Study of Effect of Process Parameter On Tensile Strength, Yield Strength and Percentage Elongation in Friction Stir Welding of AA 6063 Alloy

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Abstract- *The purpose of this paper is to optimize the process parameter to get the better mechanical properties of friction stir welded AA6063 alloys. AA 6063 is a medium strength alloy and has a wide application in a shop fittings, irrigation tubing and extrusions. It is normally used in intricate extrusions. It has a good surface finish, high corrosion resistance. Friction stir welding (FSW) is an emerged solid state welding process and has different advantages over conventional welding. The process parameter considered in study are welding speed, spindle speed and tool pin geometry while all experiments are carried out at optimum 0.2 mm plunge depth. The experiments were carried out by using Taguchi L9 orthogonal array. All the experiments were carried out in a vertical machining center. Tensile specimen is prepared according to ASTM E8 specifications in order to determine the optimum responses. The process is optimized for ultimate tensile strength (UTS), yield strength (YS) & percentage elongation (%E). Analysis of variance is used to determine the important process parameter that affect the quality of weld joint. Based on the experimental data optimum condition is determined in order to obtain a high quality of weld joint. Grey relational analysis (GRA) is a technique used for optimization.*

Keywords- Plunge depth, Tensile strength, Mechanical deformation, Advancing side, , AA6063 alloy.

I. INTRODUCTION

Aluminum and its alloys offer a unique combination of advantages with an extremely wide range of capability and applicability. Aluminum alloys are light weight materials having density is about 1/3 that of steel or copper alloys. AA 6063 alloy is the most widely used because of its extrudability.

Friction stir welding is invented at The Welding Institute (TWI) UK in 1991[1]. In contrast with conventional welding two objects are placed with no gap and high pressure. Third body is rubbed against two clamped objects. This tool is plunged into the joining region of two objects and translated along joint line [2]. Tool rotational speed, plunge depth and tool geometry mostly influences the quality of weld joint which can withstand the deformation without premature failure during post weld forming [3].

FSW tool is a critical component in the success of a weld. Tool consists of rotating round shoulder and threaded pin that creates friction followed by heating by softening alloy [5]. However FSW tool experiences high stresses and high temperature for a particular hard alloys such as steels and titanium alloys [4, 5, 6].

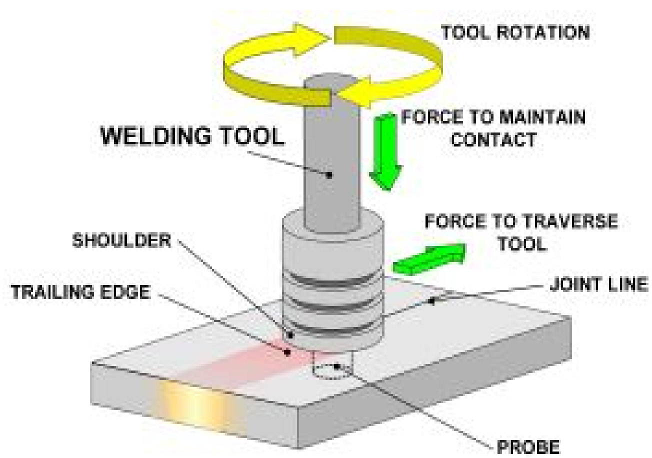

Figure 1. Principle of friction stir welding

The necessary power requirement is a function of various parameters that includes material, feed rate, spindle speed, tool geometry and tool depth. FSW is immune to the defects and property deteriorations such as melting, elimination of fumes, porosity, spatter, low shrinkage and weld distortion. In addition to the extensive mechanical deformation induces dynamic recovery and dynamic recrystallization that refine microstructure [8]. Tool material is sufficient harder than base metal so that it creates a sufficient friction, heat and sound weld. As steel is harder than the aluminum it requires the more frictional heat. The dependence on friction and plastic work precludes significant melting in workpiece and avoids many difficulties arising from change of state.

II. EXPERIMENTAL WORK

Experimentation and analysis work is carried out by following way

A) Identifying the important process parameters.

There are large numbers of parameters which affects the quality of friction stir welding. Some experiments were conducted in order to determine feasible ranges of process parameters. There parameters namely, welding speed, spindle speed and tool geometry and are considered while all experiments are conducted at constant plunge depth of 0.2 mm.

