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Effect of Friction Stir Welding Parameters on the Quality of Al-6%Si Aluminum Alloy Joints

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Abstract

Welding is a common joining technique for a large number of metals and materials. Today, there are many types of welding processes in various industries. Friction stir welding is a solid-state welding process that was first applied for aluminum alloys. In this process, heat is generated by friction between a rotating tool and the base material. The weld defects are extremely important because principally result in a significant reduction in the quality and strength of welding joints, and as a result, the premature failure happens in the joints. Hence, the study on the weld defects is very much essential to obtain an appropriate quality for products. In the present work, the effect of tool travel speed and tool rotation speed on the quality of friction stir welded joints in Al-6%Si aluminum alloy was investigated. For this aim, the butt joints were produced at tool travel speed of 50, 75, and 125 mm/min and tool rotation speed of 800, 1000, and 1200 rpm. Having finished the welding process, the general visual inspection of external surface and cross-section surface was carried out. In this study, the lateral flash defect occurred in most welding joints. The welding joints with more lateral flash were produced at the lowest tool rotation speed and at the lowest tool travel speed. The incomplete root penetration defect was observed in all welding condition. The tunneling defect was detected only in joint welded at tool travel speed of 75 mm/min and tool rotation speed of 1000 rpm.

1. Introduction

Among the joining processes, welding is very important because of high joint efficiency, simple set up, flexibility and low fabrication cost [1]. A lot of materials can be joined using various welding processes, including friction stir welding (FSW), friction stir spot welding (FSSW), ultrasonic welding (USW), tungsten inert gas (TIG), laser beam welding (LBW), metal inert gas (MIG), metal active gas (MAG), and arc stud welding (ASW) which all of processes have different advantages and disadvantages in terms of cost, appropriateness, labor, training, efficiency, time, temperature, and simplicity [2–7].

Due its corrosion resistance and light weight among other properties, aluminum and its alloys are part of the major engineering materials, and indispensable for various industries. As a result of its wide areas of applications, aluminum and its alloys keep on attracting different areas of research [8].

FSW is a solid-state welding process which was invented and patented in 1991 by The Welding Institute (TWI). This process is applied for welding the butt and lap joints in ferrous and non-ferrous metals and plastics [9]. It is basically a simple process where a non-consumable rotating tool with a specially designed pin profile and shoulder is inserted into the abutting edges of metal sheets or plates to be joined and traversed along the line of joint [10,11]. As the rotating pin moves along the weld line, the base material is heated up by the frictional heat generated by the shoulder and stirred by the rotating pin. Hence, this process is similar to the extrusion process. Due to the temperatures well below the melting point in this process, problems associated with the liquid/solid phase transformation are avoided [12]. Compared to conventional welding processes, FSW has many advantages. For example, it produces no harmful gases or toxic fumes, consumes much less energy, doesn't need any flux, filler metal or shielding gas and is therefore considered to be an environmentally friendly, energy efficient material joining process [13].

Weld defects can cause serious problems. For example, they reduce the quality and strength of welding joints, and result in the premature failure in the joints. Hence, the investigation on the occurrence of weld defects in friction stir welded joints is very much essential.

Non-destructive tests (NDT) are widely applied to inspect the base materials and joints in various industries. This type of test has a special place in the welding industry. One of the advantages of non-destructive tests is the ability to perform on a specimen for many times. The common non-destructive tests applied in industry are classified in following: (a) Visual Test (VT): It is based on visual observations. Visual tests can be performed as direct or indirect. This method can detect only surface discontinuities. (b) Penetrant Liquids Test (PT): It is based on capillary action in liquids. This method can detect only surface discontinuities but its accuracy is somewhat more than VT. (c) Magnetic Particles Test (MT): It is based on magnetic flux leakage. This method can detect surface and sub-surface discontinuities. Its accuracy is more than VT and PT. (d) Ultrasonic Test (UT): It uses ultrasound waves. This method can detect both surface and internal discontinuities. This method has accuracy more than previous methods. It also can be applied to measure the specimen thickness. (e) Radiography Test (RT): It uses X-ray and gamma-ray. These rays have very short wavelength and are able to arrive into specimen.

In this paper, the effect of FSW parameters on the quality of butt joints produced in Al-6%Si aluminum alloy is studied.

