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Effects of Rotating Speed and Feed Rate on Mechanical Behaviors in EN-AW6060 Aluminum Alloys Bonded by Using Friction Stir Welding

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Abstract: In the study, 5mm thick ENAW-6060 aluminum plates were butt welded from one side through friction stir welding (FSW), which is a solid state bonding method, by using 3 different rotating speeds and feed rates.In the welding process, universal milling was used. Tension test was applied to welded connections to determine the effects of different rotating speeds and feed rates on mechanical behaviors. Results obtained from tension tests revealed that the rotating speed and feed rate affect the tensile strength results of EN AW-6060 aluminum plates bonded by using FSW.

Key words: Friction Stir Welding · EN AW-6060 Series of Aluminum Plates · Mechanical Properties

INTRODUCTION

Aluminum alloys are widely used as high specific strength material in automotive, avionics and ship-building industries. Friction stir welding is a solid state welding method.Aluminum alloys have been proved to be highly efficient in bonding materials other than non-ferrous ones such as cooper and magnesium.

In this welding method, materials could be bonded before reaching fusion heat. By using FSW, it is possible to produce strong and high quality welding. In this process, there is no oxidation and pores. FSW is more advantages than conventional welding methods. Because there isn't any formation of smoke and spark and the cost is low. FSW has been used pretty successfully in avionics, automotive and ship-building industries [1]. In FSW, firstly the parts to be welded are pressed with a clamp on a base. The, a rotating cylindrical pin is moved along the connection line by pushing it slowly to center line of the connection until it contacts with the work-piece. Heat from friction results in plastic deformation of the material against the tool and the material is extruded by moving it towards the back of the tool [2]. Welding is made with the forward movement of the pin, which is the heat source. The mechanisms dominating FSW are friction, plastic deformation and recrystallization. All of these mechanisms could be triggered in aluminum alloys [3]. In the literature, there are many studies on the mechanical behaviors of aluminum alloys bonded through FSW and aluminum-based metalmatrix composites. Al 6013-T4 alloy and X5CrNi18-10 stainless steel were connected by using FSW [4]. Two distinct alloys, TC1 Ti alloy and LF6 Al alloy, were connected through FSW and interface features were investigated [5]. To calculate the heat generated due to the plastic deformation in FSW process, 'Johnson-Cook Plasticity Model' was applied [6]. With thermo-mechanical simulations for FSW, heat transmission areas were detected. Residual stresses were calculated by means of 3D force analysis in the weld zones [7]. Composite Al_2O_3 particles and aluminum matrix (AA7005) material reinforced volumetrically by 10% were bonded by FSW and weld zone was studied [8]. AA7020-O Al plates were connected with FSW and the effects of rotating speed and feed rate in welding operation on the microstructure and mechanical features were studied [9]. 1 mm-thick AA 6060-T4 Al alloy plates, by using two different pins, were bonded with FSW. Microstructure and mechanical features of the connection were compared and analyzed

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[10]. To simulate FSW, solid mechanic based on finite element models and calculating procedures was developed by the authors [11]. 3D mechanical models were presented for FSW [12]. To different alloy plates, Al6061-T6 and AZ31, were bonded using FSW process by interposing foil between them. To reinforce the weld-connection, the effect of the foil, being the 3rd material in the weld zone, on weld-connection was researched [13].Frictionstirwelding (FSW) is a simplethree-dimensionalthermomechanical model waspresented [14].6 mm thick plates of 5052 Al and AZ31 Mg alloys were bonded by using FSW and welding operation is examined [15].For FSW, without mixer pin, a new concept, by using a rotating tool it was suggested that thin Al alloys plates could be welded. The experiments regarding welding process were executed by using concave-flute-shoulder tools [16]. 2024-T3 and 0,8 mm thick 6082-T6 plates, thin aluminum alloys, were bonded in the rolling direction using FSW. They were bonded both in a similar and different way and analyzed [17]. Material flow of aluminum alloys were empirically examined during FSW process [18]. By using FSW 7075-T6 and 2024-T3 Al alloys were bonded and mechanical features of weld zone were examined. Welding speed, micro hardness distribution and tensile features of weld zone were examined [19].AA5083-H18 plates were bonded by using FSW. Thermo-mechanical features of weld zone were investigated through finite element method [20]. During FSW, material flow was examined with the help of a surface-tracking pin [21]. Al359+%20 SiCmetalmatrix composite plate was bonded by FSW and eroding of mixer pin was investigated in the process [22]. Following the bonding process of nanostructuredAl-4.0Y-4.0Ni-0.9Co alloy by using FSW, ductility feature of the weld zone was examined [23]. Microstructure and mechanical features of welding were examined following the bonding operation of Al alloys by using FSW [24].

