International Journal of Enhanced Research in Management & Computer Applications
ISSN: 2319-7471, Vol. 6 Issue 8, August-2017, Impact Factor: 3.578

Parametric Optimization for Friction Stir Welding of AL 6063 Alloy Using Taguchi Technique

Neeraj Hooda[1*], Pardeep Gahlot[2], Narender Kaushik[3], Sumit Khatri[4], Jag Mohan[5]

[1,4,5]M.Tech student, Department of Mechanical Engineering, UIET MDU Rohtak, Haryana, India
[2]Assistant professor, Department of Mechanical Engineering, UIET MDU Rohtak, Haryana, India
[3]Research Scholar, NIT Kurukshetra, Haryana, India

ABSTRACT

Taguchi approach and analysis of variance were applied to find out the best control parameters for the mechanical properties of the joints of friction stir welded AL 6063 alloy. The evaluation of the consequence of process parameters such as tool rotational speed, transverse feed and tilt angle on tensile strength, % of elongation and hardness of friction stir welded AL 6063 alloy were investigated in this study. On the analogy, nine experiments were performed based on L9 orthogonal array of Taguchi's methodology of three input parameters with three levels. Analysis of variance was employed to find the levels of significance of input parameters. The results indicated that tilt angle has the greatest effect on tensile strength and transverse speed have greatest effect on hardness and % of elongation as well. The results were confirmed by further experiments.

Keywords: AL 6063, Friction stir welding, Tensile strength, Hardness, % of elongation, Taguchi technique, Analysis of variance.

INTRODUCTION

The Friction Stir Welding (FSW) is the method of welding in which two solid states surfaces are joined with the help of non -consumable tool. This method was invented and later patented by The Welding Institute (TWI) in 1991. In FSW, a cylindrical tool with a special designed pin is rotated and inserted into the joint area between two pieces of plate material. The parts have to be tightly or rigidly clamped to forbid joint faces from being forced apart. Frictional heat develop between the wear resistant welding tool and the work pieces lead to the latter to soften without getting up to melting point, permitting the tool to move along the weld line. A plastic flow in the material is induced by the heat input, the stirring action and the forging action of the tool , forming a solid state weld [1].The plasticized material, transmitted to the trailing edge of tool pin, is forged by intimate contact with the tool shoulder and pin profile. There four different micro structural zones noticed in a FSW weld such as: (i)Base Metal(BM) (ii)Heat Affected Zone(HAZ) (iii) Thermo-mechanically affected Zone (TMAZ) & (iv) Nugget Zone (NZ) [2]. Usually high welding speed lead to ultimate tensile strength increases as compare to low welding rate in as welded condition but it is reversed after post weld heat treatment and the welding process softens the material which lead to decrease the hardness, tensile strength and increases the ductility of material[3] In FSW, it is understood that increase in the weld speed and decrease in the TRS, lead to reduce in the heat input necessary for joining leading to decrease in the thickness of TMAZ and HAZ which, lead to increases in the tensile properties [4]. On cooling, a solid phase bond is obtained between the work pieces .While using FSW in high temperature materials, FSW is turned out very successful on number of alloys and materials, including stainless steel, titanium and high-strength steels. This welding technique provides many benefits such as it produces no fumes, no arc and need no filler metal. Thus we can say that it is an eco- friendly method. Application of FSW give tremendous result in joining ferrous and non-ferrous alloys that were joined by using conventional welding techniques with huge difficulties. The main objective of any manufacturer for choosing a welding method is to get a best quality of welded joint by right selection of most appropriate welding parameters .Robust design given by Taguchi is one of the best method for reaching at a conclusion while choosing most appropriate welding parameters within very short time and at less materials cost and labor effort. Taguchi techniques are being used for large number of products and processes to find out the performance measures and various parameters with minimum variations. To ensure a successful and effective welding cycle the tool speed and tool geometry must be opted with care, as both of these parameters are very important. [6].Various studies have been carried to find out the amount of heat generated and transferred to the joint area. A simplified model is stated in the following equation. **Q = □□FK.** The schematic process is shown in Figure 1.

