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M. KEMAL KULEKCI* A. SIK**

EFFECTS OF TOOL ROTATION AND TRANSVERSE SPEED ON FATIGUE PROPERTIES OF FRICTION STIR WELDED AA 1050-H18 ALUMINIUM ALLOY

WPŁYW OBROTU I PRĘDKOŚCI PRZESUWU POPRZECZNEGO NARZĘDZIA NA WŁASNOŚCI ZMĘCZENIOWE SPAJANYCH TARCIOWO PRÓBEK ZE STOPU AA 1050-H18

In this study fatigue behaviour of friction stir welded butt joints of Al-1050-H18 was investigated. Friction stir welds of Al 1050-H18 aluminium alloy material was performed on a semiautomatic milling machine. In the study the same material was welded with different parameters to identify the effect of parameters variation on fatigue behaviour of studied aluminium alloy. FSW tool rotation and transverse speed were accepted as variable parameters while others held fixed. The results of fatigue tests of welded joints showed that the temperature regimes in FSW over required level negatively affect the fatigue endurance limit of the studied joints. Comparison of test results obtained with different tool rotation and transverse speed show that an optimisation is needed to obtain reasonable fatigue endurance limit.

Keywords: Friction stir welding, Friction welding, Fatigue behaviour, Aluminium

W pracy przedstawiono wyniki zmęczeniowych badań połączeń z Al-1050-H18, przeprowadzonych sposobem tarciowym. Spawy ze stopu Al-1050-H18 wykonano za pomocą półautomatycznego urządzenia. Zmieniano parametry spawania, aby zbadać ich wpływ na zmęczeniowe zachowanie badanego stopu Al. Zmiennymi parametrami były prędkość obrotowa wrzeciona oraz przesuw poprzeczny, pozostałe parametry były ustalone. Wyniki prób zmęczeniowych pokazały, że spawanie tarciowe, w zakresie temperatur powyżej wymaganego poziomu, negatywnie wpływa na wytrzymałość zmęczeniową złączy. Porównanie wyników testów, otrzymanych przy różnychprędkościach obrotowych i przesuwu wskazuje na potrzebę optymalizacji parametrów w celu uzyskania odpowiedniej wytrzymałości zmęczeniowej.

1. Introduction

Friction stir welding (FSW) was developed and patented by The Welding Institute (TWI-UK) [1]. FSW offers a new, low cost alternative to fusion welding procedures due to the low power requirements, no gas shielding and no special joint edge preparation [2]. The process is repeatable, can be easily monitored and does not produce any major safety hazards such as fume or radiation [3]. Aluminium alloys with good heat transfer, high strength, good formability and weight saving are being used for aerospace structure, shipbuilding, railway cars, etc. Aluminium has several chemical and physical properties that influence its welding characteristics. The specific properties that affect the welding of aluminium and its alloys are its oxide characteristics; the solubility of hydrogen in molten aluminium; its thermal, electrical and non-magnetic characteristics; its lack of colour change when heated and its alloys wide range of mechanical properties and melting points [4]. FSW of aluminium alloys has advantages over fusion welding processes. Problems in fusion welding of aluminium alloys such as solidification cracking, liquation cracking, and porosity are eliminated with FSW due to its solid-state nature of the process [5, 6]. In FSW procedure the joining takes place through the movement of a rotating shouldered tool with profiled pin plunged into the joint line between two pieces of sheet or plate material as seen in Figure 1. When the rotating pin tool moves along the weld line, the material is heated up by friction produced between the shoulder of the tool and the workpiece to be weld [7]. The strength of the metal of the interface between the rotating tool and workpiece falls to below the applied shear stress as the temperature rises, so that plasticized material is extruded from the leading side to the trailing side of the tool. The tool is then steadily moved along the joint line giving a continuous weld [8]. The plates to be welded are secured to prevent the butted joint faces

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* MERSIN UNIVERSITESI, TARSUS TEKNIK EGITIM FAKULTESI, 33480 – TARSUS, TURKEY
** GAZI UNIVERSITY, INDUSTRIAL ARTS EDUCATION FACULTY, BESEVLER, ANKARA, TURKEY

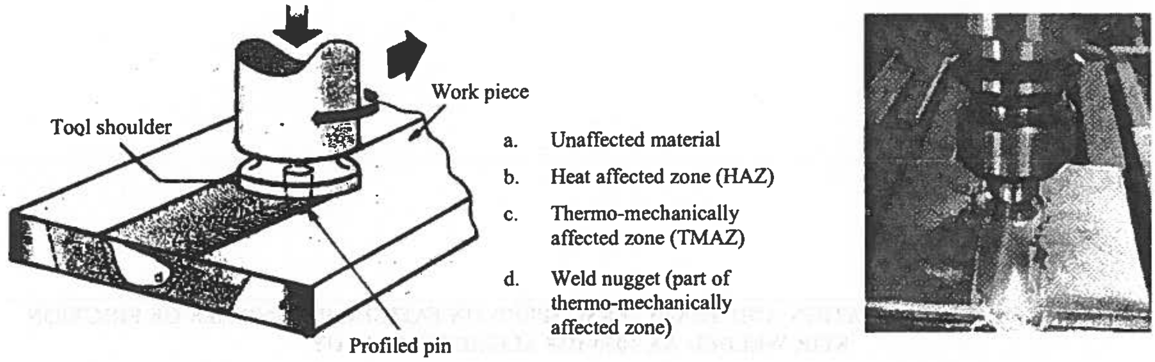

Fig. 1. a) Schematic illustration of friction stir welding process and microstructure of heat affected zone [4], b) FSW application on conventional milling machine