In this study, EN AW-6060 series of Al plates were used and these plates were bonded using FSW. Equipment required for welding was provided and effects of welding process parameters on mechanical behaviors were researched.

Experimental Studies: In this study, EN AW-6060 Al alloys were used. While the nominal chemical composition of the alloy was given in Table 1, its mechanical features were given in Table 2. After having been cut into pieces by 5x100x300 mm from standard EN AW-6060 plates and butt welded, the pieces were fixed to the planer without leaving any void formation between them. In welded-joints, a mixer pin with screw profile made up of 4140 steel was used as seen in Figure 2. In the FSW process, rotating speed, feed rate and profile of mixer pin, determined according to the literature study -having significant effect on microstructure and mechanical behaviors- were chosen and applied carefully. In FSW connections, parameters seen in Table 3 were used. To detect the mechanical behaviors, welded-joint samples, prepared according to the DIN 50109 standard and to criteria given in Figure 3, were used. Tensile

Table 1: Nominal chemical composition of the material used in experiments

	Elements of Composition (% byweight)							
Material	Cu	Fe	Si	Zn	Mn	Mg	Cr	Al
EN AW-6060	max0,10	0,10-0,50	0,30-0,60	max 0,13	max 0,10	0,35-0,60	max0,05	Balans

Table 2: Mechanical features of EN AW-6060 series of Al material

E(Mpa)	G(Mpa)	ν	P(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	Rotationspeed rev/min	Feed rate mm/min	Samplenumber
ENAW-6060	Screw	900	100	S1
			100	S2
			100	S3
		1250	150	S4
			150	S5
			150	S6
		1500	180	S7
			180	S8
			180	S9

