

Mechanical and microstructural properties of EN AW-6060 aluminum alloy joints produced by friction stir welding

İ. KÜÇÜKRENDECI*

Sakarya University, Akyazi Vocational School, Department of Machine Technology, Akyazi/Sakarya, Turkey

Abstract. In the study, the mechanical and microstructural properties of friction stir welded EN AW-6060 Aluminum Alloy plates were investigated. The friction stir welding (FSW) was conducted at tool rotational speeds of 900, 1250, and 1500 rpm and at welding speeds of 100, 150 and 180 mm/min. The effect of the tool rotational and welding speeds such properties was studied. The mechanical properties of the joints were evaluated by means of micro-hardness (HV) and tensile tests at room temperature. The tensile properties of the friction stir welded tensile specimens depend significantly on both the tool rotational and welding speeds. The microstructural evolution of the weld zone was analysed by optical observations of the weld zones.

Key words: friction stir welding, microstructure, mechanical properties, aluminum alloys.

1. Introduction

Friction stir welding (FSW) is a solid state welding technique. This process is effective for welding of various aluminum, magnesium and copper alloys. In the FSW process a non-consumable rotating steel tool consisting of two parts, pin and shoulder, moves along the weld seam. The joining is accomplished as a result of the localized frictional heat and plastic deformation associated with the movement of material from the front to the back of the rotating pin [1].

Several investigations were carried out to study the mechanical and microstructural properties of aluminum alloy joints produced by FSW. Some studies performed on the topic. The influence of the tool rotational and welding speeds on such characteristics was studied [1]. An approximate finite element model of the joint, taking into account the spatial dependence of the tensile strength properties, was made, modelling a bending test of the weldments [2]. A large-diameter thin-walled aluminum alloy tube was produced by friction stir welding combined with spinning, and the tube's microstructure and mechanical properties were investigated [3]. Mechanical and microstructural properties of Al-5083/St-12 lap joints made by FSW were analyzed [4]. The effect of processing parameters on the mechanical and microstructural properties of dissimilar AA6082-AA2024 joints produced by friction stir welding was studied [5]. The microstructural characterization evidenced, in the FSW zone, a substantial grain refinement of the aluminium alloy matrix and a significant reduction of the particles size [6]. Butt joints of 1060 aluminum alloy and commercially pure copper were produced by friction stir welding (FSW) and the effect of welding parameters on surface morphology, interface microstructure and mechanical properties was investigated [7]. The effect of severe plastic deformation (SPD), FSW and heat treatment on the microstructure and mechanical properties of the welds and sheets was exam-

ined [8]. The effect of processing parameters on mechanical and microstructural properties of AA6056 joints produced by FSW was analysed [9].

In this study, 10 mm thick of EN AW-6060 aluminum alloy plates joined by friction stir welding process. The effect of tool rotational speed and welding speed were studied on the weld zone. Microstructural and mechanical properties of welded EN AW-6060 aluminum alloy plates using FSW were investigated.

2. Experimental procedures

The alloy used in this study is EN AW-6060 aluminum alloy. The chemical composition of the alloy is listed in Table 1. The mechanical properties of the alloy is given in Table 2. The EN AW-6060 base metal has ultimate tensile strength of 220 MPa and percent elongation of 13%, respectively. The FSW process is shown in Fig. 1. In the Fig. 1, two plates of EN AW-6060 Al alloy were welded. Each Plate have dimensions of 300 mm (length)×100 mm (width)×10 mm (thickness). A FSW tool made from 4140 steel with a 5 mm pin diameter, 20 mm shoulder diameter, and pin length of 6 mm was used (see Fig. 2). The welding processes were conducted using vertical milling machine at three different tool rotation speeds, typically, 900, 1250, and 1500 rpm. Three different welding speeds were selected as 100, 150 and 180 mm/min. In Table 3 was listed the parameters of FSW. The tool angle and friction pressure was held constant. The dimensions of tensile specimens is showed in Fig. 3. This specimens were machined from the welded plates. The welded zone was positioned in the middle of the specimen. The ultimate tensile strength and the percentage of elongation have been determined. Tensile tests are conducted by using Zwick-Roell 250 tensile testing device. The microstructural properties of the welds were investigated using Nikon op-

*e-mail: ikucukrendeci@sakarya.edu.tr

tical metallurgical microscope. The welded specimens were obtained by cutting direction perpendicular to the junction surfaces. The specimens were grounded, polished, and etched before the examination. Microhardness measurements were made with the Emco Test MCC025G3M device. Vickers microhardness tests with 100 g load were carried out for measuring the hardness across the welded joint. In the analysis, standard pyramidal tip (136°) was used. The measuring range was selected (1 mm).