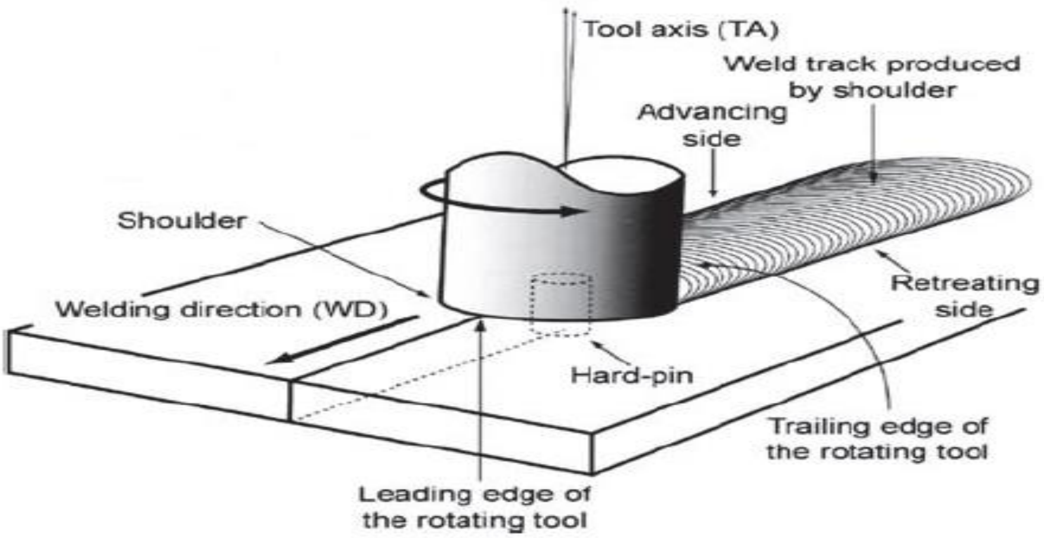

Figure 1: Friction stir welding process

EXPERIMENTAL PROCEDURE

Material

AA6063 material is used for this investigation in the form of plates of size 100 x 50mm x 5 mm. AA6063's Chemical composition is listed in Table1.

Table.1: AA6063's Chemical composition

Element	Si	Fe	Cu	Mn	Mg	Zn	Ci	Tr	Al
%	0.2-0.6	0.35	0.1	0.1	0.45-0.9	0.1	0.1	0.1	Bal

Tool Design

The tool should be made of a material that can withstand the whole process and offer adequate frictional heat generation. When choosing a material to manufacture the FSW tool the material is to be welded must be considered. The tool material should be stronger and have a good wear resistance than the material to be welded and should have high melting temperature [7]. A basic and schematic design for a FSW tool is given in Figure 2. 1. This cylindrical design is compared to other complex and still emerging tool variants.

FSW tools follows some basic pattern in terms of shapes and geometries. They are generally made up of three basic features:

1) A shoulder section;
2) A probe and
3) Any external features on the probe.

The shoulder is designed relatively large, as compared to the probe, profiled surface. Although the probe makes the initial contact with pre-welded material but the shoulder has a larger contact area and produces more friction.

Fig. 2: Weld tool

Welding Parameters

For this study following parameters are considered. They are
1. Tilt Angle (TA)
2. Transverse Speed (TS)
3. Rotational Speed (RS)

The different parameters considered for welding is given in the table.

FSW Process

The plates are placed in butt configuration of 100 mm length; 50 mm width and the FSW process is performed in direction normal to the plates. The tool rotation is in the direction of translation of the tool. The two plates that have to weld are kept in the bed and they are fixed very tightly using the clamps in the bed. These clamps hold the plates tightly even larger pressure or force is acted on it. With the help of the hydraulic devices the movement of the bed, rotation of the motor and movement of tool holder are done and they are operated by using the Control buttons which are present in control panel in FSW machine. The machine and assembly are shown in fig.