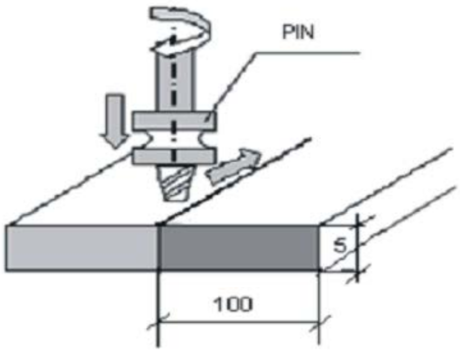

Fig. 1: Schematic diagram of FSW model

Fig. 2: Mixer pin used in FSW

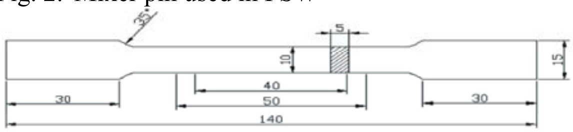

Fig. 3: Size of the samples used in tensile tests according to DIN 50109

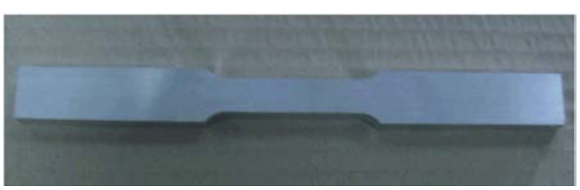

Fig. 4: Samples of solderless connection

Fig. 5: Samples welded at 900 rpm

Fig. 6: Samples welded at 1250 rpm

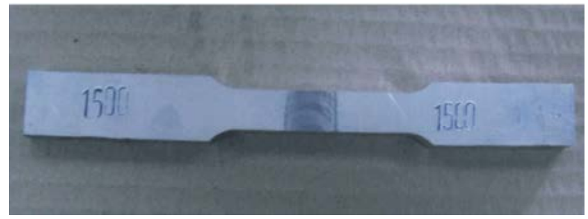

Fig. 7: Samples welded at 1500 rpm

tests/experiments were applied to these prepared samples. Tensile tests were conducted in ASAŞ factory labs and strain and tensile curves were obtained by using Zwick-Roell 250 tensile testing device. In tensile tests, values chosen as follows: pre-load as 5 N/mm^2, elasticity module speed as 5 mm/min, Rp (yield stress) rate as 5 mm/min and test speed as 10 mm/min.

Pictures of the tensile tests of welded-joint and solderless connection samples numbered S1-S9 bonded by using screw profile mixer pin are seen in Figures 4-7.

RESULTSAND DISCUSSION

The results of tensile tests/experiments are shown in Figures 8-9. In Figure 8, strain-tensile graphics of welded-joint samples are seen. In figure 9, strain-tensile graphics of welded and solderless connection samples are seen together.

In Figure 10, values of tensile stress-strain and in figure 11, results of tensile tests of welded-joints samples, bonded with varying rotating speeds and feed rates as shown in Figure 8, are seen.

When Figure 10 is examined, it is seen that tensile stress-strain values of samples numbered S1-S3 are greater than those of the samples numbered S4-S9. And it is clear that tensile stress-strain values of samples numbered S4-S9 are close to each other.

If Figure 11 is examined, it is seen that tensile values of samples numbered S1-S3 are greater than those of the samples numbered S4-S9 and it is clear that tensile values of samples numbered S4-S9 are close to each other.

In Figure 10 and 11, it is clearly seen that a better welding strength was obtained when the welding process was carried out at 900 rpm rotating speed and 100 mm/min feed rate compared to different speeds and rates. From the

Results:

Legends	Nr	L0 mm	EMod kN/mm²	Rp 0,2 N/mm²	Rm N/mm²	A %	Fm N
	1	50,01	61,94	66,20	83,04	6,94	10009
	2	50,01	68,72	67,88	95,91	8,32	11571
	3	50,02	67,22	64,81	97,25	9,64	11670
	4	50,02	22,66	56,84	74,69	5,32	8958
	5	50,03	29,79	53,70	79,54	3,90	9722
	6	50,03	45,86	55,33	74,95	6,94	9066
	7	50,01	37,51	53,26	72,83	6,16	8855
	8	50,03	26,84	53,38	77,90	5,41	9294
	9	50,02	30,18	55,13	83,39	6,60	10071