2. Materials and Methods

2.1. Base material and welding process

The base material employed in this study was 5 mm thick Al-6%Si aluminum alloy plates. Butt joints of the base material were fabricated using single pass FSW process at tool travel speed of 50, 75, and 125 mm/min and tool rotation speed of 800, 1000, and 1200 rpm. The combination of parameters for welding processes is listed in Table 1. In this study, the welding process was carried out in a flat position using the Azin Sanat Farasoo **(**ASF) model P42 machine and the plates were previously fixed by a clamping fixture. The welding machine and its apparatus are shown in Fig. 1. The AISI type H13 hot work tool steel was used to make FSW tool including a cylindrical shoulder with 17 mm diameter and a cone shaped pin with larger diameter of 7 mm, smaller diameter of 6 mm and length (height) of 3 mm.

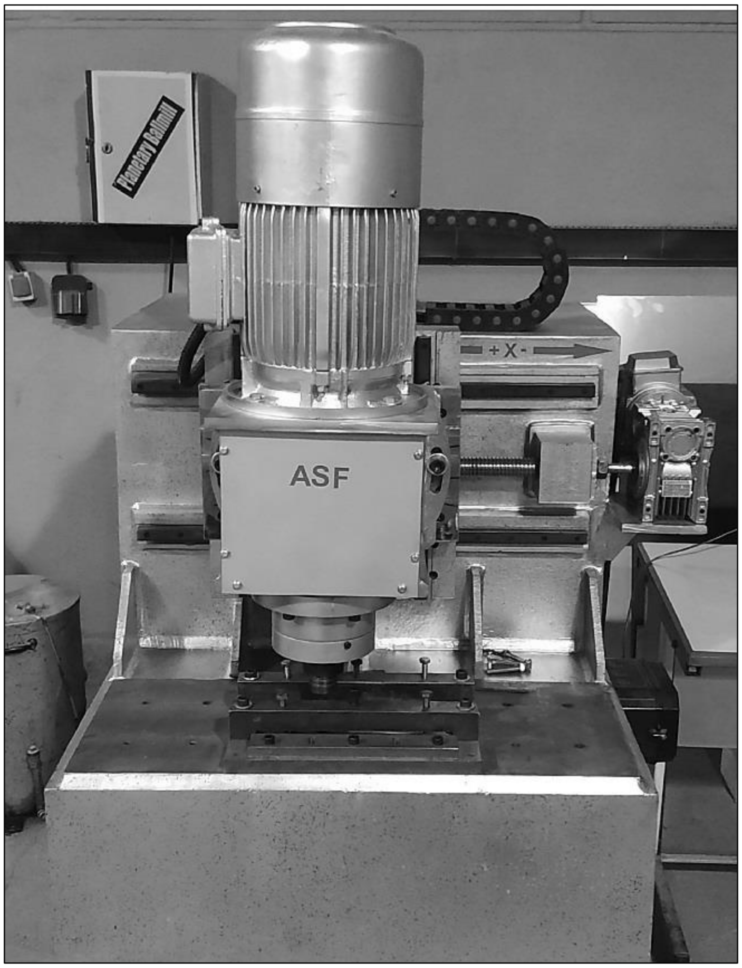

Figure 1. The FSW machine applied in the present study

2.2. Inspection

Having finished the welding process, in the first step of investigation, the general visual inspection (VT) was carried out on the external surface of all welded joints. Visual inspection is a qualitative and non-destructive examination to verify the presence of macroscopic and external (surface) defects. For more investigations, all joints produced in different welding conditions were cut transversely to the weld line, and then the surface of cross-section in joints was mechanically ground, polished, and subjected to visual inspection.

2.3. Tensile tests

Tensile tests with speed of 1 mm/min were carried out using the SANTAM testing machine to study the effect of FSW parameters on the mechanical strength of welding joints. For this aim, the perpendicular tensile specimens with 25 mm gauge length were extracted from the welded joints.

Table 1. The combination of FSW parameters for welding processes

FSW Sample	Tool Travel Speed (mm/min)	Tool Rotation Speed (rpm)
(a)	100	800
(b)	100	1000
(c)	100	1200
(d)	50	1000
(e)	75	1000
(f)	125	1000

