Experimental Investigation for Mechanical Properties of Aluminium Alloy Al 6061 Considering Different Parameters of FSW

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Abstract-*The paper deals with Experimental investigation for Mechanical properties of Aluminium Alloy Al 6061 Considering different Parameters of FSW. Two different type of tool shapes and shoulder surfaces for single weld configurations were used in experiments. It was shown that both tool types produce high quality butt joints free from defects or imperfections as visual inspection was done. The best tensile performance was obtained for FSW joints produced by a taper tool and the results obtained for joints produced by threaded tool shoulder are significantly lower. Tensile strength test indicated that welding speed is the main parameter which effect the tensile strength. Feed rate and tool shape are effecting second and third respectively. As the Impact toughness and Micro-hardness test are conducted, Feed rate is the main factor, Welding speed, Tool shape are effecting respectively. As a result of the experiment the welding speed 600 RPM, Feed Rate 40 mm/min and Taper probe tool are the best optimum levels to get maximum strength of mechanical properties. The differences between mechanical properties using different parameters were predicted based on a recently elaborated mathematical model developed for FSW joints.*

Key Words: *Al Alloy, Design of Experiments, Orthogonal Array, ANOVA, Regression equation*

1. Introduction

Aluminium has property low weight with high strength, comparable to that of structural steels. High tensile strength in relation to density (referred to as specific strength) as well as high corrosion resistance make aluminium alloys the primary structural material used for various structural elements of critical importance in aviation, automotive, transport, military, ship-building, civil engineering and other industries.Friction stir welding is a variant of friction welding that produces a weld between two work pieces by heating and plastic displacement caused by a rapidly rotating tool that traverse the weld joint. Heating is done by both frictional rubbing between the tool and the work pieces and by viscous-plastic dissipation of the deforming material at high strain rates. Friction stir welding uses a non-consumable, rotating welding tool to create heat locally. A common tool design is the shape of a rod with concave area with a pin, coaxial with the axis of rotation. The work pieces are rigidly clamped and are supported by a backing plate, or anvil, that bears the load form the tool and constrains deformation of the material at the back side of the joint. As we start the process, the rotating friction stir welding tool is plunged into the weld joint, until the shoulder of the tool makes contact with the top surfaces of the work pieces. Frictional rubbing and viscos plastic dissipation cause the heated material to soften and plastically flow. The motion of the tool displacement of the softened material to produce the weld. As the tool moves in forward direction with continues speed and feed rate the metals gets soft due to heat gained. Thus welding is completed

This goal of this study was to investigate the effect of parameters welding speed , Feed Rate and Tool shape on the mechanical properties of FSW butt joints of 6061 Aluminium Alloy. In addition, based on the newly elaborated models and Regression equations developed for FSW joints, the differences in mechanical properties on the advancing and retreating sides were explained.

2. Taguchi Method

The Taguchi method involves reducing the variation in a process through robust design of experiments. Taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varies.. This allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources. With the help of Minitab 17 the Taguchi L8 was employed to analyze the results of Experimental investigation for Mechanical properties of Aluminium Alloy Al 6061 Considering different Parameters of FSW.

3. Experimental Details

3.1 Material & Butt-weld joint Dimensions: The material used in experiments was Al 6061 Aluminium alloy. A long sheet of dimension (L*B) (4' * 1' ft. = 121.92 *30.48 cm) or (1210 * 300 mm) mm of 5 mm thickness were taken from the supplier. 16 plates were made of dimension (300*75*5 mm) .From these plate we were able to make 8 butt -joints of Al 606 using FSW. The nominal chemical composition of the Aluminium Alloy Al 6061 is presented in Table 1

Table 1: Chemical Composition of Al (Wt. %)

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.8 %	0.7%	0.4%	0.15%	1.2%	0.35%	0.25%	0.15%	96.5%

3.2 Welding Procedure

With the help of trial experiments three parameters like tool rotational speed, welding speed and tool shape were considered for friction stir welding of Aluminium Alloy. After selection of the range of the parameters design matrix was developed and is presented in Table 2 and table 3 respectively.