Table.2 Process Parameters

SAMPLE NO.	ROTATIONAL SPEED(RPM)	TRANSVERSE SPEED(MM/MIN)	TILT ANGLE
1	1200	79	0
2	1200	95	1
3	1200	124	2
4	1350	79	1
5	1350	95	2
6	1350	124	0
7	1500	79	2
8	1500	95	0
9	1500	124	1

A set of 27 samples are prepared to find out the mechanical properties are shown in Figure 6.

Figure.3: Friction Welding Machine

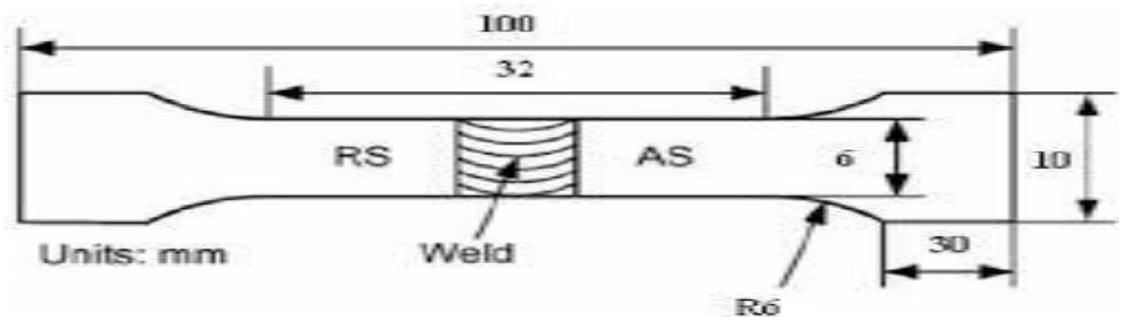

Fig.4: TEST SAMPLES FOR TENSILE TESTING

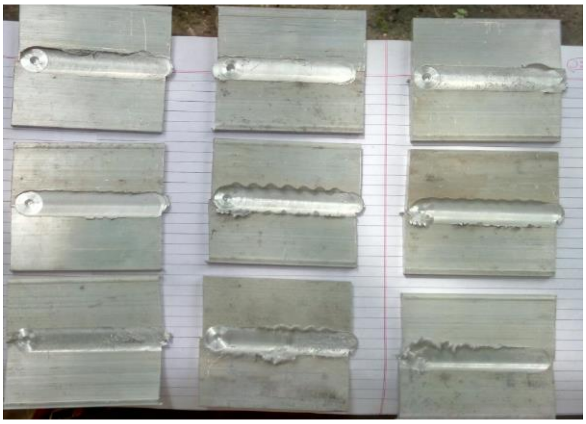

Fig.5: Friction stir welded joints

Fig.6: SAMPLES BEFORE TESTING

Fig.7: TESTED SAMPLES

RESULTS AND DISCUSSIONS

The quality of the FSW joints were described by tensile strength and hardness and the influence on the output response S/N ratio of welding parameters for each control factor was calculated. To analyze the test run results S/N ratio was used because it represents both the average and variation of the experimental results. In this research work, maximum tensile strength was the objective function and larger the better S/N ratio was chosen as a larger S/N ratio relates to better quality characteristics.

Tensile Strength Analysis

Table.3: Process parameters and experimental results

Sample no.	R.S(RPM)	T.S(MM/MIN)	T.A	UTS(KN/MM^2)	SIGNAL TO NOISE RATIO	MEAN
1	1200	79	0	73.55	37.3317	73.55
2	1200	95	1	76.33	37.6539	76.33
3	1200	124	2	83.66	38.4504	83.66
4	1350	79	1	62.33	35.8939	62.33
5	1350	95	2	80.33	38.0976	80.33
6	1350	124	0	86.66	38.7564	86.66
7	1500	79	2	88.33	38.9222	88.33
8	1500	95	0	108.33	40.6950	108.33
9	1500	124	1	56.33	35.0148	56.33

The nine experiments were executed based on the L9 orthogonal array. The effect of different parameters such as tool rotational speed, translational feed and tilt angle of Al 6063 alloy was analyzed. The observational values of tensile strength and their S/N ratios and is shown in table 3. To avoid the extra calculations work, Minitab 17 statistical software [8] was used to calculate S/N ratio and plot the main effect graphs. Delta shows the common difference between the maximum and minimum values for the corresponding parameters. The generated response table 4 for signal to noise ratios given below shows the peak value of various parameters according to three different levels and it clearly determines the peak value ranks of parameters.