3. Results and Discussions

The surface of butt joints produced by the FSW process is shown in Fig. 2. The welding direction is indicated in this Figure. Among the visual defects, the lateral flash was observed in most welded joints, resulting from the outflow of the plasticized material from underneath of the shoulder [14]. The defects like lateral flash reduce the quality of welding joints and impact the manufacturing cost [15,16]. The results of this study showed that there is a relation between tool travel speed, tool rotation speed and occurrence of lateral flash. The most value of lateral flash was observed in Fig. 2-a (at the lowest value of tool rotation speed) and in Fig. 2-d (at the lowest value of tool travel speed). Comparatively, the lower value of lateral flash was observed in Fig. 2-c (at the highest value of tool rotation speed) and in Fig. 2-f (at the highest value of tool travel speed). In other words, the lateral flash value decreased for the highest tool rotation speed or tool travel speed in this study. Almost no lateral flash was observed there in Fig. 2-b (at tool travel speed of 100 mm/min and tool rotation speed of 1000 rpm). Hence, it seems to be the optimum condition in this work. The cross-section surface of welding joints is shown in Fig. 3. According to this Figure, incomplete root penetration (IRP) defect was observed in all welding condition. The occurrence of this defect means that a portion of joint root is not completed and filled with weld metal. This defect can be avoided with increasing of weld penetration in joint root. Generally, weld penetration depends on the value of FSW parameters. The IRP defect seriously hampers the joint strength [17]. The tunneling defect was detected in joint welded at tool travel speed of 75 mm/min and tool rotation speed of 1000 rpm (Fig. 3-e). This is a common defect in FSW which significantly affects the mechanical properties of the welded joints. It is not normally visible on the surface as it is formed inside, below the surface [18].

The results of tensile tests are shown in Figs. 4 and 5. As shown in Fig. 4, the failure has similarly occurred in the middle of the weld line in all tensile test specimens. According to the Fig. 5, when tool rotation speed was increased from 800 to 1000 rpm at tool travel speed of 100 mm/min, the yield strength and UTS of the welded joints increased 20 and 10 MPa, respectively. But more increase in tool rotation speed from 1000 to 1200 rpm resulted in decreasing yield strength and UTS, 26 and 20 MPa, respectively. The higher strength of joint welded at 1000 rpm (sample b) can be due to the higher quality of joint in this condition. According to Fig. 2, no lateral flash is observed in sample b.

