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Experimental and Numerical Investigation of material flow and heat propagation in friction stir welding of AA6063 & AA6061

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ABSTRACT:

Friction stir welding (FSW) is an effective means of solid-state joining. It can weld thin plates with good weld joint that's why it is gradually replacing the riveting technique. In recent years, the application of Aluminum alloys gained a good attention because of its advanced mechanical, physical and tribological properties. Aluminum alloys 6061&6063 has very good corrosion resistance, weld ability, high fatigue strength and moderate strength. In this paper, FSW of 6 mm thick AA6061&6063 plates were performed .The weld joint was tested for ultimate tensile strength (UTS) , Rockwell harness number (HR) and Wear test at particle temperature and simulation of material flow and heat evolution during friction stir welding by using ANSYS workbench tool

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Keywords: Friction stir welding, AA6061, AA6063, UTS, HR, Wear test.

INTRODUCTION:

Friction stir welding is relatively new solid state welding process. FSW was initially invented by the 'The Welding Institute (TWI)' in December 1991 in the United Kingdom. The patents of the FSW process are also held by the TWI, UK [1]. This welding technique can weld a wide range of materials and as it needs almost negligible pre welding preparations, thus automation of this technique can reach to a high degree.

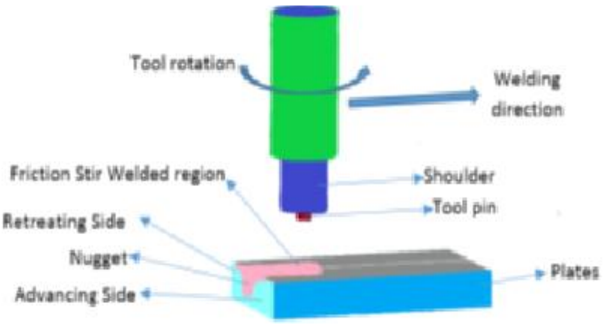

Figure 1.systematic diagram of friction stir welding

parameters, tool design and joint configuration. The welding parameters consist of tool rotation speed, welding speed, and axial forces.

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Former two parameters are more significant than the last one. The properties of base material is also effect the weld quality. The tool design is very important because welding parameters are dependent on the design of tool. The parameters involve in tool design are pin diameter, shoulder diameter, profile of pin and shoulder, plunge depth, and tilt angle. Each of these parameters are significant and affect the quality of weld. The design of joint is also important and it involves like parallelness of edges and smoothness of edges of plates to be joined [3].

LITERATURE REVIEW

Rao C.M. et al [4] had investigated the microstructure and hardness of the AA6061 joints obtained by the FSW. They found the average gain size in order as follows: HAZ >TMAZ>NZ. The minimum hardness value was 80.2 HV in HAZ and maximum value was 106.32 in base metal (BM). The tensile strength of weld zone were less than that of BM. Rhodes C.G. et al. [5] had studied the microstructural changes occur in AA7075-T6 due to FSW. They found that there were recrystallization of the grains in the weld nugget and the dislocation density in nugget was lower than the base metal. Kimapong K. et al. [6] had investigated the effect of tool geometries on AA 6061-T1.They found that left and right screw pin profiles were producing good joints compared to cylindrical and conical tool. The maximum tensile strength was 168 MPa at 2000 rpm and 125mm/min welding speed. Trimble D. et al. [7] had studied the effect of FSW on 4.8mm thick AA2024-T3 plates. They found that triflute pin was most effective shape for higher welding speeds and scroll shoulder design was better than concave shoulder design. Kwon Y. et al. [8] had done FSW of 2 mm thick AA5052-O at various rotational speed and found that the grain size was smaller in stir zone (SZ) than the base material, and it was decreases with the increase of tool rotation speed.