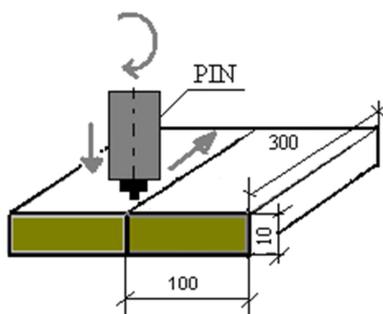


Fig. 1. Welding position and dimensions [mm]



Fig. 2. Mixer pin used in FSW

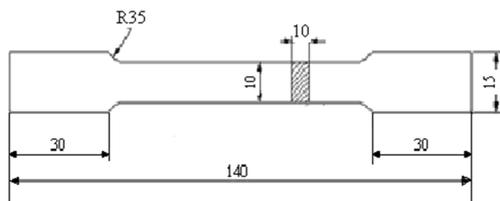


Fig. 3. Size of the specimen used in tensile tests according to DIN 50109

Table 1
 Chemical composition of EN AW-6060 Al alloy (wt.%)

Cu	max 0.10
Fe	0.10–0.50
Si	0.30–0.60
Zn	max 0.13
Mn	max 0.10
Mg	0.35–0.60
Cr	max 0.05
Al	Balans

Table 2

Mechanical properties of EN AW-6060 Al alloy

E [Mpa]	G [Mpa]	ν	ρ [kg m ⁻³]	Rm [MPa]	Pp02 [Mpa]	RG [MPa]	A [%]	HB	HV
69500	26100	0.33	2700	220	185	140	13	75	80

Table 3

Welding parameters for FSW

Material	Profile of mixer	Rotation speeds rev/min (rpm)	Welding speeds mm/min	Specimen number
EN AW-6060	Screw	900	100	S1
			150	S2
			180	S3
		1250	100	S4
			150	S5
			180	S6
		1500	100	S7
			150	S8
			180	S9

3. Results and discussion

3.1. Mechanical properties. Figures 4–6 show the distributions of the micro-hardness along the center line on a cross-section of the welds at different rotational and speeds. It has been observed that, in most cases, the hardness profiles have closer shapes. In the weld zone, hardness values has slightly lower than the base metal. The hardness of the weld zone can be attributed to the extra-fine grained structure. In Fig. 5, the highest hardness values is observed in the speed of 150 mm/min. Hardness values are close to each other In the speed of 100 mm/min and 180 mm/min. In Fig. 7, the variation of the hardness at the center of weld zone with the welding speed at different tool rotational speeds is showed. It is clear that at 900 rpm tool rotational speeds has lower values of the hardness according to 1250 and 1500 rpm. In the tool rotational speed of 1500 rpm, hardness values of the center of the weld zone has increased to 900 and 1250 rpm.