Table 1. Process parameters and response variables

Sr. No	Process parameters	Response variables
1	Welding Speed(mm/min)	Ultimate Tensile Strength(N/mm^2)
2	Spindle Speed(rpm)	Yield Strength (N/mm^2)
3	Tool Geometry	Percentage Elongation

Table 2. Fixed variables for experimentation

Sr. No	Fixed variables
1	Material AA 6063 alloy
2	Sample dimensions (100x100x5) mm

B) Determining the working range of process parameters.

In this investigation AA 6063 aluminum alloy having dimensions 100*100*5 mm is used to get the quality of a weld in a single pass of weld. Chemical compositions on weight percentage of the AA 6063 is Mn 0.10% , Fe 0.35%, Mg 0.41%, Si 0.42%, Zn 0.08%, Ti 0.10 Cr 0.10 and balance is Al. The mechanical properties of the base material are given in table3.

Table 3. Mechanical properties of the base material

Proof Stress	Tensile Strength	Elongation	Shear Strength	Vickers Hardness
160 MPa	195 Mpa	14 %	150 Mpa	80 HV

The plates were properly positioned and clamped by suitable clamping devices. The steps in a process include the plunging, dwell and transversing and tool retracting. The tool used in a process is a made up of oil hardened non shrinking tool steel (OHNS). In order to get the sufficient friction between tool and material, tool must be harder than base material. Heat treatment is carried out to get the hardness of 52 Hrc. The shoulder diameter of tool is 22 mm while pin diameter is 6 mm. Tool pin profile is varied in a circular, triangular and square shape. The chemical composition of a OHNS is shown in a table.

Table 4. Chemical composition of OHNS

C	Si	Mn	Cr	W	V
0.90	0.20	1.90	0.30	0.5	0.10

Pilot experimentation is carried out to decide the level of each process parameters and the result of same is presented below in table 5.

Table 5. Process parameters and their levels

Sr. No	Process parameters	Level 1	Level 2	Level 3
1	Welding Speed(mm/min)	40	50	60
2	Spindle Speed(rpm)	2000	2250	2500
3	Tool Geometry	Circular	Triangular	Square

C) Design of orthogonal array based on Taguchi method.

Taguchi's philosophy is an efficient tool for the design of high quality manufacturing system. Dr. Genichi Taguchi, a Japanese quality management consultant, has developed a method based on orthogonal array experiments, which provides much reduced variance for the experiment with optimum setting of process control parameters.

Orthogonal array (OA) provides a set of well balanced (minimum experimental runs) experiments and Taguchi's signal-to-noise ratios (S/N), which is logarithmic functions of desired output serve as objective functions for optimization. This technique helps in data analysis and prediction of optimum results. In order to evaluate optimal parameter settings, Taguchi method uses a statistical measure of performance called signal-to-noise ratio.

The S/N ratio takes both the mean and the variability into account. The S/N ratio is the ratio of the mean (signal) to the standard deviation (noise). The standard S/N ratios generally used are as follows: Nominal is best (NB), lower the better (LB) and higher the better (HB). The optimal setting is the parameter combination, which has the highest S/N ratio.

Table 6. L9 orthogonal array

Sr. No	WS	SS	TG	UTS	YS	%E
1	40	2000	Circular	75	41	4
2	40	2250	Triangular	118.32	62.38	13.60
3	40	2500	Square	119.05	78.68	13.20
4	50	2000	Triangular	61.56	27.02	2.02
5	50	2250	Square	91.25	47.92	9.03
6	50	2500	Circular	77.89	42	4.80
7	60	2000	Square	65.98	39.71	2
8	60	2250	Circular	75.78	37.53	3.20
9	60	2500	Triangular	89.35	46.08	5.20

III. RESULTS AND DISCUSSION

1. Signal-to-noise ratio (S/N ratio)

In order to evaluate optimal parameter settings, the Taguchi method uses a statistical measure of performance called signal-to-noise ratio. The S/N ratio developed by Dr. Taguchi is a performance measure to select control levels that best cope with noise.

In the Taguchi method, the term signal represents the desired value (mean) for the output characteristics and the term. Therefore it the ratio of the mean to the S.D. S/N ratio is used to measure the quality characteristics deviating from the desired value.

a. Analysis of S/N ratio for tensile strength

Larger tensile strength is the desirable property of the weld joint. So in case of tensile strength, larger the better option has been chosen for calculation of S/N ratio. From table 3, optimal parameters setting for tensile strength is, welding speed is 40mm/min, spindle speed is 2500 rpm and tool pin profile is square.