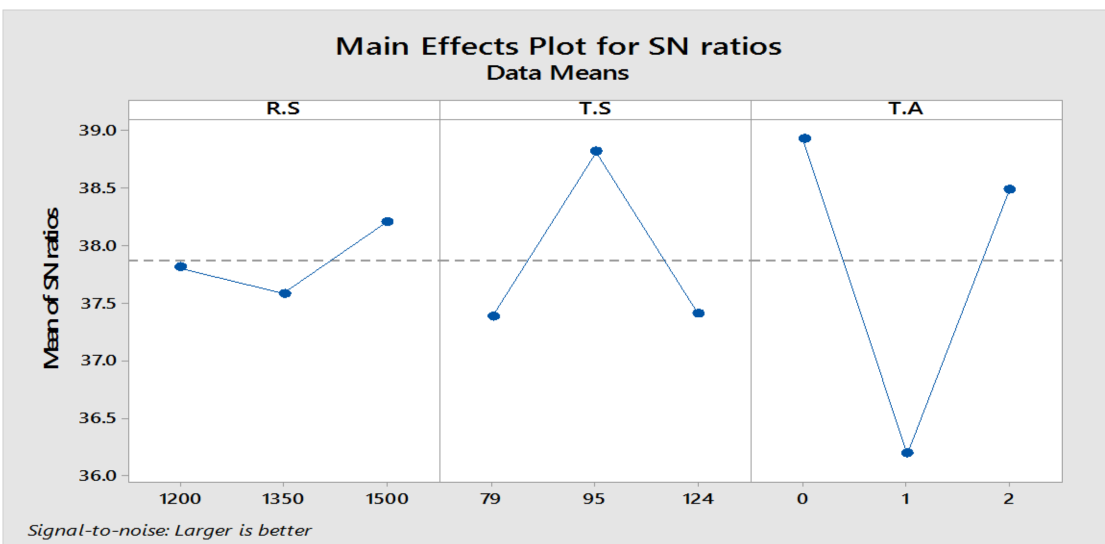

Fig.8: Main effects plot for S/N ratio

Table.4: Response Table of Signal to Noise Ratios

Larger is better

Level	R.S	T.S	T.A
1	37.81	37.38	38.93
2	37.58	38.82	36.19
3	38.21	37.41	38.49
Delta	0.63	1.43	2.74
Rank	3	2	1

It indicate main effects plot for S/N ratio showing that tensile strength is maximum when rotational speed, transverse feed, and tilt angle are at a level of $R.S_3$, $T.S_2$,$T.A_1$ i.e. rotational speed at 1500 rpm, transverse feed at 95 mm/min and tilt angle at 0 respectively

Table. 5: ANOVA table for tensile strength

SOURCE OF VARIATION	DEGREE OF FREEDOM(DF)	SUM OF SQUARES (SS)	ADJUSTMENT OF SQUARES (SS)	ADJUSTMENT OF MEAN OF SQUARES(MS)	FISHER VALUE (F)	PROBABILITY VALUE(P)	% CONTRIBUTION
R.S	2	106.3	106.3	53.13	0.26	0.792	5.73
T.S	2	348.8	348.8	174.38	0.86	0.537	18.8
T.A	2	995.5	995.5	497.75	2.46	0.289	53.87
ERROR	2	405.5	405.5	202.48			21.86
TOTAL	8	1855.5					100

Regression Equation

UTS = 79.54 - 1.69 R.S_1200 - 3.10 R.S_1350 + 4.79 R.S_1500 - 4.80 T.S_79 + 8.79 T.S_95
- 3.99 T.S_124 + 9.97 T.A_0 - 14.54 T.A_1 + 4.57 T.A_2

The percentage of contribution clearly shows in the table 5 that the tilt angle feed 'T.A' is the most significant factor for the performed experiment with 53.87% of the total contribution. Rotational speed 'R.S' is at third place paying 5.73% of the contribution and the transverse speed 'T.S' is at second place of 18.8% of contribution.

