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An experimental analysis and optimization of process parameter on friction stir welding of AA 6061-T6 aluminum alloy

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ABSTRACT

This research paper friction stir welding of 6mm thick plates of the AA6061-T6 aluminium alloy is effectively consummate using a simple cylindrical pin tool made of high carbon high chromium D2 steel. The aluminium alloy plates are welded using different tool rotation speeds, i.e. 710, 900, 1120 and 1400 RPM and the tool travel speeds of 16 and 20 mm/min. The microstructures of the friction stir welded specimens show that the process has resulted in important particle modification in the weld nugget region.[1] The maximum value of ultimate tensile strength and yield strength are obtained at a rotational speed of 1400 RPM and welding speed of 20 mm/min. The micro hardness results reveal that there is a reduction of 41.95 % in the hardness of the weld nugget region as compared to the base alloy. Surface roughness are observed to be minimum at maximum rotational speeds i.e. 1400 RPM in friction stir welding 6061 aluminium alloy.

Keyword: Friction stir welding, metal flow, process parameters, mechanical properties, chemical properties tensile test.

I. INTRODUCTION

Friction Stir Welding (FSW) is a fairly recent welding technique, invented by The Welding Institute (TWI), Cambridge, UK. This technique utilize a non-consumable rotating welding tool to generate frictional heat and deformation at the wedding location, thereby affecting the formation of a joint, while the material is in the solid state. Friction Stir (FS) welded joints are characterized by the absence of filler-induced problems since the technique requires no filler[2]. The basic concept of FSW is remarkably simple. A non delicate rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of the sheets or plates to be joined and subsequently traversed along the joint line. In figure 1, the FSW tool rotates in the counterclockwise direction and travels from left to right. The advancing side is on the right, where the tool rotation direction is the same as the tool travel direction (opposite the direction, and the retreating side is on the left, where the tool rotation is opposite the tool travel direction (parallel to the direction of metal flow)[4]. In contrast to conventional welding technologies, the FSW process takes place in the solid phase below the melting point of the metals to be joined [8]. The interference between the welding tool and the metal to be welded generates plastically deformed zone through the associated stirring action. the same time, the thermo-mechanical plasticized zone is produced by friction between the tool shoulder and the top plate surface and by contact of the material with the tool edges, inducing plastic deformation. The probe is slightly shorter than the thickness of the work piece [12].

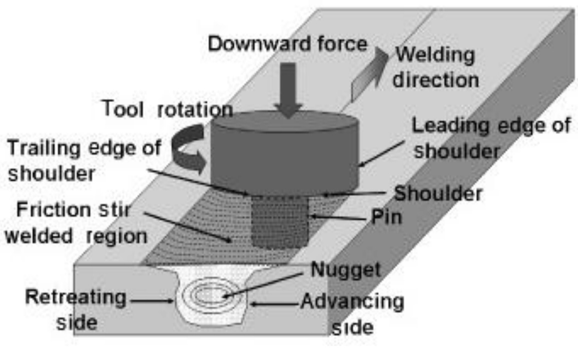

Fig. 1 Schematic diagram of friction stir welding

Objectives

Observance in view the above research gaps, it was planned to examine the effects of FSW process parameters on mechanical and metallurgical properties of friction stir weldment of aluminium alloy AA6061-T6.

- The chemical composition testing of AA6061-T6 aluminium alloy plates using Optical Emission Spectrometer.
- The characterization of AA6061-T6 aluminium alloy plates by using Optical microscope[3]
- Hardness, tensile strength and surface roughness testing of AA6061-T6 Base plates.
- Fabrication of tool for friction stir welding of aluminium alloy AA6061-T6 plates.
- Friction stir welding of aluminium alloy AA6061-T6 plates.
- Chemical composition testing of friction stir welded joints using Optical Emission Spectrometer.
- Characterization of friction stir welded joints by the help of Optical microscope.
- The Hardness and tensile strength or surface roughness testing of friction stir welded joints.

II. EXPERIMENTAL PROCESS

Configuration in the welding workpiece of the tool

For the experimentation studies, the work piece material is an AA6061-T6 aluminum alloy plate of 3mm thickness, which chemical composition is given in table 1. The plate is cut and machined into rectangular welding samples of 150 mm length by 30 mm width, and then the samples are butt welded perpendicular to the rolling direction using a welding machine.