EXPERIMENTAL PROCEDURE

In this study, thin plates of AA6063&6061 were used. The dimensions of the plates were 200x85x6 mm. The aluminum alloy 6061&6063 sheet was initially cut into the required size from the big sheet by shearing operation. The sheets were then end milled by the vertical milling machine. The milling of the plates brings the accuracy in terms of smoothness and make edges parallel and also milling removes hardness and stresses induced by the shearing at the edges. The plate edges were cleaned by the emery papers to remove burrs and scratch marks formed due to the milling tool cutting edges. This makes the smoother and thus reduces the gap between two edges of plates. The chemical composition of AA6061&AA6063 is shown in table 1

Table 1 Composition of AA6061

components	mg	si	fe	cu	zn	ti	mn	cr
Wt%	0.4-0.8	0.5-1.2	Max0.7	3.9-5.0	Max 0.25	Max0.15	0.4-1.2	Max 0.1

Table 2 Composition of AA6063

components	si	fe	cu	mn	mg	cr	zn
Wt%	0.4	0.5	1.2-2.0	0.30	2.1-2.9	0.18-0.28	5.1-6.1

In my experiment, the tool pin material was H13 die steel having cylindrical shape. The tool has pin diameter of 4 mm, pin length of

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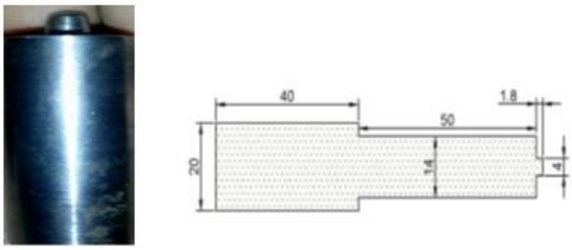
1.8 mm and shoulder diameter of 14 mm.



Figure;2 steel tool and their dimension

The two important parameters i.e. welding speed and rotational speed of tool and tool and work piece temperature was considered for the experiment. There were three levels was selected for each variable.

Table 3. Process parameters and their levels parameters.

Parameters	Level1	Level2	Level3
Welding speed(mm/min)	40	50	60
Rotational speed of tool(rpm)	900	1200	1400

By using the design of experiment (DOE), L9 orthogonal array (OA) was selected for carrying out the experiment is shown in table 3.
pn=tool front part, tn= tool rear part,
ss=retreating side ,sn=advancing side

Table 4 Experimental table based on AA6063&6061

Rotational speed Rpm	Welding speed mm/min	Initial temperature				After 10 sec				After 20sec			
		pn	tn	ss	sn	pn	tn	ss	sn	pn	tn	ss	sn
900	40	31	31	31	31	98	39	105	63	209	51	77	63
900	50	31	31	31	31	95	40	100	65	200	60	80	68
900	60	31	31	31	31	93	39	96	64	190	61	82	64
1200	40	31	31	31	31	178	50	112	85	180	63	100	85
1200	50	31	31	31	31	200	60	115	90	216	70	77	121
1200	60	31	31	31	31	160	51	100	80	175	65	100	112
1400	40	31	31	31	31	182	51	110	90	207	64	104	85
1400	50	31	31	31	31	202	65	120	82	200	72	100	85
1400	60	31	31	31	31	175	69	91	80	190	70	112	94

FSW was performed according to the L9 OA by using computer numerical controlled (CNC) vertical machining entre with power capacity of 3.5kW at the spindle.

Infrared thermometer:

An infrared thermometer is a thermometer which infers temperature from a portion of the thermal radiation sometimes called blackbody radiation emitted by the object being measured. They are sometimes called laser thermometers if a laser is used to help aim the thermometer, or non-contact thermometers or temperature guns, to describe the device's ability to measure temperature from a distance. By knowing the amount of infrared energy emitted by the object and its emissivity, the object's temperature can often be determined. Infrared thermometers are a subset of devices known as "thermal radiation thermometers".

The most basic design consists of a lens to focus the infrared thermal radiation on to a detector, which converts the radiant power to an electrical signal that can be displayed in units of temperature after being compensated for ambient temperature. This configuration facilitates temperature measurement from a distance without contact with the object to be measured. As such, the infrared thermometer is useful for measuring temperature under

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circumstances where thermocouples or other probe type sensors cannot be used or do not produce accurate data for a variety of reasons.

