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INFLUENCE OF THE FRICTION STIR WELDING PROCESS PARAMETERS ON IMPACT ENERGY AND MICROSTRUCTURE OF AA6063 Al ALLOY

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Abstract. The joining of AA6063 plates of 12 mm thickness was carried out by friction stir welding (FSW) technique. In the present investigation, the AA6063 was welded with the tool rotational speed of 470, 590,740 and 900 RPM and at a welding traverse speed of 16, 31.5, and 50 mm/min. Charpy V- notch impact test was carried out to analyze the impact strength of the welded specimen at a room temperature, -30°, and -60°. With increasing the tool rotational speed impact energy behavior shows a substantial change in mechanical properties. The microstructure was investigated and the grain size was measured to get the minimum grain size.

Keywords: Friction stir welding, Aluminum Alloys, Impact Energy, Microstructure, Grain Size.

1. INTRODUCTION

Friction stir welding (FSW) is the most important and welding process in the field of aluminum joining and most important of which is its ability to weld generally non-weldable aluminum alloys [1]. A rotating tool with a specially designed pin shape and shoulder profile is inserted into the abutting edges of sheets or plates to be joined and subsequently traversed along the joint line [2]. The initial aluminum FSW studies conducted at The Welding Institute (TWI) used a cylindrical threaded pin and concave shoulder tool machined from tool steel [3]. From 1991 until now the researchers all over the world looking at FSW of aluminum alloys. The researchers discovered the effect of FSW's parameters on mechanical and microstructure of welded joints. For example Jamalian et al. [4] found that increasing the traverse speed, the material underwent severe mechanical stresses and experienced an extensive dynamic recrystallization, which increased the number of nucleation sites and reduced the grain size. Chen et al., [5] studied the microstructure of (FSW) AA6061 and they found that the average grain size in the four zones in follows the order of BM > HAZ > TMAZ > NZ. Approximately in many of papers the influence of Tensile Strength has discuss and investigate by researchers [6,7,8]. Adamowski et al., [9] studies the FSW to investigate the properties and microstructural changes in Friction Stir Welds in the aluminum alloy 6082-T6 in function of varying process parameters. They found that the tensile strength of FSW welds is directly proportional to the travel / welding speed. Impact is a most important factor in calculating the life of a structure or machine. e.g., in an aircraft, impact can take place by a bird during landing and takeoff the aircraft might be struck by debris that is available on the runway, and also different causes. Thus the impact strength must be computed for the safety and to design a component of high factor of safety. Impact tests are used to find the toughness of materials. The research work on the study of joining of dissimilar alloys and the impact strength behavior of the weld joint are very few [6]. Umasankar Das and Vijay Toppo [10] investigated the FSW joining of dissimilar AA6101-T6 and AA6351-T6 aluminum plates of 12 mm thickness and they found that the rotational speed of the tool increases to 1100 rpm, the impact energy of the joint also increases and with further increase in the rotational to 1300 rpm, the impact energy decreases. In the present study, friction stir welding of AA6063 under various welding conditions has been carried out. The effects of tool rotational speed and traverse speed on evaluation of impact strength of welded joints at room and low temperature investigated. Also the micro and macrostructure were investigated

2. EXPERIMENTAL PROCEDURES

2.1. Materials

The aluminum alloys used in this study were AA6063 plates with 12 mm thickness with cold rolled. The chemical compositions of AA6063 is listed in Table 1. The aluminum plates have dimensions of 400 mm length, 80 mm.

Table 1. Chemical composition of 6063 aluminum alloy (wt.-%).

Alloy	Si	Fe	Mg	Mn	Cu	Al
AA6063	0.35	0.36	0.36	0.01	0.01	Bal.

2.2. DESIGN OF EXPERMENT (DOE)

Welding parameters used in this investigation are tool rotational speed in RPM and welding transverse speed in mm/min. welding conditions sorted based on the fall factorial design to evaluate the effect factors of the (FSW) of AA6063 and main effects using all experimental tests.