Confirmation Test for Tensile Strength

Tensile strength = RS3 + TF2 + TA1 – 2(T)
Where, T is the total mean of tensile strength in MPa
RS3 is the average tensile strength at second level of rotational speed at 1500 rpm
TF2 is the average tensile strength at second level of transverse feed at 95 mm/min
TA1 is the average tensile strength at second level of tilt angle 0
Substituting the values of various terms in equation,

Tensile strength = 84.33 + 88.33 + 89.51 − 2×79.59 = 103.09 MPa

The final step was to verify the improvement in tensile strength by conducting experiments with optimal conditions. Confirmation experiment was conducted at the optimum setting of process parameters. The rotational speed, transverse speed and tilt angle were set at 1500 rpm, 958mm/min and 0 respectively. The average tensile strength of friction stir welded Al 6063 found to be 108.33 MPa that was within the confidence interval of the predicted optimal of tensile strength with the joint efficiency of 95.16%.

% of elongation analysis

Table.6: Process parameters and experimental results

Sample no.	R.S(RPM)	T.S(MM/MIN)	T.A	% of elongation	SIGNAL TO NOISE RATIO	MEAN
1	1200	79	0	4.540	13.1411	4.540
2	1200	95	1	8.080	18.1482	8.080
3	1200	124	2	7.071	16.9896	6.061
4	1350	79	1	6.061	15.6509	6.061
5	1350	95	2	7.071	16.9896	7.071
6	1350	124	0	7.071	16.9896	7.071
7	1500	79	2	4.040	12.1276	4.040
8	1500	95	0	8.580	18.6697	8.580
9	1500	124	1	3.535	10.9678	3.535

The nine experiments were executed based on the L9 orthogonal array. The effect of different parameters such as tool rotational speed, translational feed and tilt angle of Al 6063 alloy was analyzed. The observational values of % of elongation and their S/N ratios and is shown in table 6.

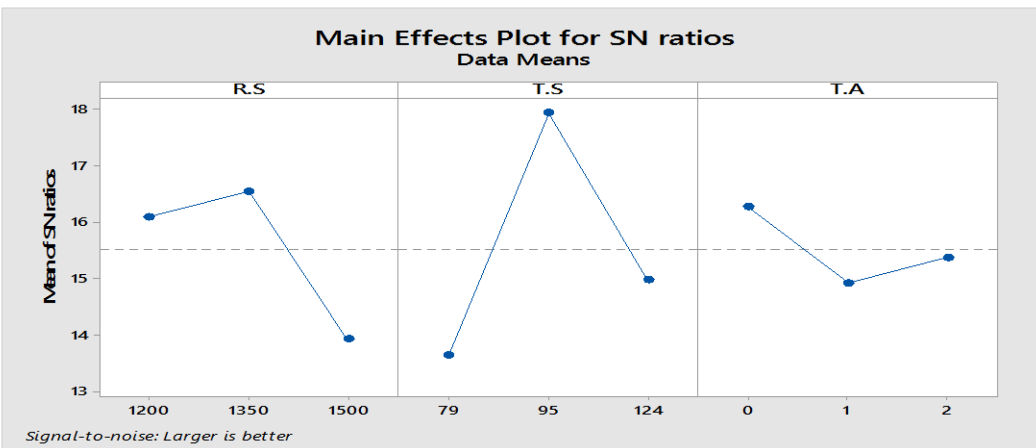

Fig. 9: Main effects plot for S/N ratio

Table.7: Response Table of Signal to Noise Ratios

Nominal is best

Level	R.S	T.S	T.A
1	16.09	13.64	16.27
2	16.54	17.94	14.92
3	13.92	14.98	15.37
Delta	2.62	4.30	1.34
Rank	2	1	3