Fig. 8: Tensile test results I

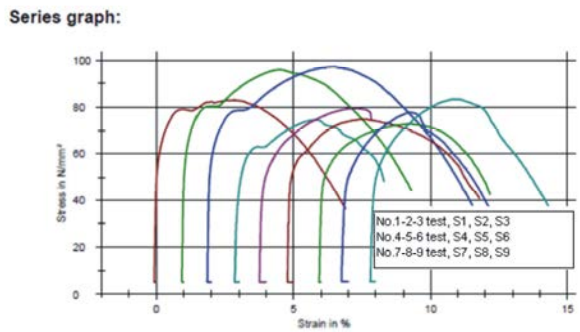

Fig. 9: Tensile test results II

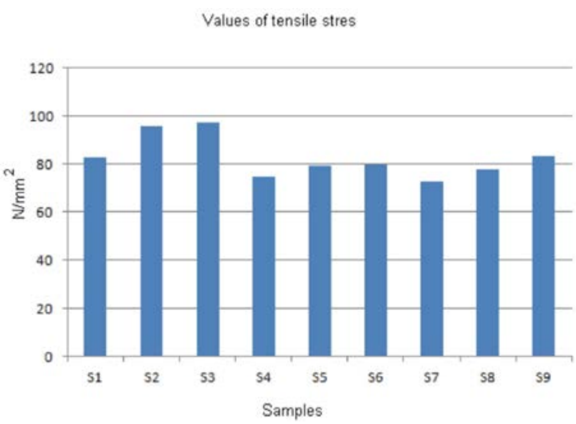

Fig. 10: Values of tensile stress

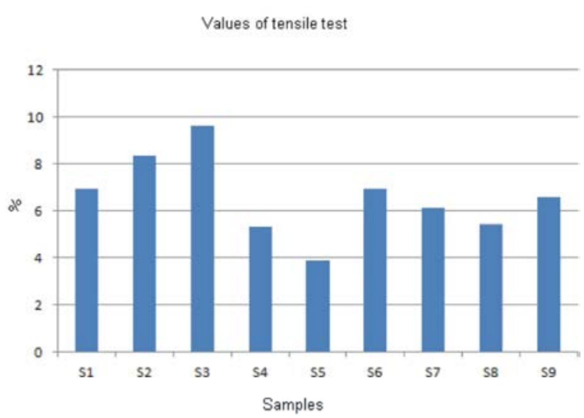

Fig. 11: Results of tensile tests

researches made after rupture, it was seen that all the samples ruptured by forming necks. In this case, it can be said that there were ductile fractures in all samples.

When compared to other speeds and rates, 900 rpm rotating speed and 100 mm/min feed rate, creating a lower temperature in the bonding zone, shrinks ITAB zone and thus affecting the mechanical behaviors of the connection positively. At 1250 rpm rotating speed and 150 mm/min feed rate or at 1500 rpm rotating speed and 180 mm/min feed rate, high heat generation occurred, which widened ITAB zone, thereby decreasing the strength of the connection.

When appropriate rotating speed and feed rate are chosen, the amount of material carried and extruded backward per rotation increases. This increase in the amount of material which is mixed with the help of screw grooves and extruded backward leads to a strong/intense extrusion. As a result of this, the hardening and shrinking of the grains in the connection zone have positive effects on the mechanical features of weld zone. Therefore, not only a strength increase takes place in mechanical behaviors of weld connection, but also strain hardening and shrinking of grains are observed [25].

Due to the viscosity increase of the material in the weld pool resulting from high heat generation, extrusion intensity increases, leading to grains growth. As a result of this, a strength decrease is observed in the weld zone in addition to a brittle fracture behavior [25].

At high rotating speeds and feed rates, as a consequence of heat decrease, a faster cooling takes place in the connection zone. Besides, in proportion to the increase in feed rate, as the increase in the amount of material carried and extruded backward per rotation will reduce the intensity of the extrusion, grain shrinking and granule hardening will be seen less.

CONCLUSION

In this study, 5 mm-thick EN AW-6060 Al alloy plates were butt welded successfully from one side by using screw mixer pin -having screw geometry- through FSW method. From welding seam of welded-joints, it was seen that there were no residue, void and disconnected zone in the joint face. Real tension and tensile curves were obtained from tensile tests applied to the samples of welded-joints. It was found that rotating speed of mixer pin, feed rate and the profile of the mixer pin had significant effects on the strength of the welded-joints. When the real strain and tensile curves of the welded samples connected by increasing the rotating speed of the mixer pin and feed rate were examined, high heat generation was observed. Also grain growth took place due to the increase in the intensity of extrusion caused by the increase in the material viscosity in the weld zone. As a result of this, it can be inferred that strength reduction and brittle fracture occurred in the samples. It is recommended that researchers also conduct similar tests with double-sided welding applications in the coming days.

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