2.3. Tools Design and FSW Process

The FSW process of the AA6063 plates shows in Fig. 1. The FSW was carried out on conventional milling machine and using four different tool rotational speeds, typically, 470, 590,740, and 900 RPM, and three different welding transverse speeds, typically, 16, 31.5, and 50 mm/min. The plates were put side by side to make butt welding joint. The depth of shoulder inside the plate was constant as 1 mm. The tool having taper pin profile and the shoulder have flat surface was used to weld the AA6063. Fig. 2 shows a schematics illustration of the tool. The tool was made from K110 tool steel. The tool has tapered pin profile with 8 mm diameter with tapered angle of 5.3° with the length of 10.8 mm. The tools have a shoulder diameter of 40 mm with flat surface. The tilt angle was constant at 0°.

Fig. 1 Friction stir welding process.

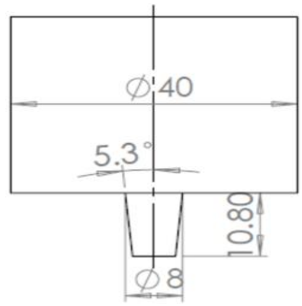

Fig. 2 Schematic illustration of the tool used in the present study dimensions in mm

2.4. Charpy Impact Test

Impact test was carried out on the welded specimens to determine the impact energy absorbed. The samples were cut by Wire-EDM to get the accurate profile. The impact test specimens were prepared as per the ASTM E23 standards having 55 mm long and of square section with 10 mm sides, in the center of length, a notch V notch of 450 , 2 mm depth with a 0.25 mm radius of curve at the base of notch placed at the weld centerline. The schematic diagram of impact test specimen is shown in Fig.3. The impact test impact test was carried out on the welded specimens at different three temperature: room temperature, -30°, and -60°. Three specimens were machined from each joint and average data have been reported.

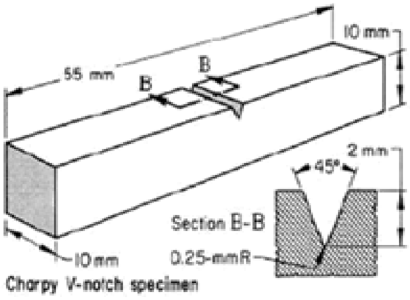

Fig. 3 Charpy V-notch dimensions according to ASTM E23.

2.5. Metallographic Examinations

After FSW, Specimens were ground under water on a Metasery Grinder 2000 rotating disc using silicon carbide abrasive discs of increasing fineness (100, 120, 180, 220, 240, 320, 400, 600, 800, 1000, 1200, 1500, 2000, and 2500 grit). Then they were polished using 10 µm alumina paste. Micro-etching was carried out using a killer solution (1 ml HF 40% + 4 ml HCl +2 ml NHO_3 + 93 ml of H_2O) for 5.5 min at ambient temperature. The location of image of grains were in the middle of sample (6 mm from upper side). The grains were measured by Jmicrovision software by measuring 40 grains in X20 and calculate the average of

40 grains. While macro-etching was carried out using a chemical solution, which consists of 4 ml HF, and 100 ml H_2O for 8 to 12 min at ambient temperature.

3. RESULTS AND DISCUSSION

Table 2, 3 and 4 shows the results of impact test of FSW of AA6063 at room temperature, -30°, and -60. From Table. 2, it is noted that at impact test done with room temperature, the maximum impact energy is 89.99 Joule at tool rotational speed of 740 RPM and with Welding transvers speed of 31.5 mm/min. From Table. 3, at impact test done with temperature = -30°, the maximum impact energy is 98.66 Joule at tool rotational speed of 590 RPM and with Welding transvers speed of 31.5 mm/min. And from Table. 4, at impact test done with temperature = - 60°, the maximum impact energy is 107.8 Joule at tool rotational speed of 470 RPM and with Welding transvers speed of 16 mm/min.