Table 1: The chemical composition of Al-alloy AA6061-T6

Cu	Mg	Si	Fe	Ni	Mn	Zn	Pb	Sn	Ti	Cr	Va	Al
0.217	1.02	0.182	0.321	0.011	0.065	0.163	0.012	0.003	0.061	0.046	<0.01	97.09

The microhardness, tensile strength and surface roughness of base metal i.e. AA6061-T651 aluminium alloy are given in the table 2

Table 2: Mechanical & Surface Properties of AA6061-T6

Base Alloy	ɔhardness (Hv)	Ultimate tensile strength (kN/mm^2)	% Elongation	Surface Roughness (μm)
AA6061-T6	92	0.57	23.39	3.53

Fig. 2 Test specimens of aluminium alloy AA6061-T6

Procedure

The specimens to be friendly using friction stir welding are held on a dedicated fixture in order to prevent the displacement during the welding. At the weld line, at a distance of 10 mm from the extreme edges; a hole of diameter 6 mm is drilled. The purpose of this hole is to provide an easy path to the tool to plunge into the work-piece material.[7]The fixture with the work-pieces is then clamped tightly on the table of the converted vertical milling machine. The friction stir welding tool is then mounted on the collet of the machine spindle and the spindle is rotated at desired rotational speed. The rotating tool pin is forced into the work-piece till the shoulder touches the upper surface of the work-piece. The length of the pin is kept slightly shorter than the thickness of the work pieces; therefore, the tool could be prevented to penetrate through the work- pieces into the base plate. A dwell time of 40 second has been given the tool after the plunge so that, sufficient frictional heat could be generated[.4] The tool is stimulated forward in the direction of weld line at desired welding speed. After the welding is consummate the tool is pulled out of the work-piece 10 mm before reaching the extreme edge of the work- piece[6] The specimens welded using different process parameters are shown in figure 3 and various welding parameters used in this study are given in the table 3.

Fig. 3 Friction stir welded AA6061-T6 alloy specimens

Table 3 FSW Process Parameters

Specimen No.	Rotational Speed (rpm)	Translation Speed (mm/min)
1	710	18
2	710	22
3	900	16
4	900	20
5	1120	18
6	1120	22
7	1400	16
8	1400	22

III. MICROSTRUCTURE OF THE JOINTS

The micro-structural testing of the base alloy and as welded specimens is done at M/s Spectro Analytical Lab, delhi (India), using optical microscopy. Versamet Unitron 5463 inverted optical microscope with a zooming range of 50-400 µm has been used to study the microstructural evolution. The specimens for microstructural testing have been prepared using ASM 9 standards. The procedure for metallographic specimen preparation is as follow[7]

- In specimen was first ground on 60 grit paper, so that scratches were produced roughly at right angle to those initially existing on the specimen and produced through preliminary grinding.
- The grinding was then continued on the No. 80 paper, again turning the specimen through 90° and grinding until the previous scratch marks are removed.
- This process is repeated with the No.120, 1800, 220, 320, 400, 600 and No. 800 papers.

- In the next step, specimens are thoroughly polished on a rotating polishing wheel by Alumina powder. After fine polishing the specimens were etched with Keller's reagent (5 ml HNO_3).

Now the specimen was placed on the microscope to test the microstructure

Fig, 4 Micro structural Testing diagram

Microhardness of base alloy AA6061-T6 and of as welded specimens is evaluated using Vickers Hardness Tester at M/s Spectro Analytical Lab, delhi (India). The microhardness tester is Mitutoyo make. The test load applied was 100gf with a dwell time of 10 seconds. The microhardness of all welded specimens was tested in different zones on the both sides of the weld at transverse plane i.e. in the base metal zone, HAZ, TMAZ and in the weld nugget zone.

IV. TENSILE TESTING OF JOINTS

Tensile properties such as ultimate tensile strength, yield strength and % elongation of the base metal and friction stir welded specimens of AA6061-T6 aluminium alloy was investigated at M/s Mahendra Fasteners, chabri bazaar delhi (India). Tensile test were carried out using Ifotech universal testing machine. The tensile test specimens were cut from the base alloy and as welded specimens according to ASTM E8 standards using CNC Wire Cut EDM machine. The WEDM machine available at M/s Quality Engineers, Rohtak (India) has been utilized to take out the tensile specimens. The dimensions of tensile specimens are shown in figure 8. The specimens were mounted on the Innotech UTM and load was applied until the specimen broke.

Surface Roughness Testing

The surface roughness of the base alloy AA6061-T6 and as welded specimen was investigated using Mitutoyo SJ-201 surface roughness tester available at university Institute of Engineering & Technology, Kurukshetra (India). The surface roughness of the specimens along the full length of the weld bead was measured.

Fig. 5 Surface Roughness Tester

V. DISCUSSION OF THE RESULTS

This chapter includes results of chemical composition testing and mechanical testing of friction stir welded specimens. The results of mechanical tests i.e. microhardness and tensile strength are also discussed. The surface roughness results of as welded specimens are also included and discussed in details. Also the relationship between chemical, mechanical and surface properties are attempted to be established.