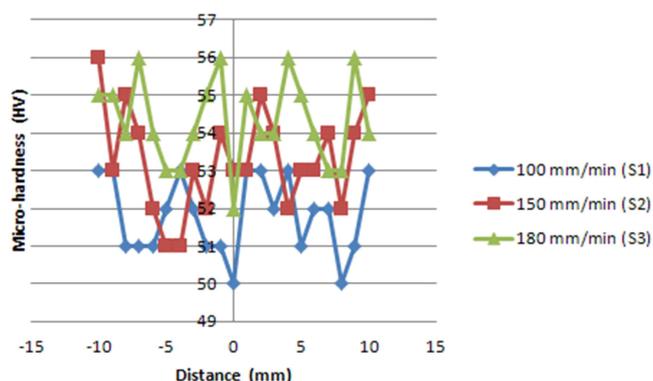


Fig. 4. Micro-hardness distributions at 900 rpm

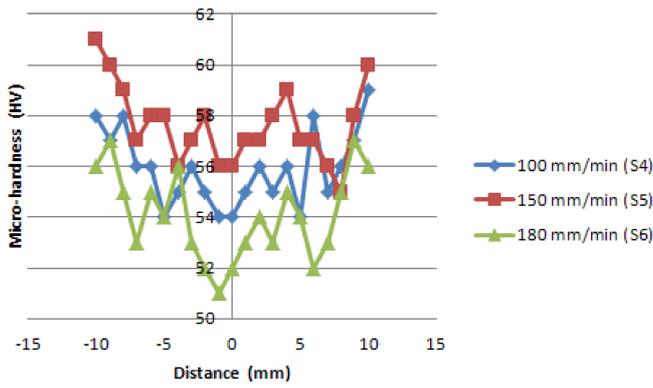


Fig. 5. Micro-hardness distributions at 1250 rpm

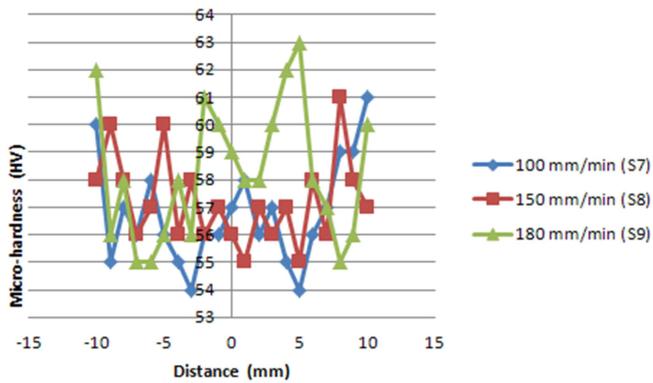


Fig. 6. Micro-hardness distributions at 1500 rpm

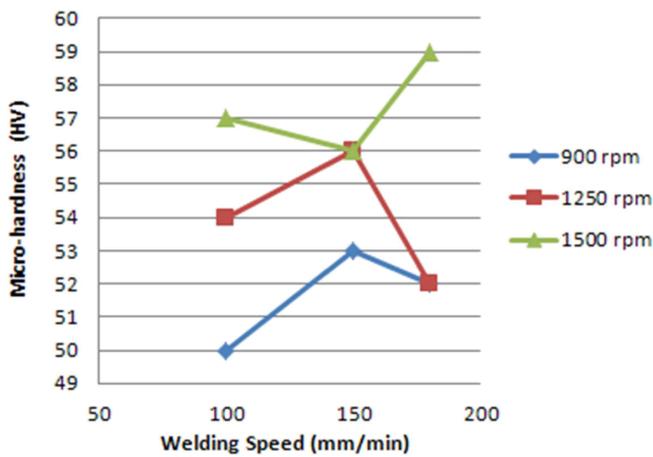


Fig. 7. The variation of the hardness at the center of weld zone (the welding speed: 100, 150 and 180 mm/min and the tool rotational speed: 900, 1250 and 1500 rpm)

In Fig. 8, the variation of the tensile properties with welding speed at several tool rotational speeds is showed. It is clear that, at 900, 1250 and 1500 rpm tool rotational speed, increasing the welding speed decreases the tensile strength of the FSW joints tensile specimens. The values of tensile strength of 900 rpm are lower than 1250 and 1500 rpm. The FSW tensile specimens exhibited lower elongation percent than the base material. It can be said that increasing the tool rotational

speed decreases the ductility of the samples. The tensile specimens FSW at tool rotational speed of 900 rpm exhibited the highest ductility when compared with the tensile specimens FSW at both 1250 and 1500 rpm. The welding speed can be effective on the ductility of the tensile specimens.