Table 2. The Results of Impact Test of FSW of AA6063 at Room Temperature

Tool Rotational speed (RPM)	Welding speed (mm/min)	Room Temperature				
		Sample 1	Sample 2	Sample 3	Average Impact Energy (Joule)	Standard Deviation
470	16	92.01	70.79	86.35	83.05	10.99
590		45.21	57.24	61.16	54.54	8.312
740		12.65	6.61	19.14	12.8	6.266
900		19.9	14.94	18.56	17.8	2.566
470	31.5	78.45	78.36	75.53	77.45	1.66
590		85.91	87.56	87.82	87.1	1.036
740		84.4	97.2	88.36	89.99	6.553
900		10.55	9.81	5.18	8.513	2.91
470	50	93.75	76.35	63.25	77.78	15.3
590		81.09	71.34	77.45	76.63	4.927
740		37.51	45.24	48.42	43.72	5.611
900		34.79	16.07	37.77	29.54	11.76

Table 3. The Results of Impact Test of FSW of AA6063 at Temperature = -30°

Tool Rotational speed (RPM)	Welding speed (MM/Min)	Temperature: -30°				
		Sample 1	Sample 2	Sample 3	Average Impact Energy (Joule)	Standard Deviation
470	16	75.24	82.75	61.3	73.1	10.88
590		80.95	90.14	102.6	91.24	10.89
740		14.47	14.04	13.44	13.98	0.517
900		66.73	79.64	83.44	76.6	8.759
470	31.5	97.55	66.73	77.34	80.54	15.66
590		99.14	98.9	97.95	98.66	0.629
740		22.89	25.47	25.41	24.59	1.473
900		5.48	5.85	5.76	5.697	0.193
470	50	97.72	54.26	77.13	76.37	21.74
590		90.24	99.16	86.45	91.95	6.525
740		79.38	95.88	52.08	75.78	22.12
900		51.94	51.54	51.12	51.53	0.41

Table 4. The Results of Impact Test of FSW of AA6063 at Temperature = -60°

Tool Rotational speed (RPM)	Welding speed (MM/Min)	Temperature: -60°				
		Sample 1	Sample 2	Sample 3	Average Impact Energy (Joule)	Standard Deviation
470	16	103	106.2	114.1	107.8	5.726
590		96.01	96.11	90.53	94.22	3.193
740		7.04	12.56	6.95	8.85	3.213
900		88.64	88.41	90.24	89.1	0.997
470	31.5	54.81	86.86	66.73	69.47	16.2
590		79.53	85.5	70.37	78.47	7.621
740		32.49	32.25	28.36	31.03	2.318
900		15.97	8.27	17.01	13.75	4.774
470	50	97.25	108.3	85.77	97.1	11.25
590		78.73	95.15	97.2	90.36	10.12
740		83.21	92.42	67.29	80.97	12.71
900		37.53	26.35	46.16	36.68	9.932

Fig. 4, Fig. 5, and Fig. 6 shows the photographic image for maximum values in impact test at room temperature, temperature = -30°, temperature = -60°. It is noted that, in all maximum samples the fracture occur in notch and not passes to another side of sample.

Fig. 4. Sample of maximum Impact Energy = 89.99 Joule at Room Temperature with Tool Rotational Speed = 740 RPM, and Welding Transverse Speed = 31.5 mm/min.

Fig. 5. Sample of maximum Impact Energy = 98.66 Joule at Room Temperature with Tool Rotational Speed = 590 RPM, and Welding Transverse Speed = 31.5 mm/min.

Fig. 6. Sample of maximum Impact Energy = 98.66 Joule at Room Temperature with Tool Rotational Speed = 470 RPM, and Welding Transverse Speed = 16 mm/min.

Fig. 7 and Fig. 8 shows the effect of tool rotational speed on impact energy at different welding transverse speeds and different temperatures. The main effect is as tool rotational speed increase the impact energy decrease. Fig. 9 shows the effect of temperature on impact energy at different welding transverse speed. The impact energy increase as the temperature decrease except at Welding Transverse Speed of 16 and 31.5 mm/min with tool rotational speed of 740 RPM, the impact energy decrease as the temperature increase.