from being forced apart as the probe passes through and along the seam. The heat affected zone is much wider at the top surface (in contact with shoulder) and tapers down as the probe diameter reduces [8, 9]. The combined frictional heat from the probe and the shoulder creates a highly plasticized "third body" condition around the immersed probe and adjacent containing materials of workpiece. This highly plasticized material provides hydrostatic effect as the rotating tool moves along the joint, which helps the plasticized material to flow around the tool [2, 10, 11].

In this study the effect of parameters of friction stir welding on the properties of joining was investigated. Changes in the properties of welds were assessed taking into account the test results of specimens, which machined out from plates that welded with various tool rotation (rpm) and transverse speed.

2. Experimental procedure

The material used in this study was commercial AA 1050-H18 aluminium alloy. Initially aluminium alloy plates were machined out in the sizes of 200 mm length, 100 mm in width and 4 mm in thickness. The chemical composition and mechanical properties of studied material are listed in Table 1.

TABLE 1
Properties of AA 1050-H18 aluminium alloy

<table>
<tr><th colspan="8">Chemical Composition %</th></tr>
<tr><td>Al</td><td>Si</td><td>Ni</td><td>Zn</td><td>Fe</td><td>Sn</td><td>Ti</td><td>Cu</td></tr>
<tr><td>99.50</td><td>0.10</td><td>0.0015</td><td>0.05</td><td>0.30</td><td>0.0010</td><td>0.04</td><td>0.05</td></tr>
<tr><th colspan="8">Mechanical Properties</th></tr>
<tr><td colspan="2">Yield strength (MPa)</td><td colspan="2">Tensile strength (MPa)</td><td colspan="2">Elongation (%)</td><td colspan="2">Hardness-HB (MPa)</td></tr>
<tr><td colspan="2">120</td><td colspan="2">140</td><td colspan="2">3</td><td colspan="2">196</td></tr>
</table>

The main parameters of FSW are; properties of material to be welded, tool material, tool geometry, tool rotation speed, welding speed and the angle between axis of tool and vertical milling machine tool holder axis. In this study welding speed and tool rotation speed were selected as variable weld parameters, while others selected as fixed. Premachined plates were abutted along a longitudinal section and fastened rigidly on the table of the vertical semiautomatic milling machine. The rotating tool was fixed to the spindle of the milling machine and the spindle of the milling machine was adjusted at an angle of 1.5 degree away from the spindle's travel path. During applying FSW firstly the surface of the workpiece was come in contact with the shoulder and at this stage vertical insertion of tool towards plates were stopped. To generate the required pre-frictional heating, the shoulder of rotating tool was held in its initial position for 30 seconds rubbing with the surface of workpiece. then tool was moved along the joint line. During experimental studies friction stir welds were carried out at different tool rotation and transverse speed as listed in Table 2.

TABLE 2
Tool rotations (rpm) and transverse speeds of the FSW tool

FSW No	Tool rotation (rpm)	Transverse speed (mm/minute)	Ratio of tool rotation to transverse speed (rotation/transverse index)
1	1000	120	8.33
2	1500	120	12.5
3	2500	120	20.83
4	2500	200	12.5

FSW welds were applied in transverse direction to the rolling direction of the plates. Typically, the surface appearance of FSW was a regular series of partially circular ripples, which point towards the start of the weld. The surface colours of friction stir welds were silvery white for studied material. In order to evaluate the effects of tool rotation (rpm) and transverse speed on fatigue behaviour of single-sided butt welds, three point bending fatigue tests were applied to specimens machined out from welded plates.

The fatigue tests were carried out in a three-point bending fatigue tests machine. Fatigue tests were made using 8 specimens for base material and for each group of welded joints. For all of the fatigue tests endurance limit was taken as 1,00E+06 cycle as recommended in literature. Dimensions of the fatigue test specimens are given in Figure 2. The stress values of the tests were calculated using the following classic beam formula [12].