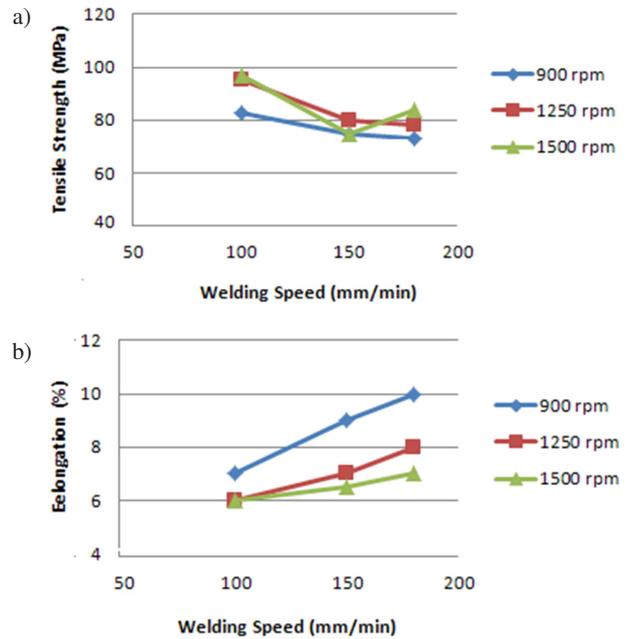


Fig. 8. Variation of tensile properties (a) tensile strength and (b) percentage elongation]

3.2. Microstructural investigations. Typical microstructure of FSW joints is showed in Fig. 9. The microstructure shown in Fig. 9 are for a specimen welded at tool rotational speed of 1500 rpm and welding speed of 100 mm/min. It is clear that, the macrostructure of the FSW alloy consists mainly of four distinct zones, typically, A: dynamically re-crystallized zone, B: thermodynamic re-crystallized zone, C: heat affected zone, D: the main metal. The “B” zone experiences both temperature and deformation during FSW and characterized by a highly deformed structure. The heat affected zone “C”

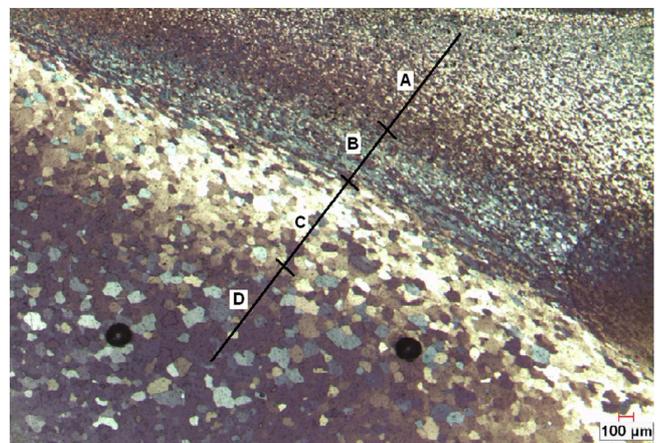


Fig. 9. Microstructure of FSW joints at 1500 rpm and 100 mm/min

is the zone that is believed to be unaffected by any mechanical effects but only the thermal effects caused by the frictional heat generated by the shoulder and tool pin rotation [1]. Typical microstructures of FSW joints at tool rotational speeds of 900 and 1250 rpm and welding speed of 100 mm/min are showed in Figs. 10 and 11.