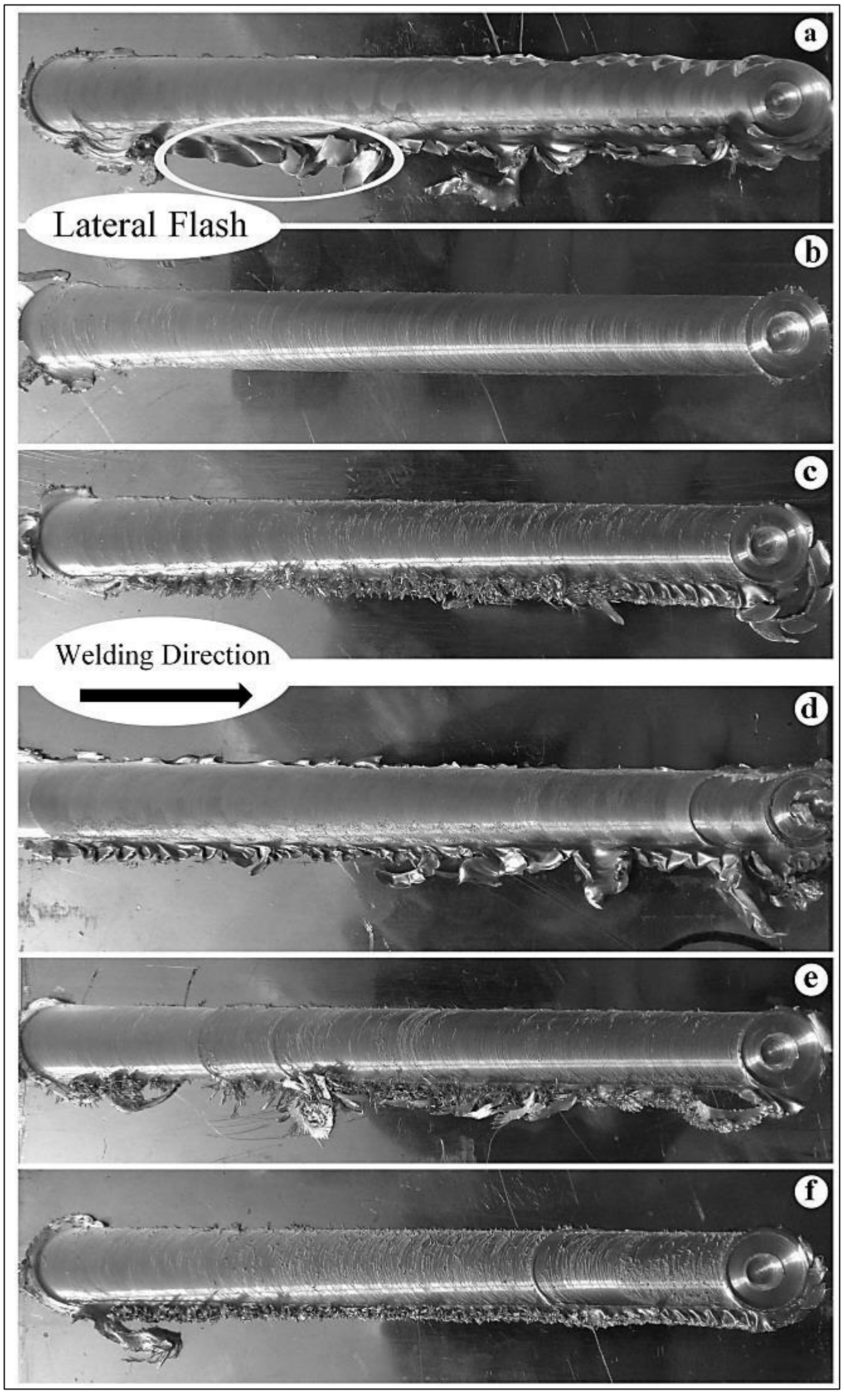

Figure 2. The surface of FSW joints.

When tool travel speed was increased from 50 to 75 mm/min at tool rotation speed of 1000 rpm, the yield strength and UTS of the welded joints decreased 6 and 16 MPa, respectively. But more increase in tool travel speed from 75 to 125 mm/min resulted in increasing yield strength and UTS, both 18 MPa. The lower strength of joint welded at 75 mm/min (sample e) can be due to presence of the tunneling defect in weld in this condition. Hence, the weld defects in FSW can reduce the joint strength [19-21].