Table 2 : Parameters of Experiment

S. No	Variables	Units	Level 1 (-)	Level 2 (+)
1.	Tool shape		Taper	Thread
2.	Welding speed	RPM	600	700
3.	Feed rate	mm/min	30	40

Experimentations were performed as per the design matrix. Single pass procedure was followed to fabricate the joints. Weld joint was made by joining two plates having dimensions (300 x 75x 5) mm using single side welds. The plates to be welded were securely clamped in the fixture so that the plates stay in place and do not fly away due to the welding forces.

Table 3: Design Matrix for Experiment

S. No.	Tool shape	Welding speed	Feed rate
1	-	-	-
2	+	-	-
3	-	+	-
4	+	+	-
5	-	-	+
6	+	-	+
7	-	+	+
8	+	+	+

The rotational motion of the spindle was started and the tool was than kept in contact with the surface of the plates and the pin was penetrated to a predetermined depth in the surfaces of the plates to be welded.

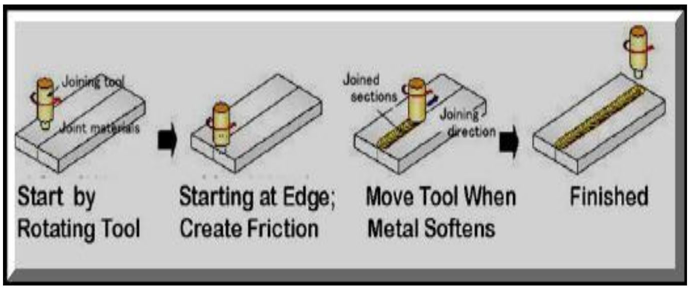

Fig. 1: Set up of friction stir welding process

The tool was given some time as it rotates in contact with the surfaces to soften the material due to the frictional heat produced and afterwards the tool was given forward motion which formed the weld. The tool was withdrawn after the weld was completed; the process leaves a hole at the end of the joint.

Visual inspection was performed on all welded sample in order to verify the presence of possible external defects such as surface irregularities, excessive flash and lack of penetration or surface open tunnel, voids etc.

3.3 Mechanical testing: The experiments were conducted as per the standard L8 (2^3) orthogonal array. As the FSW process is completed, Three mechanical tests as Tensile strength, Impact toughness and Micro-hardness are conducted to find the effect of welding parameters on

Mechanical properties of FSW Al 6061 joint. The specimen required to conduct these mechanical tests are prepared as the standard dimensions are given by ASTM (American Society of Testing Materials)

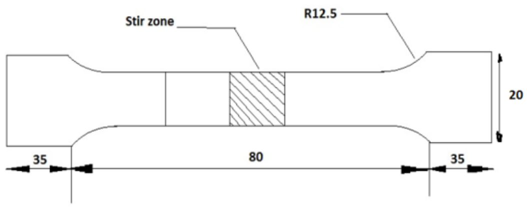

Fig. 2 ASTM Dimensions (mm) for tensile test Specimen

Fig.3 Prepared Specimen for Tensile Strength

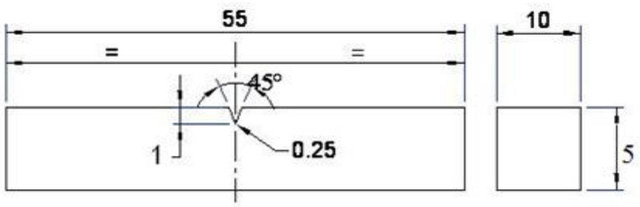

Fig. 4 ASTM Dimensions (mm) for Impact test specimen

Fig. 4 Prepared Specimen for Impact toughness

4. Results and Discussion

The results of the experiment are shown in the table .In the table T.S.T stands for tensile strength Test, I.T.T stands for impact Toughness test and M.H.T stands for Micro-hardness test.

The effect of welding parameters for Mechanical properties of Aluminium Al 6061 using FSW were analysed using Minitab 17 software.

Table 4: Experimental Results.

