FRICTION STIR WELDING PROCESS WINDOW FOR AA 7075 ALUMINIUM ALLOY

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Abstract

Aluminium alloy AA7075 has gathered wide acceptance in the fabrication of light weight structures requiring a high strength-to-weight ratio and good corrosion resistance. Compared to the fusion welding processes that are routinely used for joining structural aluminium alloys, friction stir welding (FSW) process is an emerging solid state joining process in which the material that is being welded does not melt and recast. This process uses a non-consumable tool to generate frictional heat in the abutting surfaces. The welding parameters such as tool rotational speed, welding speed, axial force are playing a major role in deciding the weld quality. In this investigation an attempt was made to find friction stir welding process window for AA7075 aluminium alloy. The formation of FSP zone has been analysed macroscopically.

Key words: Friction Stir Welding, Friction Stir Welding Process Window, FSP zone, Hardness, and Macrostructure.

Introduction

Aluminium occupies an important position in the family of metals with a very wide range of industrial and consumer applications. Its combination of lightweight, high strength and corrosion resistance are utilized extensively by modern designers to conserve energy and materials. In any structural application of this alloy, consideration of its weldability is of utmost important, as welding is largely used for joining of structural components.

Compared to many of the fusion welding processes that are routinely used for joining structural alloys, friction stir welding (FSW) is an emerging solid state joining process in which the material that is being welded does not melt and recast. Friction stir welding (FSW) was invented at The Welding Institute (TWI), UK in 1991. Friction stir welding is a continuous, hot shear, autogenous process involving non-consumable rotating tool of harder material than the substrate material. Fig. 1 explains the working principle of FSW process. Defect free welds with good mechanical properties have been made in a variety of aluminium alloys, even those previously thought to be not weldable. When alloys are friction stir welded, phase transformations that occur during the cool down of the weld are of a solid state type. Due to the absence of parent metal melting, the new FSW process is observed to offer several advantages over fusion welding [4–6].

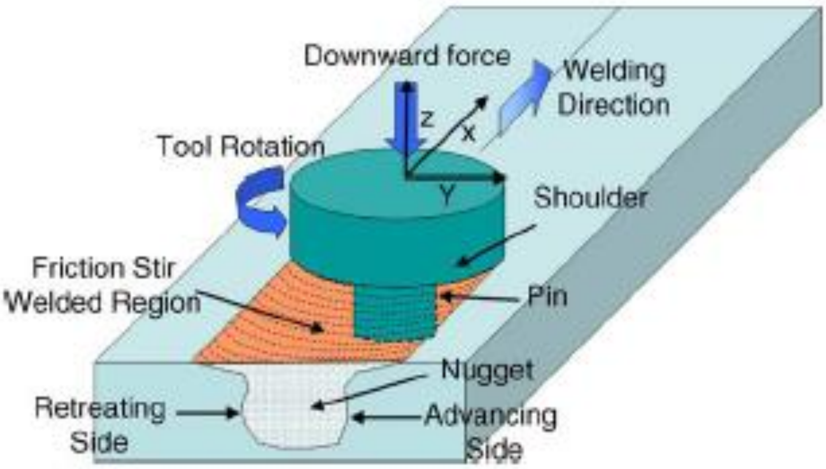


Fig.1. Schematic representation of FSW principle

FSW joints usually consist of four different regions as shown in Fig. 2. They are: (a) unaffected base metal, (b) heat affected zone (HAZ), (c) thermo-mechanically affected zone (TMAZ) and (d) friction stir processed (FSP) zone. The formation of above regions is affected by the material flow behaviour under the action of rotating non-consumable tool [7].

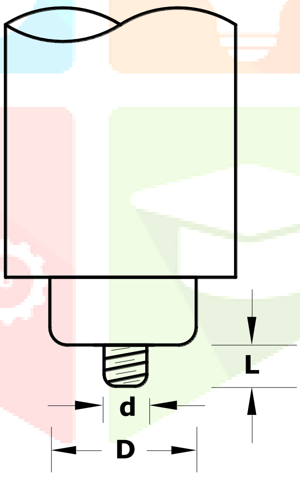
a = Unaffected Base Metal; b = Heat Affected Zone (HAZ);
c = Thermo-Mechanically Affected Zone (TMAZ);d = Friction Stir Processed (FSP) zone
Fig.2. Different regions of FSW joint

It is understood that the effect of process parameters influences on material flow behavior; microstructure formation and hence mechanical properties in friction stir welding process. Some important parameters such as rotational speed, traverse speed and axial force influence weld properties of FSW. The FSW parameters are being selected by trial and error to fix the working range to get defect free welds. This conventional experiment approach is time consuming and calls for enormous resources. Hence the present investigation is carried out to find a friction stir welding process window for AA7075 aluminium alloy to get defect free welds.