Table 5 specifications of IRX thermometer

Model	IRX-64
Range IR	-500C to 10500C (or) -580F to 19220F
Range Contact	-500C to 13700C (or) -580F to 24980F
Basic Accuracy	+1.5% of reading
Emissivity	Adjustable 0.10 to 1.0
Optical Resolution	30:1

Figure-3 IRX 64 infrared thermometer

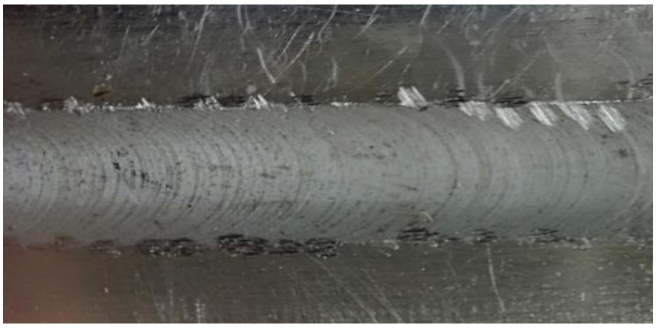

Figure:4 FSW welded plate

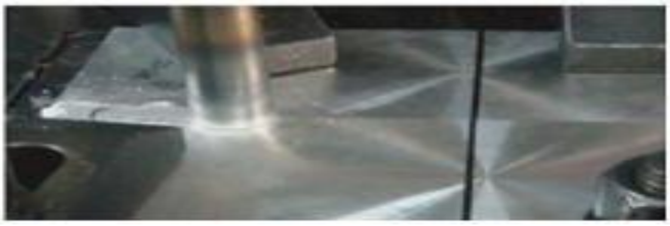

Figure:5 Process of Friction stir welding

The temperatures were recorded using infrared thermometer during welding process.

Figure:6 Recording temperature during FSW

Figure:7 welding setting

RESULTS AND DISCUSSIONS

A. Tensile test:

The tensile test was performed by using the UTM machine [model UTM-60].There were nine specimens were made from

Table 6: UTS different process parameters

parameter	yield strenght	tensile strength	elongation	reduction
900F40	95	153	13.2	25.36
900F50	93	160	10.25	26.25

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900F60	94	262	9.77	28.46
1200F40	101	185	12.56	45.26
1200F50	225	282	8.57	16.79
1200F60	156	180	11.23	23.25
1400F40	145	269	12.35	24.23
1400F50	156	190	9.77	25.12
1400F60	145	200	8.54	23.56

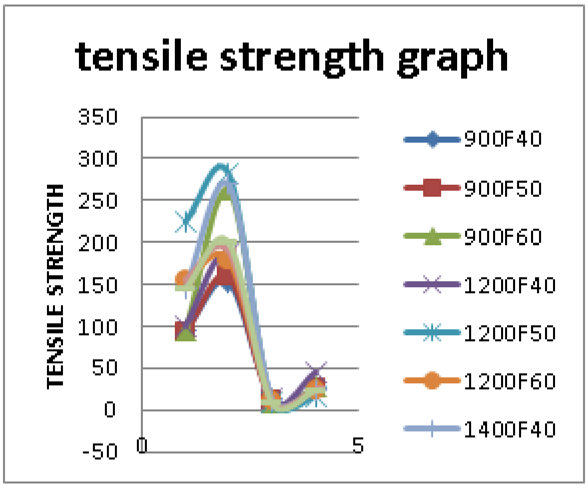

Figure:8 Tensile plot for different parameters

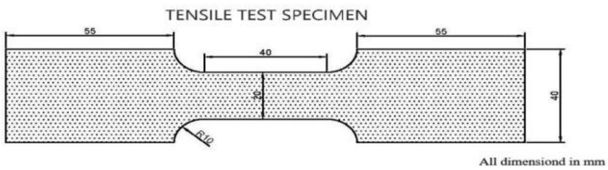

Figure:9 Tensile test specimen

B. Hardness test:

The hardness test was performed on the Rockwell hardness testing machine. It was performed at the center of the stir zone using 100 Kgf load and 10 mm hardened steel ball indenter. The obtained Rockwell hardness number is tabulated in table 5.