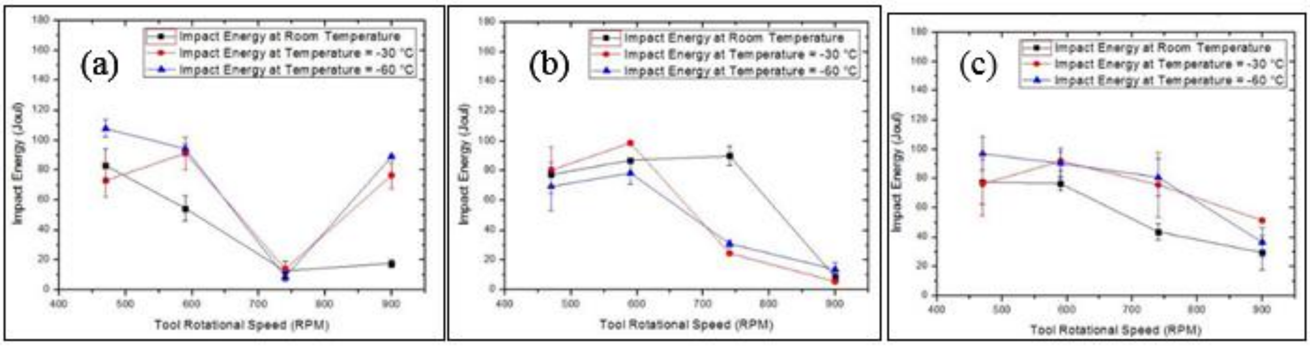

Fig. 7. Effect of Tool Rotational Speed on Impact Energy at Welding Transverse Speed : (a) 16 mm/min, (b) 31.5 mm/min, and (c) 50 mm/min.

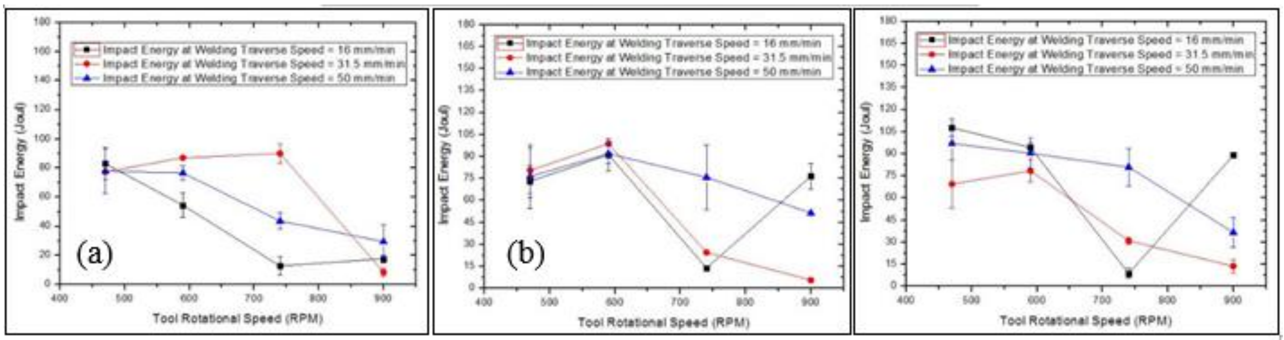

Fig. 8. Effect of Tool Rotational Speed on Impact Energy at Different Temperature: (a) Room Temperature, (b) Temperature = -30°, and (c) Temperature = -60°.

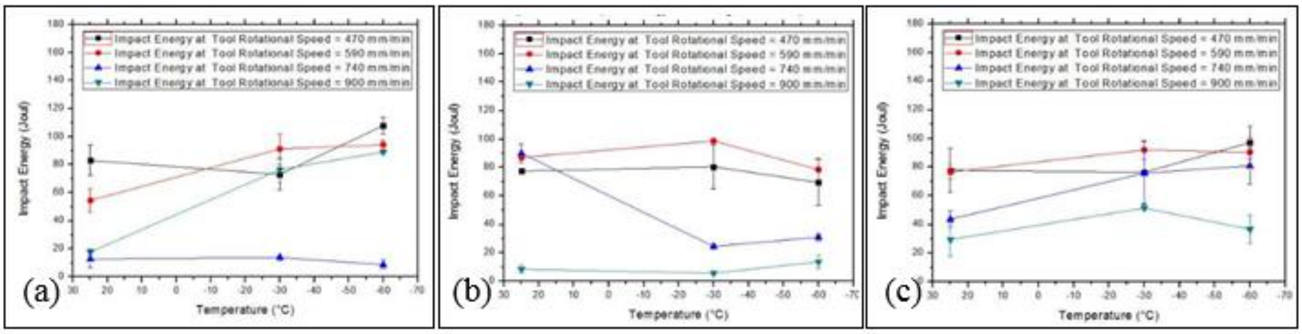

Fig. 9. Effect of Temperature on Impact Energy at Different Welding Transverse Speed: (a) 16 mm/min, (b) 31.5 mm/min, and (c) 50 mm/min.