Experimental Work

Fabrication of joints

The rolled plates of 5mm thickness were cut into the required size (300 x 75mm) by power hacksaw cutting and milling. Bead on plate welding was carried out to fabricate FSW joints. The joint was obtained by securing the plates in position using mechanical clamps. The direction of welding was normal to the rolling direction. Single pass welding procedure was used to fabricate the joints. Threaded cylindrical pin profiled as shown in Fig.3, non-consumable tool made of high carbon steel was used to fabricate the joints. An indigenously designed and developed machine (15HP; 3000 RPM; 25KN) was used to fabricate the joints. Trial experiments were carried out to find out the working limits of welding parameters. The Chemical composition, mechanical properties and the welding parameters for the AA7075 aluminium alloy is presented in Table 1, Table 2 and Table 3 respectively. Forty joints were fabricated using different combinations of rotational speed and welding speed. (i.e. 8 rotational speeds x 5 welding speeds = 40 joints). The photographs of some of the fabricated joints are displayed in Fig.4.



Shoulder Diameter (D) = 18 mm; Pin diameter (d) = 5 mm;

Pin Length (L) = 4.8mm; Thread Pitch = 1 mm;

Tool material: Tempered High Carbon Steel

Fig.3.Tool used

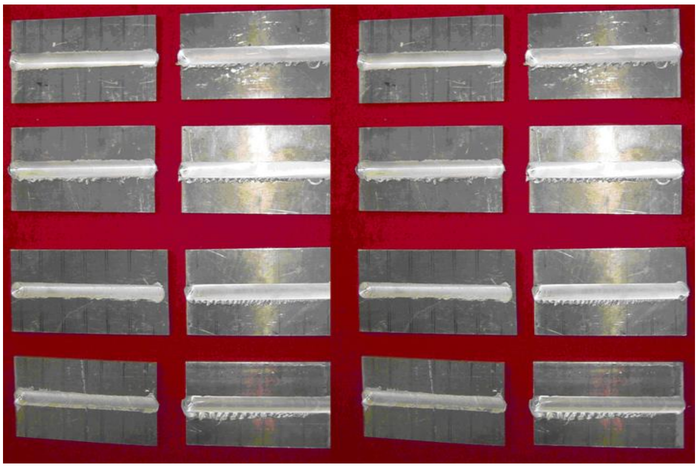


Fig.4. Photographs of some of the FSW joints

Table 1 Chemical composition (wt.%) of base metals.

Elements	Si	Fe	Cu	Mn	Mg	Zn	Cr	Ti	Al
AA7075	0.13	0.21	1.86	0.09	2.37	5.89	0.25	0.04	Bal.

Table 2 Mechanical properties of base metals.

Alloy	Ultimate tensile strength (MPa)	Elongation (%)	Vickers Hardness (0.5 kg)
AA 7075	490	11	180

Table 3 Friction Stir Welding Process Parameters used to fabricate the joints.

Alloy	Rotational speed (rpm)	Welding speed (mm/sec)	Axial Force(kN)
AA7075	700, 800, 1000, 1200,1400,1600,1800,2000	0.37,0.67,1.25,1.76,2.05	14

Characterisation of welded joints

The welded joints were sliced using power hacksaw and then machined to the required dimensions to prepare macrostructure specimens. Macrostructural analysis was carried out using a light optical microscope (VERSAMET- 3) incorporated with an image analyzing software (Clemex-Vision). The specimens were polished using different grades of emery papers. Final polishing was done using the diamond compound (1µm particle size) in the disc-polishing machine. Specimens were etched with Keller's reagent to reveal the macrostructure. From the macrostructure analysis, the formations of defect free FSP zones are identified. Some of these are shown in Table 4a and 4b. The micro hardness (Hv) was measured in the FSP region using micro hardness tester (HMV - Shimadzu, Japan).

Table 4a. Effect of tool rotational speed on FSP zone formation in AA7075 (Welding speed 2.05 mm/sec.)