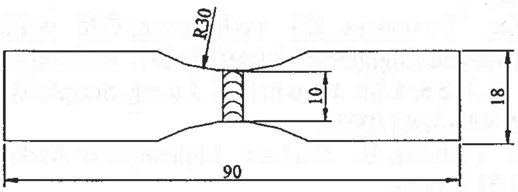

Fig. 2. Dimensions of the fatigue test specimens

$$\sigma = (M \cdot C)/I, \tag{1}$$

$$I = (b \cdot h^3)/12, \tag{2}$$

Where; σ is the maximum stress, M the bending moment, C the minimum distance between the surface of the beam and geometric centre of the section of beam, I inertia moment, b the width of the beam section and h is the thickness of the beam section. The specimens of base material were failed in the minimum throat section. The specimens of the welded plates were taken in transverse direction of weld line. The specimens of the FSW were failed in the section of heat-affected zone. This situation is in accordance with the studies in literature [13, 14]. Transverse bend test were applied to each group of FSW to evaluate the root of the welds. The tests used full-thickness strip specimens, 20 mm wide cut transverse to the weld. The results of transverse bend tests are listed in Table 3.

TABLE 3

Bend test conditions and results with the weld roots

FSW No	Inspection-comments
1	Flaw-free 180° Bend: no cracking
2	Flaw-free 180° Bend: no cracking
3	Flaw-free 180° Bend: no cracking
4	Flaw-free 180° Bend: no cracking

3. Results and discussion

Fatigue test results of FSW specimens, which welded with same transverse speed and different tool rotation, are given in Figure 3. From the figure it is seen that increase in the tool rotation results in decrease in fatigue endurance limit while transverse speed held fixed. There is not much difference between fatigue test results of welds obtained with 1000 and 1500 tool rotations as seen Figure 3. Rotation / Transverse speed indexes of the welds and fatigue test results are shown in Figure 3 shows that, greater index values results in lower fatigue endurance limit. These results show that for a fixed transverse speed there is an optimum tool rotation. Additional studies are needed to identify optimum tool rotation and transverse speed in order to obtain most suitable fatigue strength. Increasing the tool rotation from 1000 rpm to 1500 and 2500 rpm, for 120 mm/minute transverse speed reduced the fatigue strength as seen in Figure 3. Increase in tool rotation, increases the temperature in the weld region. This results shows

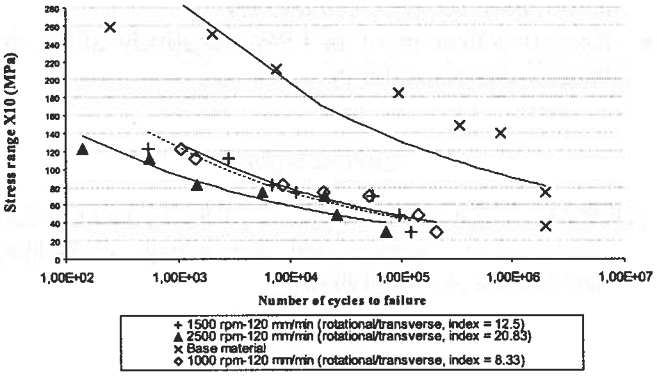

Fig. 3. Fatigue test results of friction stir welds obtained with same transverse speed and different tool rotation

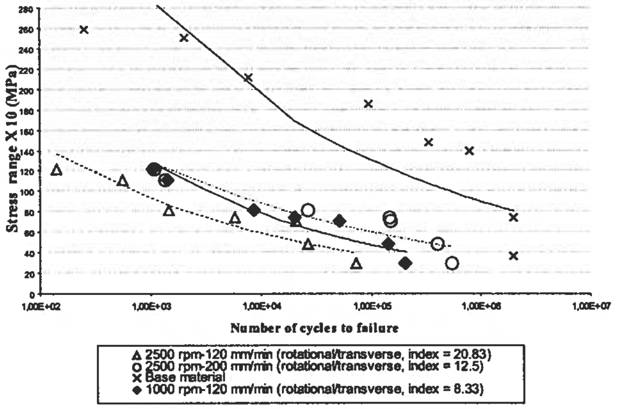

Fig. 4. Comparison of fatigue endurance limit obtained with same tool rotation and different tool transverse speeds

that excessive heat input in FSW negatively affect the fatigue endurance limit. Fatigue endurance limits of FSW specimens welded with same tool rotation and different transverse speed are given in Figure 4. The Figure 4 also verify that an optimum tool rotation and transverse speed can be identified in FSW applications. Comparison of tool rotation/transverse speed indexes show that 12.5 index value can be used for studied material to select the tool rotation and transverse speed parameters.

4. Conclusion

- In FSW process an optimisation between tool rotation and transverse speed is needed to obtain better fatigue behaviour.
- An index of rotation/transverse speed of FSW tool can be used to identify optimum tool rotation and transverse speed parameters.
- Temperature regime in stirring zone can be controlled by optimising the tool rotation and transverse speed parameters.
- An 12.5 index of rotation/transverse speed can be used for studied material to identify the tool rotation and transverse speed parameters.
- Excessive heat input in FSW negatively affect the fatigue endurance limit.

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