Sr. No.	Tool Shape	Welding Speed	Feed Rate	T.S.T	I.T.T	M.H.T
1	TAPER	600	30	90.55	20	59
2	TAPER	600	30	92.22	29	58
3	TAPER	600	30	91.17	18	59
4	TAPER	600	40	94.12	20	64
5	TAPER	600	40	95.66	21	63
6	TAPER	600	40	95.72	19	65
7	TAPER	700	30	90.55	17	60
8	TAPER	700	30	92.22	18	61
9	TAPER	700	30	91.17	17	62
10	TAPER	700	40	107.0	22	65
11	TAPER	700	40	105.3	24	66
12	TAPER	700	40	107.1	23	68
13	THREAD	600	30	58.61	16	56
14	THREAD	600	30	60.13	17	58
15	THREAD	600	30	59.11	18	57
16	THREAD	600	40	72.33	20	61
17	THREAD	600	40	75.12	21	60
18	THREAD	600	40	74.33	19	62
19	THREAD	700	30	68.22	16	57
20	THREAD	700	30	68.33	17	59
21	THREAD	700	30	70.17	16	60
22	THREAD	700	40	78.21	17	63
23	THREAD	700	40	76.33	19	64
24	THREAD	700	40	78.66	18	65

Using Taguchi Approach to Experimental Work

'Larger the better' characteristics:

$$S/N = -10\log 1/n \left(\sum 1/y^2\right)$$

where n the number of observations and y the observed data. The S/N ratio for maximum response (tensile strength, Impact strength and Micro-hardness) comes under 'larger the better' characteristic, which can be calculated as logarithmic transformation of the loss function by using above Equation.

The influence of control parameters such as welding speed, Feed Rate and tool shape on mechanical properties was evaluated. The main effects plot for SN ratio and Means are shown in figure. The effect of tool shape and welding parameters on mechanical properties of the joints was investigated. It was shown that both tool types produce high quality butt joints free from defects or imperfections. The best tensile performance was obtained for FSW joints produced by a taper tool and the results obtained for joints produced by threaded tool shoulder are significantly lower. Tensile strength test indicated that welding speed is the main parameter which effect thr tensile strength. Feed rate and tool shape are effecting second and third respectively. As the Impact toughness and Micro-hardness test are conducted, Feed rate is the main factor and Welding speed, tool shape are effecting respectively. . As a result of the experiment the welding speed 600 RPM, Feed Rate 40 mm/min and Taper probe tool are the best optimum levels to get maximum strength of mechanical properties

The S/N ratio response was analyzed using the above Equation (1) for all 24 tests and presented in Table 4. SN ratio Tables, Response tables and graphs are used to predict the regression equations

4.1 Results for S/N Ratio – Tensile strength Analysis

The S/N ratios have been calculated to identify the major contributing factors that cause variation in tensile strength. Table 5 shows the ANOVA results for S/N ratio of tensile strength of samples at 95% confidence interval. The factor, namely WS was found to be with 78.13% contribution on the basis of the p- value and the other factors FR and TS were found to be insignificant for Tensile strength of uncoated Al 6061 alloy with 13.653% and .376% Contribution. In this table ranking has done which indicate, how much factor affects the output response. Rank 1 indicates that it affects the most. In this table WS is the main factor, and then comes FR and at last TS as shown in table. It is calculated by Delta, the highest value of delta is given rank 1 and so on. Delta is calculated by subtracting lowest value from the highest value as shown in Table 6

Table 5: ANOVA for SN Ratio of tensile strength

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Pr(%)
TOOL SHAPE	1	0.0746	0.0746	48.53	0.091	0.376
WS	1	15.4849	15.4849	10068.8	0.006	78.13
FR	1	2.7055	2.7055	1759.19	0.015	13.653
TOOL SHAPE*WS	1	0.9198	0.9198	598.09	0.026	4.64
TOOL SHAPE*FR	1	0.4287	0.4287	278.73	0.038	2.16
WS*FR	1	0.2036	0.2036	132.4	0.055	1.02
Error	1	0.0015	0.0015			
Total	7	19.8186				

Table 6: Response Table for Signal to Noise Ratios

Level	Tool shape	WS	FR
1	38.34	39.64	37.66
2	38.15	36.85	38.83
Delta	0.19	2.78	1.16
Rank	3	1	2