It indicate the main effects plot for S/N ratio indicating that % elongation is maximum when rotational speed, transverse feed, and tilt angle are at a level of $R.S_2$, $T.S_2$,$T.A_1$ i.e. rotational speed at 1350 rpm, transverse feed at 95 mm/min and tilt angle at 0 respectively.

Table. 8: ANOVA TABLE FOR % ELONGATION

SOURCE OF VARIATION	DEGREE OF FREEDOM(DF)	SUM OF SQUARES (SS)	ADJUSTMENT OF SQUARES (SS)	ADJUSTMENT OF MEAN OF SQUARES(MS)	FISHER VALUE(F)	PROBABILITY VALUE(P)	% CONTRIBUTION
R.S	2	3.239	3.239	1.6195	0.44	0.693	12.45
T.S	2	14.277	14.277	7.1387	1.95	0.339	54.89
T.A	2	1.180	1.180	0.5899	0.16	0.861	4.54
ERROR	2	7.314	7.314	3.6572			28.12
TOTAL	8	26.011					100

Regression Equation

%E = 6.228 + 0.336 R.S_1200 + 0.507 R.S_1350 - 0.843 R.S_1500 - 1.347 T.S_79 + 1.683 T.S_95 - 0.335 T.S_124 + 0.503 T.A_0 - 0.336 T.A_1 - 0.167 T.A_2

The percentage of contribution clearly shows in the table 8 that the tilt angle feed ‘T.A’ is the most significant factor for the performed experiment with 54.89% of the total contribution. Rotational speed ‘R.S’ is at second place paying 12.45% of the contribution and the transverse speed ‘T.S’ is at third place of 4.54% of contribution.

Hardness Analysis

The results of Hardness of Weld Zone (WZ), Parent Metal (PM) & Heat Affected Zone (HAZ) on different sets of combination of parameters were calculated according to the Brinell hardness (HB) in the table 9.

Table. 9: Process parameters and experimental results

Sample no.	**R.S(RPM)**	**T.S(MM/MIN)**	**T.A**	**Hardness PM(HB)**	**HARDNESS TMAZ(HB)**	**Hardness HAZ(HB)**	**SIGNAL TO NOISE RATIO**
1	**1200**	**79**	**0**	71.4	48.5	63.3	**14.4178**
2	**1200**	**95**	**1**	71.5	49.2	64.1	**14.6854**
3	**1200**	**124**	**2**	72.4	50.9	64.2	**15.2087**
4	**1350**	**79**	**1**	72.5	47.3	63.1	**13.6021**
5	**1350**	**95**	**2**	71.9	48.3	64.3	**14.1602**
6	**1350**	**124**	**0**	71.2	49.2	64.9	**14.7307**
7	**1500**	**79**	**2**	71.5	47.3	62.8	**13.8714**
8	**1500**	**95**	**0**	72.4	47.5	63.3	**13.7091**
9	**1500**	**124**	**1**	72.3	48.2	63.5	**14.0301**

The nine experiments were executed based on the L9 orthogonal array. The effect of different parameters such as tool rotational speed, translational feed and tilt angle of Al 6063 alloy was analyzed. The observational values of hardness and their S/N ratios and is shown in table 9.

