses of the weld data have been conducted on similar joints of aluminium alloys. Rajamanickam and Balusamy (2008) conducted statistical analysis on the weld data obtained in FSW of 2014 aluminium alloy and concluded that the weld speed has the highest statistical influence on the mechanical properties of the welds produced. Also, Benyounis and Olabi (2008) conducted a literature survey on optimization of different welding processes using statistical and numerical approaches and concluded that modeling; control of the process parameters and optimization of different welding processes can be achieved using different statistical tools. The aim of this study is to conduct statistical analysis on the weld data obtained from dissimilar FSW of aluminium and copper in other to gain insight and understanding into the interaction between the process-properties of the resulting welds.

EXPERIMENTAL SETUP AND PROCEDURES

Materials

The material used in this study (6063 Al alloy), was received from Misr Aluminum Company. Tables 1 and 2 show the chemical composition and mechanical properties of 6063 Al alloy.

Tool Design

The tool must be designed to generate sufficient heat, through means of rotational surface contact, to create a plasticised region beneath the tool. It was realized early on in the development of FSW that the tool's design is critical in producing sound welds (Xiao *et al.*, 2003). A basic and conventional design for a FSW tool is shown in Figure 1. This cylindrical probe design will be compared to other more complex and still emerging tool variants. FSW tools follow the same basic trends in terms of their shapes and geometries. They are generally comprised of three generic features:

- A shoulder section
- A probe (also known as a pin
- Any external features on the probe.

The shoulder is designed as a relatively large, when compared to the probe, profiled surface. Although the probe makes the initial

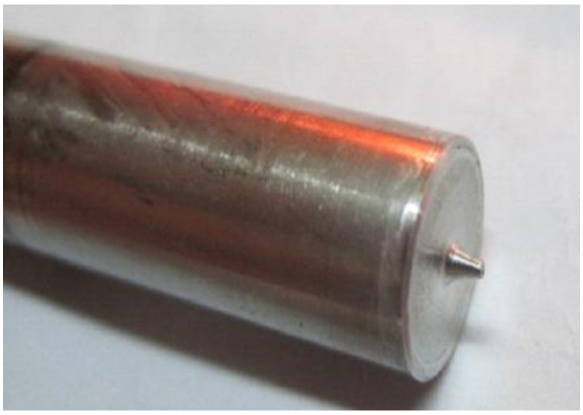
Table 1: Chemical Composition (wt %) of 6063 Al

Weight %	Al	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Other Each	Other Total
6063	Bal	0.20 -0.6	0.35	0.10	0.10	0.45-0.90	0.10	0.10	0.10	0.05	0.15

Table 2: Mechanical Properties of 6061 Al/Composite

Description	$\pm_u$ Mpa	E1%	VHD
6061	207.10	12%	74.6

Figure 1: Photo-of Stir Probe Design



contact with the pre-welded material the shoulder has a larger contact area and produces more friction.

The diameter of the shoulder will determine the amount of contact area applied to the weld material's surface. A shoulder diameter which is too small could result in insufficient heat being applied to the process through an inadequate contact area between tool and material to be joined and therefore a failed weld or broken tooling. To generate sufficient heat during the process the shoulder diameter should be a minimum of 50% larger than the root diameter of the probe with contact areas up to three times larger deemed to be satisfactory. The diameter of the tooling determines the width of the plasticized region beneath the shoulder and the width of the Thermo-Mechanically Affected Zone (TMAZ). The distinct semi-circular trail indentation left in the wake of the tool is evidence of the deformation caused by the shoulder rotation and its width is related to the shoulder diameter (Neugebauer and Stoll, 2004).

Tool Material

The tool must be made from a material which can withstand the process and offer enough frictional heat generation. When selecting a material from which to manufacture the FSW tool the material to be welded must be considered. The tool material must be sufficiently stronger and more wear resistant than the material to be welded and must also have a higher melting temperature. A tool made from a material which is too soft will wear down to an unusable state very quickly due to the constant abrasive contact involved in the process. Tools currently used for industrial applications are capable of completing over 1000 m of FSW without the need to change tool (Thomas *et al.*, 2001). Aluminum can be joined using a tool made from silver steel, however if the weld material was to be steel, the tool would have to be more temperature resistant, for example tungsten with a ceramic coating. This means the selection of an FSW tool material must be based on the weld material properties. Another type of tool material under investigation is ceramic tools. A ceramic tool is more resistant to abrasion and so will not wear as much. This tool would also be able to generate the temperatures required to join steels. Ceramic although tough is a more brittle substance than metal and so the traversing of the tool would be its biggest challenge.