4.2 Results for S/N Ratio – Impact toughness Analysis

The S/N ratios have been calculated to identify the major contributing factors that cause variation in Impact toughness. Table 7 shows the ANOVA results for S/N ratio Impact toughness of samples at 95% confidence interval. The factor, namely WS was found to be with 28.33% contribution on the basis of the p- value and the other factors FR and TS were found to be insignificant for Tensile strength of uncoated Al 6061 alloy with 54.21% and .183% Contribution. In this table ranking has done which indicate, how much factor affects the output response. Rank 1 indicates that it affects the most. In this table FR is the main factor, and then comes WS and at last TS as shown in table. It is calculated by Delta, the highest value of delta is given rank 1 and so on. Delta is calculated by subtracting lowest value from the highest value as shown in Table 8

Table 7: ANOVA for SN Ratio of Impact toughness

Source	DF	Adj SS	Adj MS	F-Value	P Value	Pr(%)
TOOL SHAPE	1	0.01320	0.01320	0.34	0.665	0.1831
WS	1	2.03529	2.03529	51.84	0.088	28.335
FR	1	3.89457	3.89457	99.21	0.064	54.218
TOOL SHAPE*WS	1	1.01548	1.01548	25.87	0.124	14.138
TOOL SHAPE*FR	1	0.04132	0.04132	1.05	0.492	0.5704
WS*FR	1	0.14329	0.14329	3.65	0.307	1.993
Error	1	0.03926	0.03926			0.545
Total	7	7.18239				

Table 8: Response Table for S/N Ratios for Impact toughness

Level	TOOL SHAPE	FR	WS
1	25.54	24.81	26.01
2	25.46	26.20	25.00
Delta	0.08	1.40	1.01
Rank	3	1	2

4.3 Results for S/N Ratio – Micro hardness Analysis

The S/N ratios have been calculated to identify the major contributing factors that cause variation in Micro hardness. Table 9 shows the ANOVA results for S/N ratio of Micro hardness of samples at 95% confidence interval. The factor, namely FR was found to be with 69.31 % contribution on the basis of the p- value and the other factors WS and TS were found to be insignificant for Tensile strength of uncoated Al 6061 alloy with 14.965% and 0.0276% Contribution. In this table ranking has done which indicate, how much factor affects the output response. Rank 1 indicates that it affects the most. In this table FR is the main factor, and then comes WS and at last TS as shown in table. It is calculated by Delta, the highest value of delta is given rank 1 and so on. Delta is calculated by subtracting lowest value from the highest value as shown in Table 10

Table 9: ANOVA for SN Ratio of Micro hardness

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Pr(%)
TOOL SHAPE	1	0.00004	0.00004	0.02	0.920	0.027
WS	1	0.21686	0.21686	89.87	0.067	14.968
FR	1	1.00018	1.00018	414.49	0.031	69.312
TOOL SHAPE*WS	1	0.21686	0.21686	89.87	0.067	15.024
TOOL SHAPE*FR	1	0.00472	0.00472	1.96	0.395	0.327
WS*FR	1	0.00241	0.00241	1.00	0.500	0.167
Error	1	0.00241	0.00241			
Total	7	1.44348				

Table10: Response Table for SN Ratios for Micro-hardness

Level	TOOL SHAPE	WS	FR
1	35.75	35.91	35.39
2	35.74	35.58	36.10
Delta	0.00	0.33	0.71
Rank	3	2	1

4.4 Graphical Representation

Main effect plots for SN ratio of Tensile strength, Impact toughness and Micro-hardness are shown as below graphs.

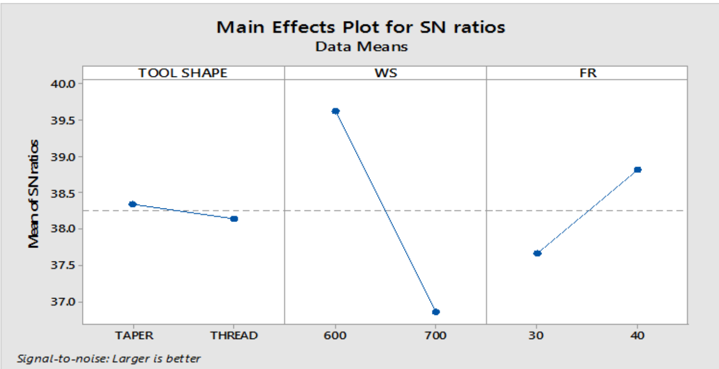

Fig. 5 Main effect Plots for SN ratio's for Tensile strength.