Table:7 HR for different process parameters

SPECIMEN	SCALE	HARDNESS VALUE (HR)	THICKNESS IN (MM)
900F40	B	54	5.35
900F50	B	55	5.4
900F60	B	61	5.35
1200F40	B	55	5.45
1200F50	B	64	5.9
1200F60	B	56	5.8
1400F40	B	60	5.22
1400F50	B	50	5.12
1400F60	B	55	5.4

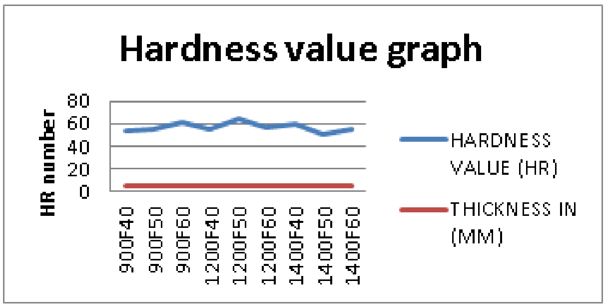

Figure:10 Hardness plot for different parameters

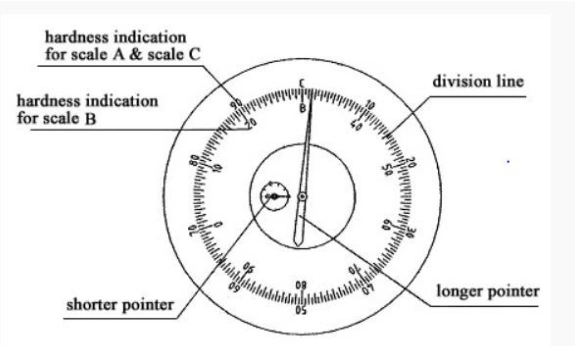

Figure:11 Schematic diagram of Indication dial gauge

C. Wear rate

Table.8 Process parameters and levels

Level	load(N)	Sliding speed, S (m/s)	Sliding distance,D (m)
1	20	2	1000
2	40	4	2000

Figure:12 wear test machine

Table:9 Wear rate for different process parameters

S.NO	LOAD	SPEED	DISTANCE	WEAR	WEAR RESISTANCE	SPECIFIC WEAR RATE
900F40	20	2	1000	1.12	0.892857	0.056
900F40	40	4	2000	1.23	0.813008	0.03075
900F50	20	2	1000	2	0.5	0.1
900F50	40	4	2000	1.12	0.892857	0.028
900F60	20	2	1000	0.5	2	0.025
900F60	40	4	2000	0.54	1.851851	0.0135
1200F40	20	2	1000	1.12	0.892857	0.056
1200F40	40	4	2000	1	1	0.025
1200F50	20	2	1000	0.2	5	0.01
1200F50	40	4	2000	0.21	4.761904	0.00525
1200F60	20	2	1000	0.9	1.111111	0.045
1200F60	40	4	2000	0.95	1.052631	0.02375
1400F40	20	2	1000	0.4	2.5	0.02
1400F40	40	4	2000	0.42	2.380952	0.0105
1400F50	20	2	1000	1.25	0.8	0.0625

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1400F50	40	4	2000	1.56	0.641025	0.039
1400F60	20	2	1000	1.66	0.602409	0.083
1400F60	40	4	2000	1.6	0.625	0.04