Table7. Response table for S/N ratio(larger the better)

Levels	Welding speed	Spindle speed	Tool geometry
1	104.12	67.51	76.22
2	76.9	95.12	89.74
3	77.04	95.43	93.07
Delta	27.22	27.92	15.84
Rank	1	2	3

b. Analysis of S/N ratio for yield strength

Larger yield strength is the desirable property of the weld joint. So in case of yield strength, larger the better option has been chosen for calculation of S/N ratio. From table 3, optimal parameters setting for yield strength is, welding speed is 40mm/min, spindle speed is 2500 rpm and tool pin profile is square.

Figure 2 The workflow of the problem taken for the study

Table 8. Response table for S/N ration (larger the batter)

Levels	Welding speed	Spindle speed	Tool geometry
1	60.83	35.91	40.18
2	38.98	49.42	45.3
3	41.11	55.59	55.44
Delta	21.85	19.68	15.29
Rank	1	2	3

c. Analysis of S/N ratio for percentage elongation

Larger percentage elongation is the desirable property of the weld joint. So in case of % elongation, larger the better option has been chosen for calculation of S/N ratio. From table 3, optimal parameters setting for % elongation is, welding speed is 40mm/min, spindle speed is 2500 rpm and tool pin profile is square.

Table 9. Response table for S/N ration (larger the batter)

Levels	Welding speed	Spindle speed	Tool geometry
1	10.267	2.673	4
2	5.283	8.61	6.94
3	3.467	7.733	8.077
Delta	6.8	5.937	4.077
Rank	1	2	3

2. Analysis of Variance

Analysis of variance (ANOVA) is a statistical model which can be used to find out effect of independent parameter on single dependent parameter and also can be used to find out the significant parameters and the percentage contribution of each parameter.

ANOVA For Tensile Strength

Table 10. ANOVA for tensile strength

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Welding	2	1474.82	737.40	170.85	0.0

speed			18		06
Spindle speed	2	1541.38	770.69 1	178.56	0.0 06
Tool geometry	2	440.17	220.08 5	50.99	0.0 19
Error	2	8.63	4.316	-	-
Total	8	3465	-	-	-

ANOVA for depth of penetration is given in table 10 indicates the significance value of various input factors. If the p value given in the last column of ANOVA table is less than 0.05, this means the factor corresponding to that value of p is significant. In present study the p value for welding speed is 0.006 coming lesser than 0.05. F value given in ANOVA table also indicates the significance of factors, higher the F value higher is the significance of that factor. Hence from table spindle speed is the significance factor.

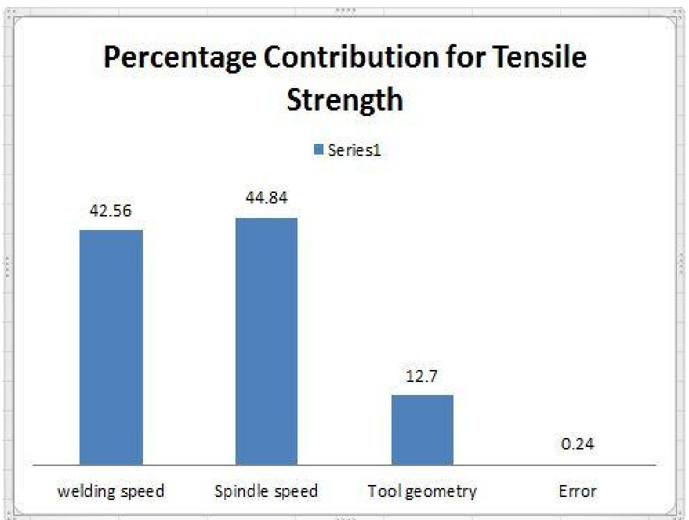

Figure 2. Percentage Contribution for tensile strength

Spindle speed is the most contributing factor for the tensile strength. Spindle speed contributes 44.84% while welding speed and tool geometry contributes 42.56% and 12.7% respectively.