International Journal of Enhanced Research in Management & Computer Applications
ISSN: 2319-7471, Vol. 6 Issue 8, August-2017, Impact Factor: 3.578

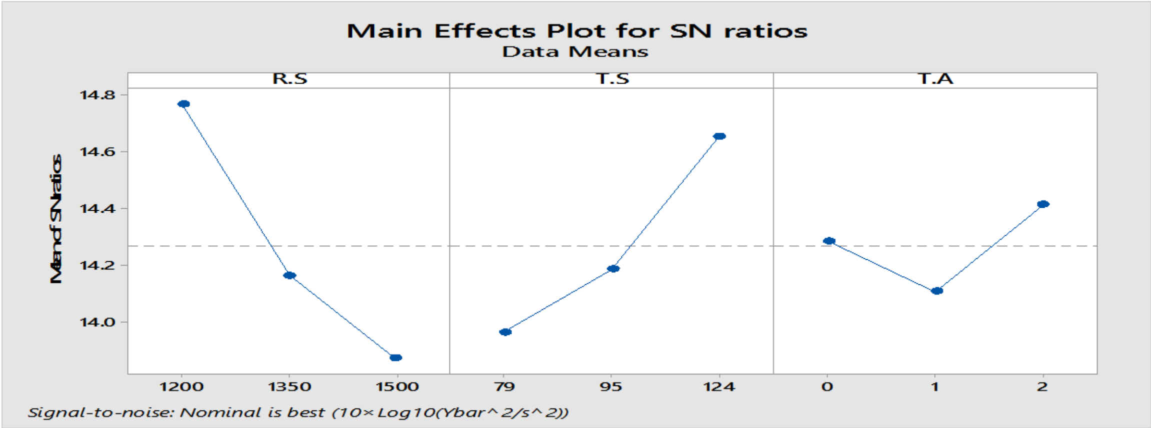

Fig.10: Main effects plot for S/N ratio

Table 10: Response Table of Signal to Noise Ratios

Nominal is best (10×Log 10(Ybar^2/s^2))

Level	R.S	T.S	T.A
1	14.77	13.96	14.29
2	14.16	14.18	14.11
3	13.87	14.66	14.41
Delta	0.90	0.69	0.31
Rank	1	2	3

It indicate the main effects plot for S/N ratio indicating that hardness is maximum when rotational speed, transverse feed, and tilt angle are at a level of $R.S_1$, $T.S_3$,$T.A_3$ i.e. rotational speed at 1200 rpm, transverse feed at 124 mm/min and tilt angle at 2 respectively.

Table .11: ANOVA TABLE FOR HARDNESS

SOURCE OF VARIATION	DEGREE OF FREEDOM(DF)	SUM OF SQUARES (SS)	ADJUSTMENT OF SQUARES (SS)	ADJUSTMENT OF MEAN OF SQUARES(MS)	FISHER VALUE (F)	PROBABILITY VALUE(P)	% CONTRIBU-TION
R.S	2	1.3089	1.0389	0.65444	5.40	0.693	35.04
T.S	2	2.0689	2.0689	1.03444	8.54	0.339	55.38
T.A	2	0.1156	0.1156	0.05778	0.48	0.861	3.09
ERROR	2	0.2422	0.2422	0.12111			6.48
TOTAL	8	3.7356					100

Regression Equation

HARDNESS HAZ = 63.722 + 0.144 R.S_1200 + 0.378 R.S_1350 - 0.522 R.S_1500 - 0.656 T.S_79 + 0.178 T.S_95 + 0.478 T.S_124 + 0.111 T.A_0 - 0.156 T.A_1 + 0.044 T.A_2

The percentage of contribution clearly shows in the table 11 that the transverse feed ‘T.S’ is the most significant factor for the performed experiment with 55.38% of the total contribution. Rotational speed ‘R.S’ is at second place paying 35.04% of the contribution and the tilt angle ‘T.A’ is at third place of 3.09% of contribution.

Confirmation Test for Hardness

It must be noted that the above table 10 shows that $R.S_1$, $T.S_3$, $T.A_3$ i.e. rotational speed at 1200 rpm, transverse feed at 124 mm/min and tilt angle at 2 respectively are among the nine combinations that are tested for the experiment. This is estimated because of the multifactor nature of the experimental design employed (9 from 3^3=27 possible combinations). Hence, there is no need of confirmation test to be carried out to check the hardness value.

