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Research Paper

THE PARAMETRIC OPTIMIZATION OF FRICTION STIR WELDING PROCESS ON ALUMINIUM ALLOY 6082-T6

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This study focused on the single response optimization of Friction Stir Welding (FSW) process by using vertical milling machine on AA 6082-T6 for an optimal parametric combination to yield favorable ultimate tensile strength using the Taguchi techniques. In order to evaluate the effect of process parameters such as tool rotational speed, traverse speed and tool shoulder diameter on ultimate tensile strength of friction stir welded aluminium alloy 6082-T6, Taguchi parametric design and optimization approach was used. Through the Taguchi parametric design approach, the optimum levels of process parameters were determined. The results indicate that the rotational speed and welding speed are the significant parameters in deciding the tensile strength of the joint and the tool shoulder diameter is the least significant parameter in deciding the tensile strength of the joint.

Keywords: Aluminium alloy, Friction stir welding, Tensile strength, Taguchi technique, Analysis of variance

INTRODUCTION

Friction Stir Welding (FSW) is a solid state welding which was developed by TWI (a research institute) in 1990, friction stir welding is broadly used for joining aluminum alloys for aerospace, marine automotive and many other application in commercial field. In friction stir welding the two aluminum plates are welded together with the help a rapidly rotating non-consumable high strength profiled probe that extends from a cylindrical shoulder. And the plates are clamped in a fixture to prevent the butted joint to force apart. Frictional heat is generated between the wear resistant of welding tool and the work pieces. This heat causes soften of material without reaching the melting point and allows traversing of the tool along the weld line. The maximum temperature reached is of the order of 0.8 of the melting temperature of the material.

Ericsson *et al*. (2003) determined whether the fatigue strength of AA 6082 using Friction Stir (FS) welds is influenced by the welding speed, and

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also to compare the fatigue results with results for conventional arc-welding methods: MIG-pulse and TIG. Adamowski *et al*. (2007) analyzed the results of tests on the mechanical properties and microstructural changes in Friction Stir Welds in the aluminium alloy 6082-T6 in function of varying process parameters. Patil *et al*. (2010) investigated the effects of different welding speeds and tool pin profiles on the weld quality of AA6082-O aluminium. Tri-flutes and taper screw thread pin were used as tool pin profiles inthis research. The friction stir welded plates of AA6082-O by using the taper screw thread pin profile reaches the ultimate tensile strength of 92.30% of the base metal ultimate strength and % elongation of 27.58%. Raghu Babu *et al*. (2008) investigated the effect of processing parameters on mechanical and microstructural properties of aluminium alloy 6082-T6 FSW joints. The experimental results indicated that the process parameters have a significant effect on weld macrostructure and mechanical properties of joints. Scialpi *et al.* studiedthe effect of different shoulder geometries on the mechanical and microstructural properties of a friction stir welded joints. The process was used on 6082 T6 aluminium alloy in the thickness of 1.5 mm. The three studied tools differed from shoulders with scroll and fillet, cavity and fillet, and only fillet. The effect of the three shoulder geometries was analyzed by visual inspection, macrograph, HV microhardness, bending test and transverse and longitudinal room temperature tensile test. The investigation results showed that, for thin sheets, the best joint has been welded by a shoulder with fillet and cavity.

TAGUCHI METHOD

The method presented in this study is an experimental design process called the Taguchi design method. Taguchi design, developed by Dr. Genichi Taguchi, is a set of methodologies by which the inherent variability of materials and manufacturing processes has been taken into account at the design stage (Peace, 1992). Although similar to Design of Experiment (DOE), the Taguchi design only conducts the balanced (orthogonal) experimental combinations, which makes the Taguchi design even more effective than a fractional factorial design. By using the Taguchi techniques, industries are able to greatly reduce product development cycle time for both design and production, therefore reducing costs and increasing profit.

The steps included in the Taguchi parameter design are: selecting the proper Orthogonal Array (OA) according to the numbers of controllable factors (parameters); running experiments based on the OA; analyzing data; identifying the optimum condition; and conducting confirmation runs with the optimal levels of all the parameters (Julie, 2007).