Friction Stir Welding Process

Two tubes to be welded were butted up against each other and clamped down using the fixture. Rotational velocity and translational velocity of the tool are set in the adapted drilling machine Figure 2. The tool is then rotated and then slowly plunged into a work piece along the interface of the sheets. The tool creates frictional heat in the work piece until the material becomes plasticized. Heat generated by the mechanical mixing process and the adiabatic heat within the material cause the stirred materials to soften without reaching their melting point. This is a major advantage of friction stir welding. Once the material becomes plasticized the tool traverses along a weld line to bond the two materials together Plasticized material is deformed around the tool and is forged into place by the substantial downward axial force of the tool shoulder. Material then consolidates into the weld joint at the trailing edge of the tool leaving a solid phase bond between the two pieces (Lienert, 2003; and Mishra, 2005).

Figure 2: Turn Table and Clamping Device for FSW of Circumferential Weld

RESULTS AND DISCUSSION

Visual Inspection During Welding Process

The visual inspection was performed during welding process to check: Initial starting point is the most important that pin must be come to the interface both pipes. Besides, the bond desired between the both pipes cannot be taken place well. And also, some gaps and cracks can be occurred as shown in Figure 3. Excessive lateral flash was also observed in most of the welds resulting from the outflow of the plasticized material from underneath of the shoulder due to high plunging tool depth Figure 4. External surface behavior (rough or smooth) and that depends on welding parameters from rotational speed of tool and welding speed.

Figure 3: Slight Weld Flash on Trailing Edge that has Exhibited More Good-Quality Welds at 1400 rpm Speed

Figure 4: Excessive Weld Flash on Trailing Edge at 485 rpm Speed

Tensile tests were conducted for each welding joint that produced welding. The test results compared with the tensile properties of base metal and the welding efficiency (based on ultimate tensile strength) for friction stir welding have been calculated for each experiment. Figure 5 show the tensile tests results and welding efficiency for each welding.

In FSW, the properties of the weld joints are highly dependent on the operational parameters and the materials to be welded.

Figure 5: Relation Between Ultimate Tensile Strength and Speed (at feed 4 mm/min)

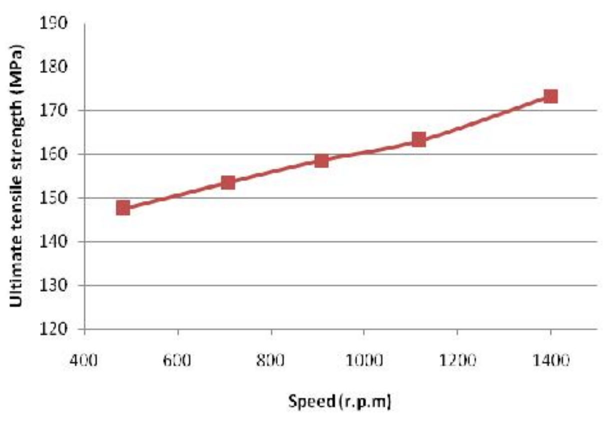
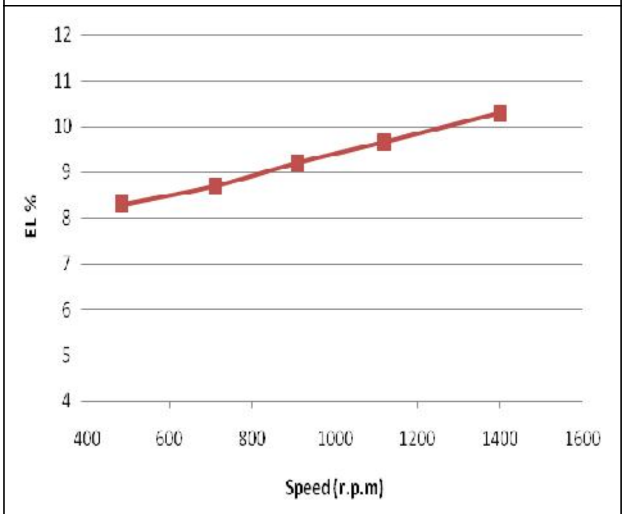


Figure 6: Relation Between Elongation and Speed (at Feed 4 mm/min)

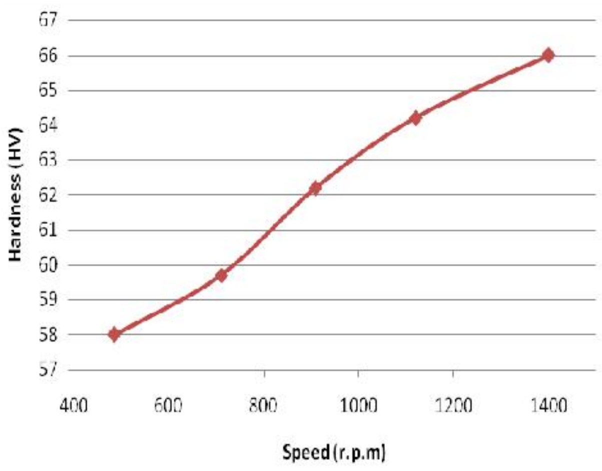


Two of the most important welding parameters are the rotational speed and the welding speed (travel speed). Figure 5 show the tensile test results for five rotational speed (485, 710, 910, 1120 and 1400 rpm) with travel speed (4 mm/min) and from above results we see increasing in tensile strength with increase the rotational. Insufficient heat input. The faster welding speed leaves less heat to the work piece and thus is generally called "cold weld" (Gerçekcioglu *et al.*, 2005; Qasim and Bashar, 2012; and Weis, 2008).