CONCLUSION

The present investigation showed that butt joint configuration of Al 6063 aluminum alloy was successfully prepared using non consumable rotating tool with tapered cylindrical pin by friction stir welding technique. The samples were considered for tensile strength, % of elongation and hardness of the welded joints. Taguchi technique and ANOVA was applied to investigate the significance of the process parameters. The following conclusions were made.

- TENSILE
  - It give the main effects plot for S/N ratio showing that tensile strength is maximum when rotational speed, transverse feed, and tilt angle are at level of $R.S_3$, $T.S_2$,$T.A_1$ i.e. rotational speed at 1500 rpm, transverse feed at 95 mm/min and tilt angle at 0 respectively
  - The percentage of contribution clearly shows in the table 5 that the tilt angle feed 'T.A' is the most significant factor for the performed experiment with 53.87% of the total contribution. Rotational speed 'R.S' is at third place paying 5.73% of the contribution and the transverse speed 'T.S' is at second place of 18.8% of contribution

- % OF ELONGATION
  - It give the main effects plot for S/N ratio showing that % elongation is maximum when rotational speed, transverse feed, and tilt angle are at a level of $R.S_2$, $T.S_2$,$T.A_1$ i.e. rotational speed at 1350 rpm, transverse feed at 95 mm/min and tilt angle at 0 respectively
  - The percentage of contribution clearly shows in the table 8 that the tilt angle feed 'T.A' is the most significant factor for the performed experiment with 54.89% of the total contribution. Rotational speed 'R.S' is at second place paying 12.45% of the contribution and the transverse speed 'T.S' is at third place of 4.54% of contribution.

- HARDNESS
  - The nine experiments were performed based on the L9 orthogonal array. The effect of different parameters such as tool rotational speed, translational feed and tilt angle of Al 6063 alloy was analyzed. The observational values of tensile strength with their S/N ratios and is shown in table 9.
  - The percentage of contribution clearly shows in the table 11 that the transverse feed 'T.S' is the most significant factor for the performed experiment with 55.38% of the total contribution. Rotational speed 'R.S' is at second place paying 35.04% of the contribution and the tilt angle 'T.A' is at third place of 3.09% of contribution

REFERENCES

[1]. Mukuna P. Mubiayi. and Esther T. Akinlabi, "Friction Stir Welding of Dissimilar Materials between Aluminium Alloys and Copper - An Overview"Proceedings of the World Congress on Engineering 2013 Vol III, WCE 2013, July 3 - 5, 2013, London, U.K.

[2]. C.J. Dawes and W.M. Thomas, (1996), Weld. J., Vol. 75, p 41.

[3]. Ratnesh Kumar Raj Singh, "Effect of Friction Stir Welding on Mechanical Properties of Dissimilar Aluminium Alloys" National Conference on Innovative Paradigms in Engineering & Technology (NCIPET-2012), Proceedings

published by International Journal of Computer Applications (IJCA).

[4]. N Rajamanickam& V Balusamy, "Effects of process parameters on mechanical properties of friction stir welds using design of experiments" Indian Journal of Engineering & Materials Sciences. Vol. 15, August 2008, pp. 293-299.

[5]. S. Sattari, H. Bisadi, M. Sajed," Mechanical Properties and Temperature Distributions of Thin Friction Stir Welded Sheets of AA5083" International Journal of Mechanics and Applications 2012, 2(1): 1-6. DOI: 10.5923/j.mechanics.20120201.01.

[6]. Ram Kumar, M. Siva Pragash and Saji Varghese, "Optimizing the Process Parameters of FSW on AZ31B Mg Alloy by Taguchi-Grey Method" Middle-East Journal of Scientific Research 15 (1): 161-167, 2013 IDOSI Publications, 2013 DOI: 10.5829/idosi.mejsr.2013.15.1.2246.

[7]. A M Khourshid and I Sabry, "Analysis and Design of Friction Stir Welding", International journal of Mechanical engineering and robotics research, Vol. 2, No. 3, July 2013.

[8]. MINITAB™ Statistical software 17.