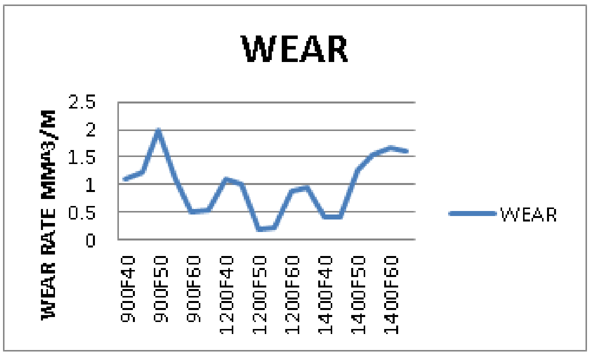

Figure:13 Wear rate plot for different parameters

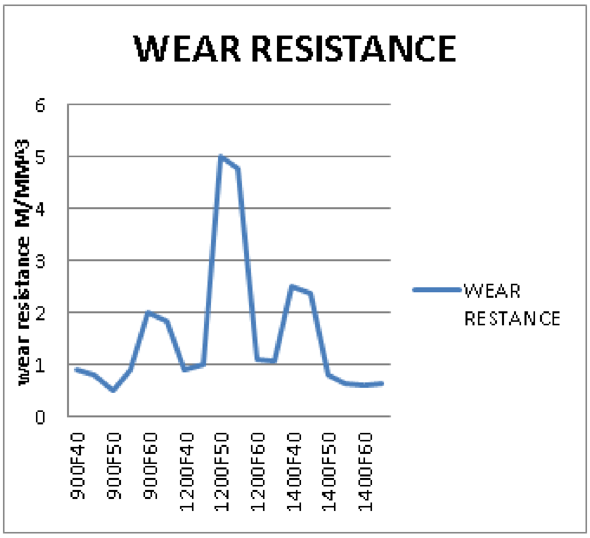

Figure:14 Wear Resistance plot for different parameters

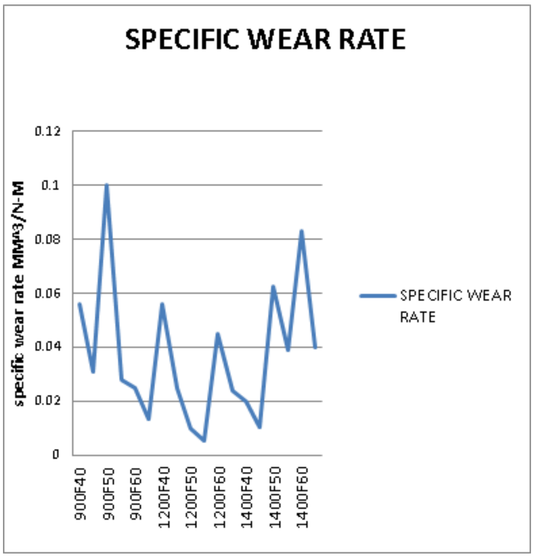

Figure:15 specific wear rate plot for different parameters

From table 9, it is clear both welding speed as well as rotational speed is significant for wear measurements

Simulation Results

To study heat transfer within an object or between objects, one may conduct thermal analysis, from which thermal quantities such as the temperature, thermal gradient, and heat flux distributions can be determined. Steady-state thermal analysis aims to find the temperature or heat flux distribution in structures when a thermal equilibrium is reached

In addition, thermal expansion or contraction of engineering materials often leads to thermal stress in structures, which can be examined by conducting thermal stress analysis.

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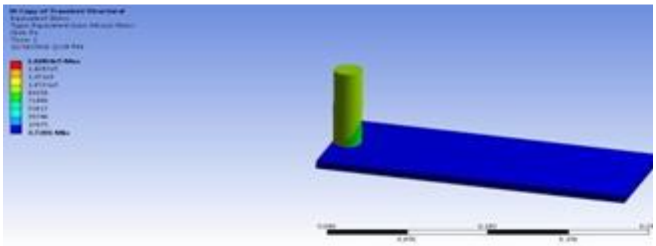