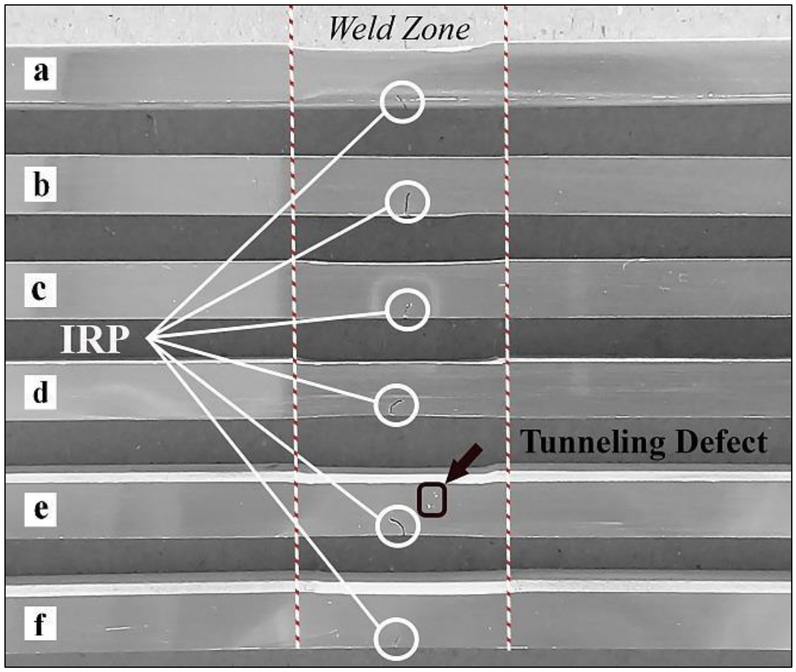

Figure 3. The cross-section surface of welding joints

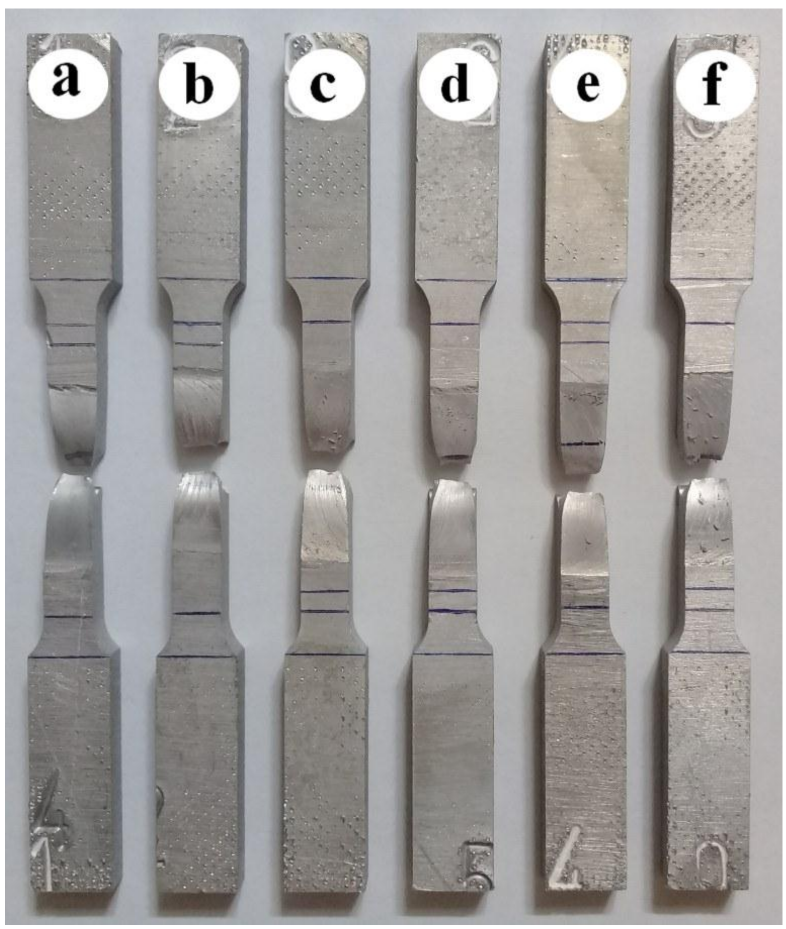

Figure 4. The tensile test specimens

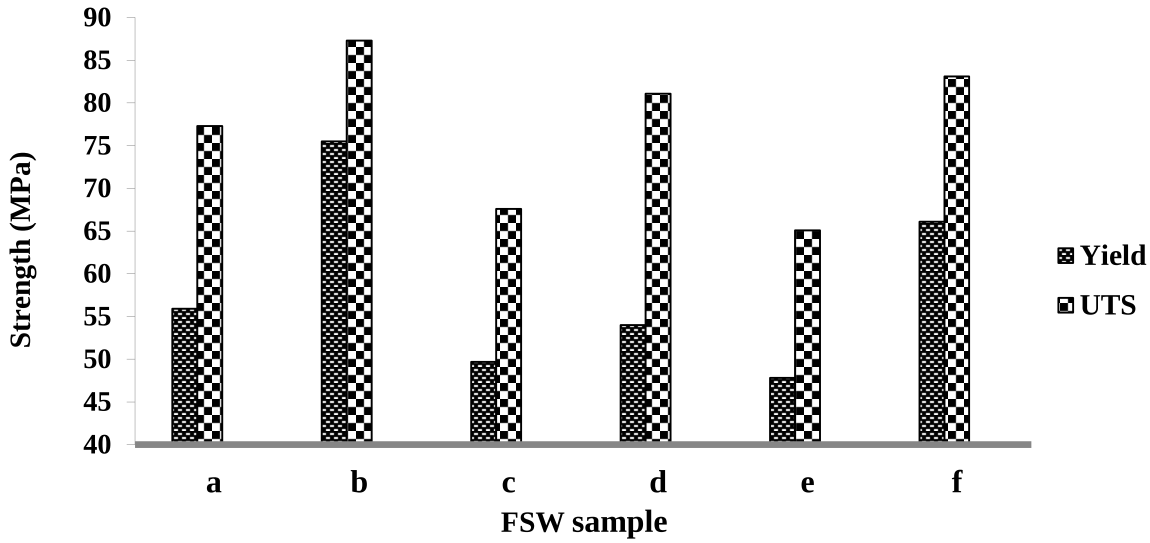

Figure 5. The results of tensile tests

Conclusions

Visual inspection was successfully conducted on the FSW joints of Al-6%Si aluminum alloy, produced in different welding conditions: (1) The lateral flash was observed in most welding joints. Most lateral flash occurred at the lowest tool rotation speed and at the lowest tool travel speed. An optimum condition for producing lateral flash-free welds was found at tool travel speed of 100 mm/min and tool rotation speed of 1000 rpm. (2) the tunneling defect was detected only in joint welded at tool travel speed of 75 mm/min and tool rotation speed of 1000 rpm. (3) the incomplete root penetration defect was observed in all welding condition. (4) When tool travel speed was fixed on 100 mm/min, the strength of the welded joints increased in first and then decreased with increasing of tool rotation speed from 800 to 1200 rpm. (5) When tool rotation speed was fixed on 1000 rpm and tool travel speed was increased from 50 to 125 mm/min, the strength of welded joints decreased in first and then increased. The effect of FSW parameters on the microstructure and impact energy of welding joints can be subjected to investigate in future studies.

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