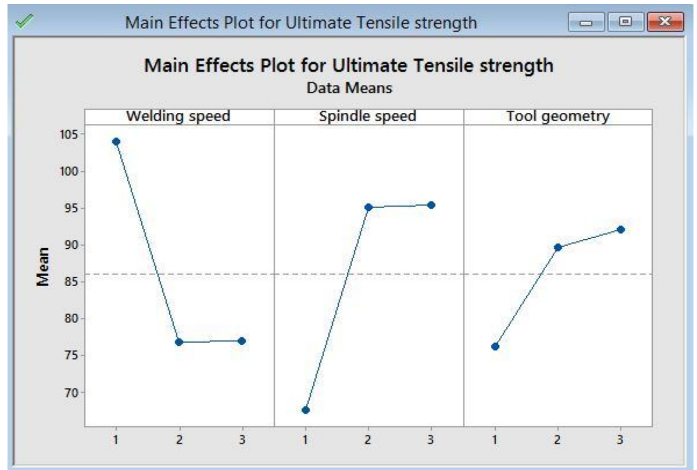

Figure 3. Main effect plot for tensile strength

ANOVA for Yield Strength

Table 11. ANOVA for yield strength

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Weldin g speed	2	870.68	435.339	49.03	0.020
Spindle speed	2	607.67	303.835	34.22	0.028
Tool geometr y	2	361.87	180.934	20.38	0.047
Error	2	17.76	8.878	-	-
Total	8	1857.97	-	-	-

ANOVA for yield strength is shown in the table 11 indicates that welding speed is the higher significant factor. While spindle speed and tool geometry are on the second and third rank.

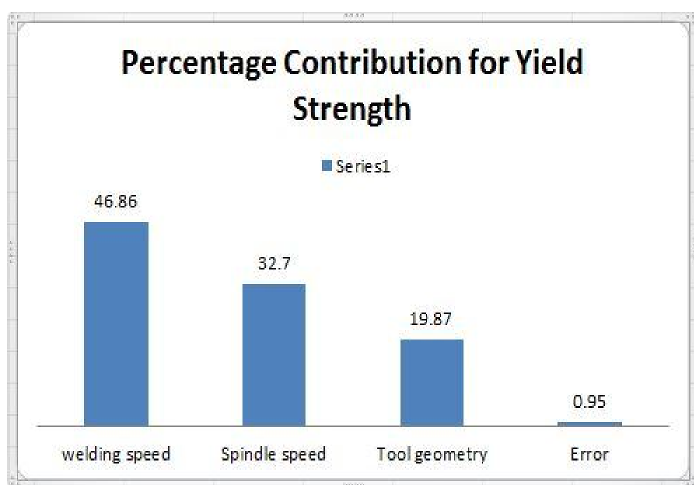

Figure 4. Percentage contribution of yield strength

Welding speed is the main influencing parameter and its contribution is 46.86% while spindle speed and tool geometry contributes 32.7% and 19.87% respectively.

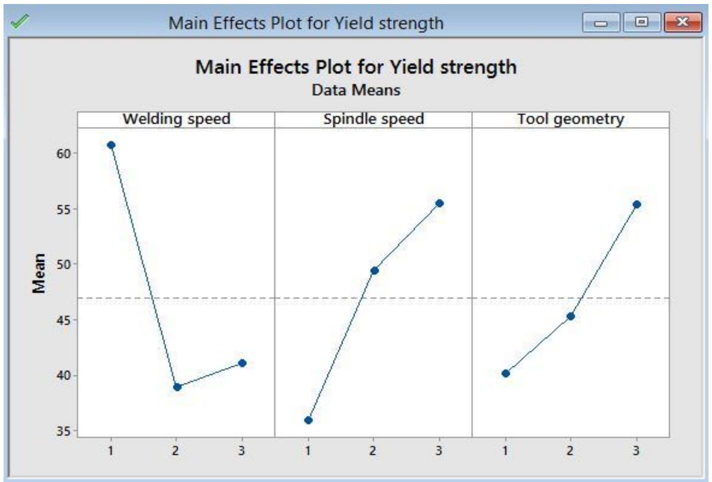

Figure 5. Main effect plot for Yield strength

As the slope of spindle speed is more than all other parameters, it is concluded that the spindle speed is most affecting parameter on a weld strength. Also welding speed is second most important parameter affecting weld strength while tool geometry affects dominantly on weld strength.