Chemical Composition

Chemical composition of FSW joints was investigated using optical emission spectrometer and the results are given in the table

Table 4 Percentage Composition of friction stir welded Aluminum Alloy AA6061-T651

Cu	Mg	Si	Fe	Ni	Mn	Zn	Pb	Sn	Ti	Cr	Va	Al
0.226	1.13	0.867	0.359	0.014	0.076	0.180	0.018	0.005	0.068	0.053	0.010	97.07

The optical emission spectrometry shows that the chemical composition of FSW joints are approximetaly same to that of the base alloy as reported in previous studies[9].

Chemical Composition Test

The composition tests using optical microscope at 200X zoom has been carried out to investigate the micro structural development during FSW of AA6061-T651aluminium alloy. The microstructures of various FSW zones

Base Alloy Of Aluminum Material

The microstructure of base alloy shows that the base alloy contains longer elongated fine grains. The average grain size is investigated to be 15-20 µm.

In Heat Affected Zone

The microstructure of heat affected zones of all as welded specimens are investigated and the results show that HAZ consists of grains having approximately the same size as that of base metal. This is because of the fact that HAZ is only exposed to the welding heat but not the deformation and re-crystallization [4]. The average grain size in the HAZ has been observed to be 15 µm.

Therm Mechanical Affected Zone

TMAZ is the transition zone between the base metal and the weld nugget, characterize by a highly deformed structure [3]. The microstructure in this zone consists of finer grains than that in the HAZ. The average grain size in the TMAZ is observed to be 10-15 µm, except in the specimen no. 7 and 8 where the average grain size is found to be 10 µm. This is due to high deformation and re-crystallization produce by high rotational speed of 1400 rpm.

Tensile Test Results

The tensile test results of base alloy and as welded specimens are shown in table 7. The ultimate tensile strength and yield strength of the base alloy are experimental to be 0.53 KN/mm^2 and 0.50 KN/mm^2 respectively. It is revealed from the results that the maximum values ultimate tensile strength and yield strength are obtained in specimen no. 8. i.e at a rotational speed of 1400 rpm and at a welding speed of 20 mm/min. The ultimate tensile strength of the as welded specimens ranges from 68% to 86% of that of the base alloy.[10] The maximum value of UTS is 0.447 KN/mm^2. The minimum value of UTS is obtained at 710 rpm and 16 mm/min. The UTS and yield strength are observed to be increased with increase in rotational speed. All tensile specimens are failed in the heat affected zone close to the boundary of TMAZ, except specimen no. 3 which failed in the nugget zone due to the presence of a tunnel defect. The tunnel defect is produced due to the low heat resulted from the lower rotational speeds.

Table 5 Tensile Test Results of Base Alloy and As Welded Specimens

	Base Aloy	Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5	Specimen 6	Specimen 7	Specimen 8
Ultimate Load	14.82	10.07	10.81	3.01	11.11	11.41	11.85	12.30	12.74
Breaking Load	12.65	8.602	9.2	2.26	9.48	9.74	10.12	10.49	10.87
Yield Load	14.22	9.66	10.38	3.01	10.66	10.94	11.37	11.80	12.22
UTS	0.52	0.35	0.37	0.07	0.39	0.40	0.41	0.43	0.45
BS	0.45	0.30	0.32	0.05	0.33	0.34	0.36	0.37	0.39
YS	0.50	0.34	0.36	0.07	0.37	0.38	0.40	0.41	0.43
% Elongation	23.33	15.86	17.03	3.8	17.49	17.96	18.66	19.36	20.06

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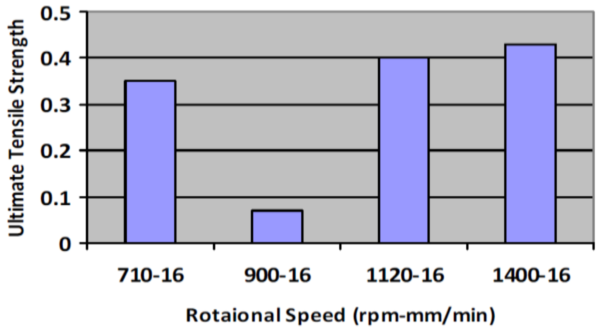
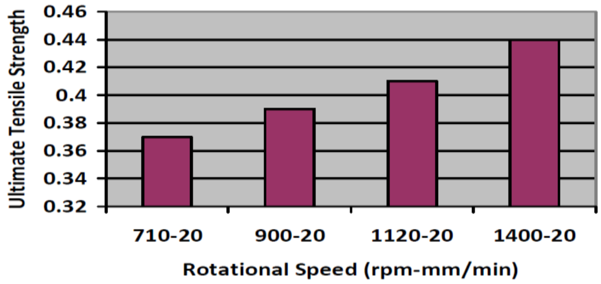


Graph 1 Rotational speed Vs Tensile strength



Graph 2 Rotational speed Vs Tensile Strength

Surface Roughness Testing Results

The effects of rotational speed on the surface roughness of the FS welded specimens were also investigated. the surface roughness results of AA6061-T651FS welded specimens at different rotational speed (710-1400 rpm). In general, as the rotational speed decreases, the roughness of the surface increases[5] The results show that the minimum average value of surface roughness of 6.71µm is observed in specimen no. 8 i.e. at a rotational speed of 1400 rpm. The maximum average value of 9.07µm is observable in specimen no.3 i.e. at a rotational speed of 900 rpm. The surface of weld region of all the as welded specimens is found to be good.