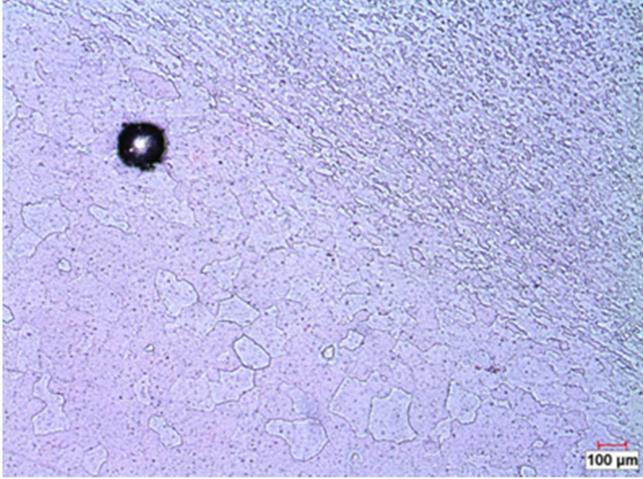


Fig. 10. Microstructure of FSW joints at 900 rpm and 100 mm/min

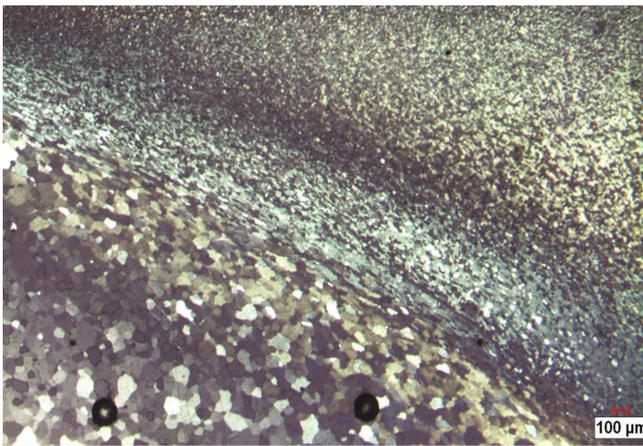


Fig. 11. Microstructure of FSW joints at 1250 rpm and 100 mm/min

4. Conclusions

Increasing welding speed, at the tool rotational speed of 1500 rpm, increases the hardness at the center of the weld

zone. At both 900 tool rotational speeds, increasing the welding speed has no significant influence on the hardness at the center of weld zone. At the tool rotational speeds of 900, 1250 and 1500 rpm, increasing the welding speed decreases the tensile strength of the FSW joints tensile specimens. Increasing the tool rotational speed decreases the ductility of the specimens. The welding speed can be effective on the ductility of the tensile specimens. The microstructure of weld zone was found to be normal evolution.

REFERENCES

- [1] A.M. Gaafer, T.S. Mahmoud, and E.H. Mansour, "Microstructural and mechanical characteristics of AA7020-O Al plates joined by friction stir welding", *Materials Science and Engineering A* 527, 7424–7429 (2010).
- [2] P.M.G.P. Moreira, T. Santos, S.M.O. Tavares, V. Richter-Trummer, P. Vilaça, and P.M.S.T. de Castro, "Mechanical and metallurgical characterization of friction stir welding joints of AA6061-T6 with AA6082-T6", *Materials and Design* 30, 180–187 (2009).
- [3] Z.L. Hu, S.J. Yuan, X.S. Wang, G. Liu, and H.J. Liu, "Microstructure and mechanical properties of Al-Cu-Mg alloy tube fabricated by friction stir welding and tube spinning", *Scripta Materialia* 66 (7), 427–430 (2012).
- [4] M. Movahedi, A.H. Kokabi, S.M. Seyed Reihani, and H. Najafi, "Mechanical and microstructural characterization of Al-5083/St-12 lap joints made by friction stir welding", *Procedia Engineering* 10, 3297–3303 (2011).
- [5] P. Cavaliere, A. De Santis, F. Panella, and A. Squillace, "Effect of welding parameters on mechanical and microstructural properties of dissimilar AA6082-AA2024 joints produced by friction stir welding", *Materials and Design* 30, 609–616 (2009).
- [6] L. Ceschini, I. Boromei, G. Minak, A. Morri, and F. Tarterini, "Effect of friction stir welding on microstructure, tensile and fatigue properties of the AA7005/10 vol. % Al₂O₃ composite", *Composites Science and Technology* 67 (3–4), 605–615 (2007).
- [7] P. Xue, D.R. Ni, D. Wang, B.L. Xiao, and Z.Y. Ma, "Effect of friction stir welding parameters on the microstructure and mechanical properties of the dissimilar Al-Cu joints", *Materials Science and Engineering A* 528 (13–14), 4683–4689 (2011).
- [8] I. Nikulin, S. Malopheyev, A. Kipelova, and R. Kaibyshev, "Effect of spd and friction stir welding on microstructure and mechanical properties of Al-Cu-Mg-Ag sheets", *Materials Letters* 66 (1), 311–313 (2012).
- [9] P. Cavaliere, G. Campanile, F. Panella, and A. Squillace, "Effect of welding parameters on mechanical and microstructural properties of AA6056 joints produced by friction stir welding", *J. Materials Processing Technology* 180 (1–3), 263–270 (2006).