ANOVA for Percentage elongation

Table 12. ANOVA for Percentage Elongation

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Welding speed	2	74.374	37.1869	77.25	0.013
Spindle speed	2	61.616	30.8081	64.00	0.015
Tool geometry	2	26.555	13.2774	27.58	0.035
Error	2	0.963	0.4814	-	-
Total	8	163.508	-	-	-

ANOVA for percentage elongation is shown in table 12. All the input factors are significant as the P- values of all are less than 0.005. F-Value of welding speed is higher, it indicates that welding speed is the most significant factor.

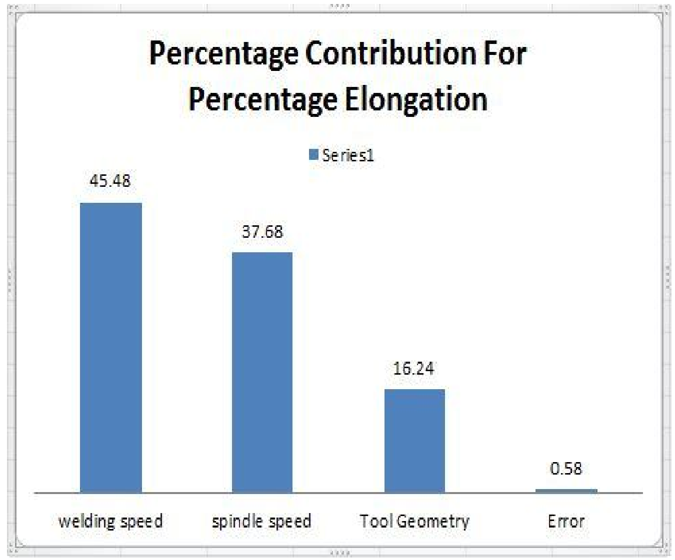

Figure 6. Percentage contribution of percentage elongation

Welding speed is the crucial parameter affecting the percentage elongation. It contributes 45.48 % while spindle speed and tool geometry affects 37.68% and 16.24% respectively.

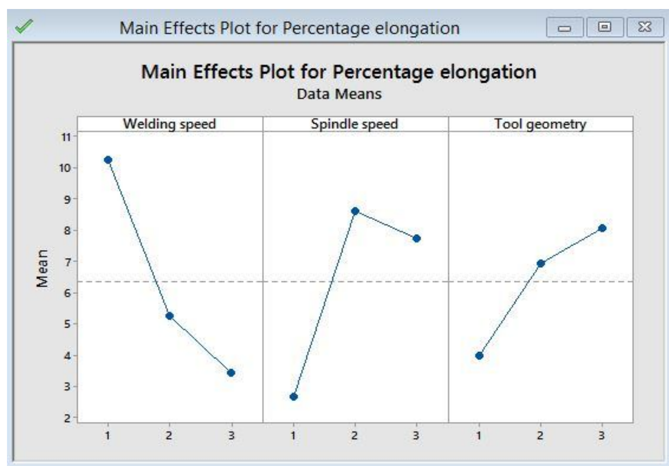

Figure 7. Main effect plot of yield strength

IV. CONCLUSION

- Maximum tensile strength is obtained at lower welding speed and higher value of spindle speed by using square pin profile tool. Lower welding speed enhances the mixing of material from advancing side to retracting side. While increase in spindle speed increases the heat due to friction. Square pin profile creates pulsating effect which enhances the material flow behaviour causing higher tensile strength.
- To get maximum tensile strength optimum parameters obtained are welding speed 40mm/min, spindle speed 2500 rpm and square tool pin profile.

- Maximum yield strength can be obtained by the same parameters as the tensile strength.
- Maximum percentage elongation can be obtained by lower welding speed, moderate spindle speed with square tool pin profile. Therefore optimum process parameters for percentage elongation are welding speed is 40mm/min, spindle speed is 2250 rpm and square pin profile tool.

V. ACKNOWLEDGMENT

Author would like to thank Lubricare pvt. Ltd. Pune for their encouragement in carrying out experiments and experimental set up. Also thanks to Mr. S. S. Sandbhor, one of the authors, for their support in carrying out this work. Also thanks to Dr. S. S. Mohite, H.O.D. of Mechanical Engineering, GCE, Karad, for their continuous support and suggestions during this project work.

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