Table 6 Surface Roughness of Aluminium Alloy AA6061-T651 at Different Rotational Speeds

Welding Parameters	Surface Roughness using 20 mm Shoulder Diameter	Surface Roughness (In µm)
710 rpm 18mm/min.		8.43
900 rpm 16mm/min.		9.05
1120 rpm 18mm/min		7.53
1400 rpm 16mm/min.		6.87

Table 7: Roughness of Surface Aluminium Alloy AA6061-T6 at Different Rotational Speeds

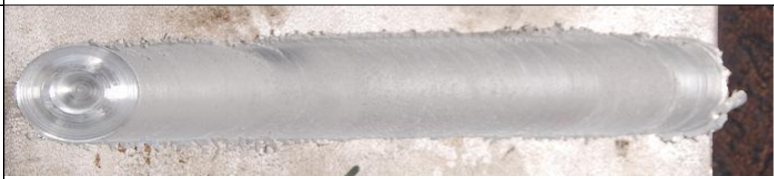
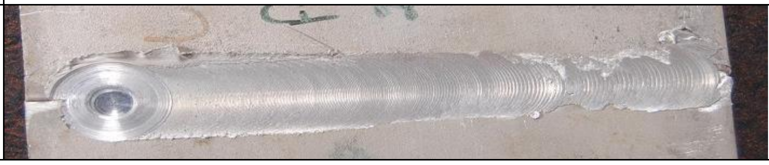
Welding Parameters	**Surface Roughness using 20 mm Shoulder Diameter**	**Surface Roughness (In µm)**
710 rpm 22mm/min.		8.43
710 rpm 20mm/min.		
900 rpm 16mm/min.		9.05
900 rpm 20mm/min.		8.95
1120 rpm 22mm/min.		7.57

Table 8: Surface Roughness of Aluminium Alloy AA6061-T651 at Different Rotational Speeds

Welding Parameters	**Surface Roughness using 20 mm Shoulder Diameter**	**Surface Roughness (In µm)**
1120 rpm 20mm/min.		8.86
1400 rpm 16mm/min.		6.87
1400 rpm 20mm/min.		6.73

CONCLUSION

Friction stir welding has prove its capacity to join various metals and alloys particularly aluminium based alloys. The thesis explore and presents the investigation of effect of welding parameters on the mechanical, tensile and chemical properties of friction stir welded aluminum alloy AA6061-T6. The relationship between mechanical properties, microstructure and surface properties with process parameters are also presented. Following conclusions are derived from the present experimental work:

- The friction stir welding has proved to be the suitable process for joining AA6061- T6 aluminum alloy and defect free joints were obtained using various combinations of process parameters[11].
- High Carbon High Chromium D2 tool steel has been used to achieve the friction stir welding. HCHCr has proved to be the efficient tool material for the successful accomplishment of FSW AA6061-T6 aluminum alloy.
- The microstructure of the friction stir welded specimens showed that the process has resulted in significant grain refinement in the weld nugget region.
- The ultimate tensile strength of the as welded specimens has reached up to 86 % of that of base alloy. The maximum value of ultimate tensile strength and yield strength were obtained at rotational speed of 1400 rpm and welding speed of 20 mm/min.
- The micro hardness results showed that there is a reduction of 42.95 % in the hardness of the weld nugget region as compare to the base alloy. The maximum hardness of the nugget zone as obtained at a rotational speed 710 rpm and a welding speed of 20 mm/min.
- The investigation of surface roughness of the welded region showed that the rotational speed has a significant effect on the surface properties of the welds. Surface roughness was observed to be minimum at maximum rotational speeds i.e. 1400 rpm.

SCOPE OF FUTURE WORK

- The studies to be conduct on friction stir welding of more aluminum alloys like 2xxx, 5xxx 6xxx and 7xxx series of aluminum alloys used in various automotive and aerospace industries.
- The research should be taken further for the analysis of forces generated during the friction stir welding process.
- The characterization of FSW welds could be done using other advanced techniques such as XRD, EPMA, DTA and SEM [13].
- The friction stir welding could be analyze using some new optimization and modeling techniques.
- The other tool materials like H13, H11, HCHCr D3,H12 etc. could be further used for the study of FSW.

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