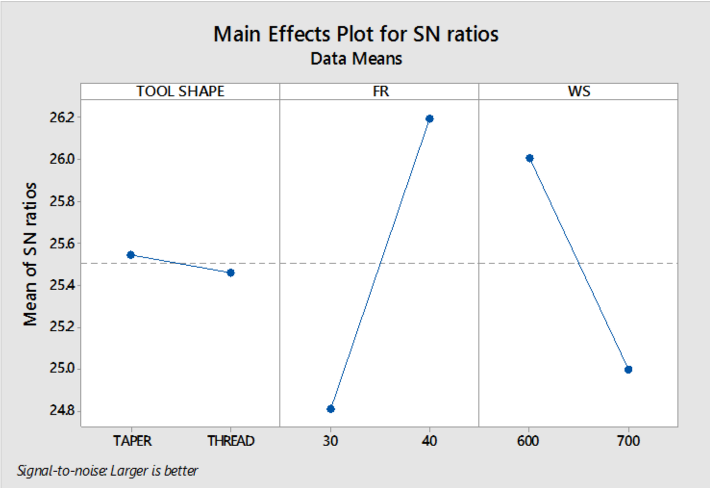

Fig. 6 Main effect Plots for SN ratio's for Impact toughness

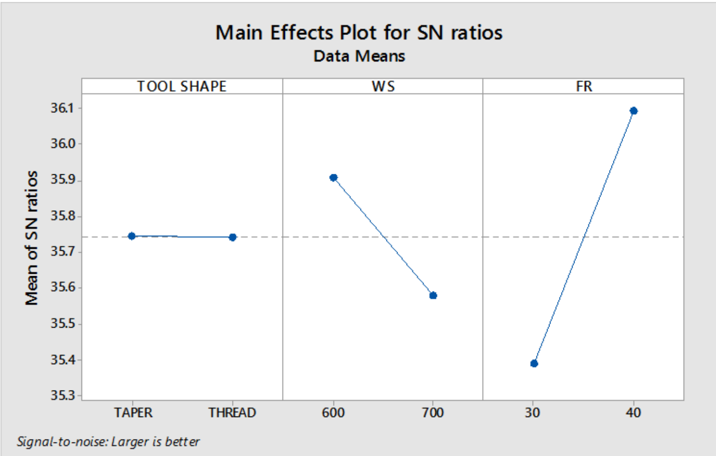

Fig. 7 Main effect Plots for SN ratio's for Micro-hardness.

4.4 Multiple Linear Regression Model Analysis

A multiple linear regression analysis attempts to model the relationship between two or more predictor variables and a response variable by fitting a linear equation to the observed data. Based on the experimental results, a multiple linear regression model was developed using MINITAB 17.

Regression Equations for output response are respectively,

Tensile strength = 267 - 0.340 WS - 0.40 FR+ 0.00225 WS*FR

Impact toughness = -11.3 + 0.0300 WS + 1.28 FR -0.00150 WS*FR

MICRO HARDNESS=43.8- 0.0000 WS + 0.93 FR - 0.00067 WS*FR

5. Conclusions

1. Three factors and two level Taguchi design was found to be an effective technique for developing mathematical models to accurately predict the main, quadratic and two-way interaction effects of various input parameters on different responses.
2. Welding speed is the main factor in case of Tensile strength , while feed rate and taper tool are the variables affecting the mechanical properties the respectively. In case Impact toughness and micro-hardness, Feed rate is the main factor while welding speed and taper tool are affecting second and third position respectively. Both tools have negligible effect on micro-hardness of FSW joint Al 6061.
3. No Visuals defects were observed in the weld joints welded at Welding speed of 600 to 700 rpm, Feed rate of 30 to 40 mm/min.
4. WS (600), FR (40) and tool (taper) are the best optimum parameters from given parameters for tensile strength, Impact toughness and micro-hardness.

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