It can be explained that the weld material is unable to accommodate the extensive deformation during welding. This may result in long, tunnel defects running along the weld which may be surface or subsurface. Low temperatures may also limit the forging action of the tool and so reduce the continuity of the bond between the materials from each side of the weld. Figures 5 and 6 show the relation between the rotational speed for the stir tool with tensile strength of the welded joint. The result above the tensile strength increase when the rotational speed increases from 1400 with joint efficiency 84.2%.

The hardness tests were conducted on the static tests specimens; show Figure 7 at intervals of 2 mm along the mid-plane of the plates. The variations in the measured hardness values are respectively plotted in the joint Al 6061 have uniform hardness distribution on HAZ. The hardness of the HAZ, in case of 485, 710, 910, 1120 and 1400 rpm rotation speeds, is uniformly distributed and shows less variation, which ranges from 50 to 55 HV. In contrast, the hardness of the HAZ of 4 mm/min traverse speed shows a very scattered value as.

Figure 7: Relation Between Hardness and Speed (at Feed 4 mm/min)



Optical Microscope (OM)

Optical microscopes observations have been done on the FS welded 6061on the base and near the weld zone Figures (8a and 8b). Optical photographs are taken in 20X scales from optic microscope with video capture. General pore structures on the surface can be seen clearly. Structure of FS welded aluminum base and joint materials are shown in Figures 8 and 9 structures are become homogenous and pore. Also grain boundaries appeared notably in Figure 9 Grain necks are constituted notably and homogeneous structure obtained, smooth and less porosity surface can be seen in Figure 9 Shrinkage of the pores initiated with 20X in Figure 5.

Figure 8a: Weld Cross-Section Macro of AL6063 (at 1400 rpm) and 4 mm/min

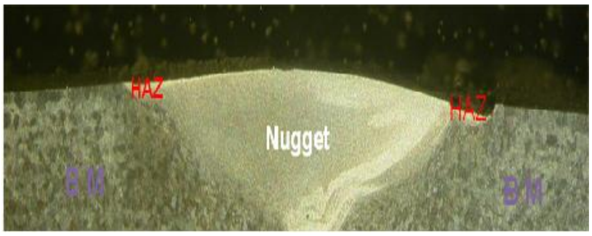


Figure 8b: Weld Cross-Section Macro of AL6063 Joints Welded at (485 rpm) and 4 mm/min

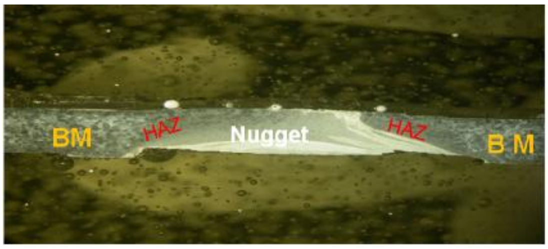


Figure 9a: Image at 200 um Magnification of 6063 Showing the Base Metal, HAZ (at 1400 rpm, Feed 4 mm/min)

Figure 9a: Image at 200 um Magnification of 6063 Showing the Base Metal, HAZ (at 1400 rpm, Feed 4 mm/min)

Figure 9b: Image at 200 um Magnification of 6063 Showing Weld Nugget Zone (at 1400 rpm, Feed 4 mm/min)

Figures 9 and 10 show the tip of the crack, which is progressing from left to right. It can be seen that the crack is preceded by a large number of voids that formed all the way along the remains of the weld line down to the root of the weld.

Figure 10a: Image at 200 um Magnification of 6063 Showing the Base Metal, HAZ (at 485 rpm, Feed 4 mm/min)

Figure 10b: Image at 200 um Magnification of 6063 Showing Weld Nugget Zone (at 485 rpm, Feed 4 mm/min)

CONCLUSION

- The designed and formulated abutting—on drilling machine module in order to execute the friction stir welding on cylindrical objects.
- The FSW of Aluminum pipe has been success fully produced.
- The FSW welds efficiency increase with increase rotation speed and decrease travels speed because As a result of thermal treatment leads to the fine grain size.
- Fine grain size microstructure obtained on weld nugget of all FSW joints.

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