Figure:16 Equivalent stress

Table:10 Force values

S.No	Time [s]	Joint Probe (Total Force X) [N]	Joint Probe (Total Force Y) [N]	Joint Probe (Total Force Z) [N]	Joint Probe (Total Force Total) [N]
1	0.2	3.99E-06	8.19E-10	-25.447	25.447
2	0.3	0.3198	-2.65E-07	-25.447	25.449
3	0.4	0.33025	-2.09E-08	-25.447	25.449
4	0.5	0.32943	3.35E-11	-25.447	25.449
5	0.6	0.33025	1.34E-10	-25.447	25.449
6	0.7	0.32971	8.18E-10	-25.447	25.449
7	0.8	0.33007	5.54E-10	-25.447	25.449
8	0.9	0.32983	5.60E-10	-25.447	25.449
9	1	0.32999	7.24E-10	-25.447	25.449

Various temperatures obtained for AA60601 & AA6063 when they were made to run at 900 rpm, 1200 rpm, and 1400 rpm at feed rates of 40, 50, and 60 mm/min.

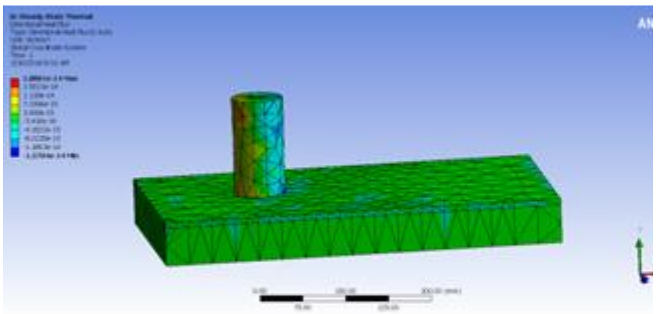

Figure:17 steady state thermal analysis(x-Axis)

Table:11 simulation table based on AA6063&6061

Rotational speed Rpm	Welding speed mm/min	Initial temperature				After 10 sec				After 20sec			
		pn	tn	ss	sn	pn	tn	ss	sn	pn	tn	ss	sn
900	40	28	28	28	28	85	32	99	58	198	48	69	59
900	50	28	28	28	28	89	35	90	60	190	56	76	63
900	60	28	28	28	28	90	36	95	62	186	59	79	61
1200	40	28	28	28	28	165	48	109	79	170	59	91	79
1200	50	28	28	28	28	195	56	102	86	210	69	76	122
1200	60	28	28	28	28	156	46	96	75	169	60	95	109
1400	40	28	28	28	28	178	46	105	80	198	59	99	79
1400	50	28	28	28	28	195	59	115	79	195	69	95	79
1400	60	28	28	28	28	165	59	85	75	185	68	105	90

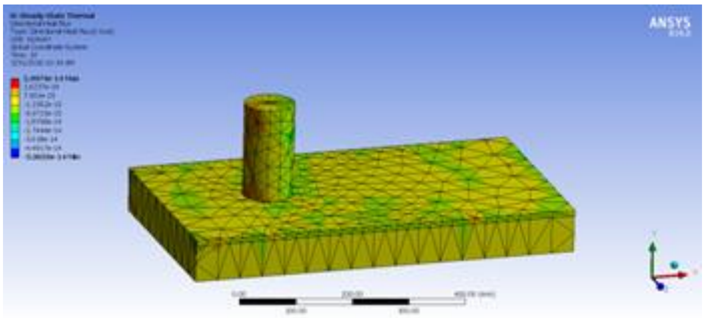

Figure:18 steady state thermal analysis(y-axis)

CONCLUSION:

The value obtained through the experiment shows that the ultimate tensile strength, hardness and wear rate are maximum at 1200 rpm and 50 mm/min [09] had also welded the AA6063&6061 plates but of thickness 6 mm with tool angle 1.91^{o}. They were achieved the best welding properties at 1400rpm and 40 mm/min, which is close to the results obtained in these experiments.

The maximum value of ultimate tensile strength , Rockwell hardness number and wear rate achieved in the experiment is 284 N/mm^2 ,64and $0.2mm^3/m$ respectively. Both the factors i.e. welding speed and rotational speed significantly affect the ultimate tensile strength , wear rate and Rockwell hardness number. Ansysis simulation software and the

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temperature results are represented in the form of graphical representation. The results are validated according to the temperatures as parameters.

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