Table. 5 shows the results of grain size of FSW of AA6063. The maximum grain size is 39 μm with sample with tool rotational speed = 470 and 900 RPM, and welding transverse speed = 31.5 mm/min. The minimum grain size is 18 μm with sample with tool rotational speed = 590 RPM, and welding transverse speed = 31.5 mm/min. Fig. 10 shows the microstructure of sample with maximum grain size is 39 μm and sample (b) with minimum grain size is 18 μm. Fig.11 shows the effect of welding traverse speed on grain size at different tool rotational speeds. The grain size is increase with increase welding traverse speed to certain level then decrees with tool rotational speed of 470 and 900 RPM. The grain size is decrease with increase welding traverse speed to certain level then increase with tool rotational speed of 590 and 740 RPM.

Table. 5. Results of Grain Size of FSW of AA6063

Rotational speed (RPM)	Welding speed (MM/Min)	Average Grain Size
470	16	28
590		23
740		29
900		26
470	31.5	39
590		18
740		21
900		39
470	50	37
590		21
740		38
900		31

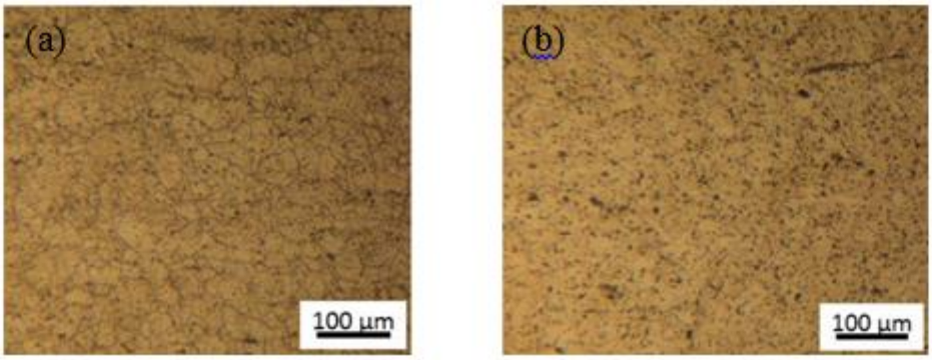

Fig. 10. Microstructure of Sample (a) Grain size = 39 µm with Tool Rotational Speed = 470 RPM, and Welding Transverse Speed = 31.5 mm/min, and Sample (b) Grain size = 18 µm with Tool Rotational Speed = 590 RPM, and Welding Transverse Speed = 31.5 mm/min.

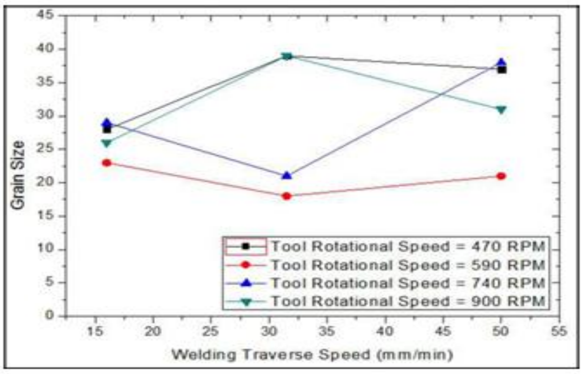

Fig. 11. Effect of Welding Traverse Speed on Grain Size at Different Tool Rotational Speeds

4. CONCLUSIONS

The following conclusions arrived from the above experimental investigation on the FSW of AA6063 at different rotational speeds and different welding traverse speeds. Friction stir welding can be used successfully to weld AA6063 in butt joint fabrication. The impact energy were studied at different temperatures. It has been observed that as tool rotational speed increase the impact energy decrease. The impact energy increase as the temperature decrease except at welding traverse speed of 16 and 31.5 mm/min with tool rotational speed of 740 RPM, the impact energy decrease as the temperature increase. The maximum impact energy was observed at 470 RPM tool rotational speed with 16 mm/min welding traverse speed at -60 temperature. The grain size is effected to tool rotational speed and the minimum grain size is 18 μm was observed at 590 RPM tool rotational speed with 31.5 mm/min welding traverse speed.

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