Tool rotational speed	Macrograph	Observation
800		Tunnel defect
1000		Pin hole defect
1200		Pin hole defect
1600		Pin hole defect
1800		No defect
2000		Pin hole defect

Table 4b. Effect of welding speed on FSP zone formation in AA7075 (Tool rotational speed 1700 RPM)

Welding speed	Macrograph	Observation
0.37		Tunnel defect
0.67		Pin hole defect
1.25		Pin hole defect
1.76		No defect
2.05		Pin hole defect

Results and discussion

In fusion welding of aluminium alloys, the defects like porosity, slag inclusion, solidification cracks etc., deteriorates the weld quality and joint properties. Usually, friction stir welded joints are free from these defects since there is no melting takes place during welding and the metals are joined in the solid state itself due to the heat generated by the friction and flow of metal by the stirring action. However, FSW joints are prone to other defects like pin hole, tunnel defect, piping defect, kissing bond, cracks etc., due to improper flow of metal and insufficient consolidation of metal in the FSP region. Of the eight rotational speeds & Axial force is used, the joint fabricated with a rotational speeds of 1700,1800,1900 rpm and the five welding speeds of 1.25, 1.76 produced defect free welds in AA7075 aluminium alloy.

The microstructure of the base metal and highest hardness FSP region of all the joint are displayed in Fig. 5a. The joints fabricated at the rotational speed of 1800 rpm and welding speed of 1.76 mm/s have shown higher strength of 121 Hv at FSP centre for AA7075 aluminium alloy in Fig. 5b.

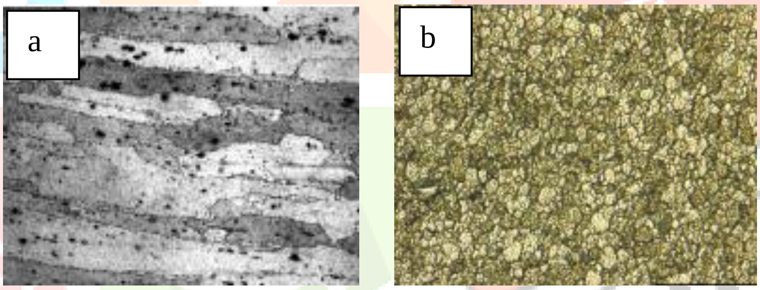


Fig.5. Optical micrographs of base metals and highest hardness FSP centre regions. (a) & (b) for AA7075

An increase in rotational speed increases the grain size due to the higher heat input (9-12) and higher hardness due to fine equiaxed grains due to dynamic recrystallisation during FSW process.

Based on the above results, we developed the friction stir welding process window for the AA7075 aluminium alloy, showed in Fig.6.

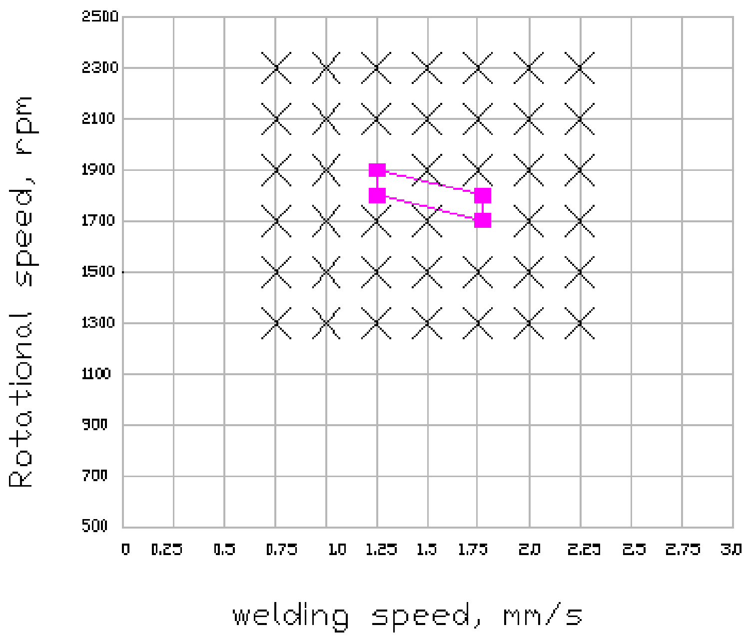


Fig. 6 Friction Stir Welding Process Window for AA7075

Conclusion

In this investigation an attempt was made to understand the effect of welding speed and tool rotational speed on the formation of friction stir processing zone in AA7075 aluminium alloy and developed the friction stir welding process window. From this investigation, the following important conclusions are derived:

(i) The developed friction stir welding process window will be used as a tool to select appropriate tool rotational speed and welding speed to fabricate defect free joints. If the rotational speed and welding speed are selected within the window, then the joints will be free from all types of defects. If the rotational speed and welding speed are selected outside the window, then the joints will contain the defects.

(ii) Of the eight tool rotational speeds and five welding speeds used in this investigation the joints fabricated at a rotational speed of 1800 rpm and welding speed of 1.76 mm/sec for AA7075 aluminium alloy.

(iii) The joints fabricated at the rotational speed of 1800 rpm and welding speed of 1.76 mm/s have shown higher strength of 121 Hv at FSP centre for AA7075 aluminium alloy.

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