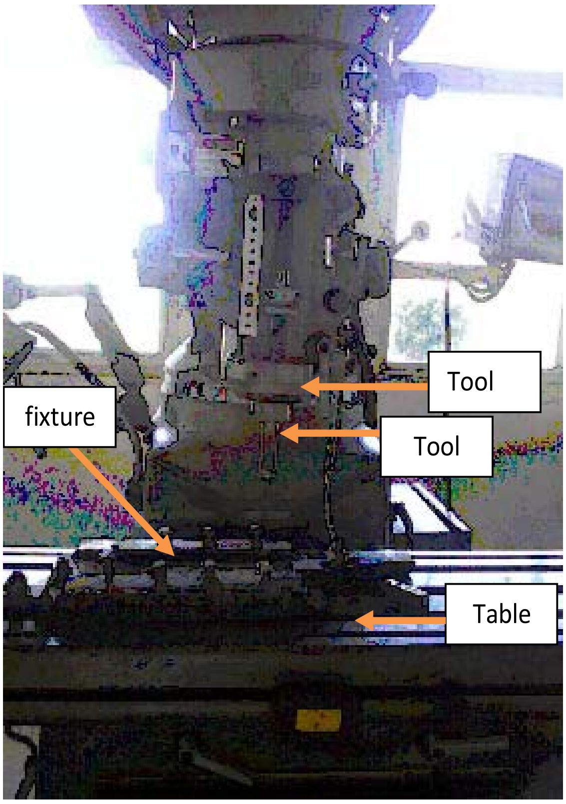
EXPERIMENTAL DESIGN

The experiments were carried out on a universal vertical milling machine as shown in Figure 1. And specification of milling machine was consisting of table with size 254 x 1370 mm^2, spindle speed variation from 70 rpm to 4600 rpm and a motor of 3 Hp.

PREPARATION OF SPECIMENS

Two aluminium alloy 6082-T6 plates of size 120 mm × 60 mm × 6 mm size plates were mounted on the fixture of vertical milling machine for making butt joint by using friction stir welding process as shown in Figure 1 and the chemical composition as well as mechanical properties were provided in Table 1. Given the Al-Mg-Si alloys are rather easily weldable even with conventional techniques; it was decided to verify weldability of AA 6082-T6 alloy by the most possible range of process parameters.

Figure 1: Pictorial View of Universal Vertical Milling Machine



The tool for welding AA6082-T6 by FSW was made of high carbon steel. The tool was consist of tool shank, tool shoulder and tool pin. Tool shank was required to hold the tool on the vertical spindle of vertical milling machine. Then tool shoulder was for producing heat due to friction and pin was used to stir the material during welding. Tool pin used during welding was cylinderial with diameter of 6 mm. For holding the tool on milling machine the shank diameter was made 17 mm. and the shoulder diameter was used as parameter for welding AA6082-T6.

Table 1: Chemical Composition of AA 6082-T6

S. No.	Elements	Observation (%)
1	Copper	0.051
2	Magnesium	0.800
3	Silicon	1.100
4	Iron	0.263
5	Manganese	0.552
6	Nickel	0.010
7	Zinc	0.039
8	Lead	0.012
9	Tin	0.009
10	Titanium	0.035
11	Chromium	0.050
12	Calcium	0.000
13	Aluminium	97.06

Selection of Parameters

The parameters which selected for this investigation were: tool rotation speed, transverse/ welding speed and Tool shoulder diameter. The number of parameters and their levels are shown in Table 2. Various experiments were conducted for optimize the response parameter (Ultimate tensile strength). Taguchi's robust Design of Experiments (DOE) methodology was used to plan the experiments statistically.

Taguchi's robust DOE methodology was used to plan the experiments statistically. L9 orthogonal array has come out as one of the possible solutions for designing the experiments. The levels for each factor during each trial are more conveniently expressed by means of experimenter's log sheet (refer Table 3).

Experimentation

The experimentation for the study undertaken consisted of nine trial runs as shown in Table 3. And results of ultimate tensile strength after welding is shown in Table 4.

RESULTS ANALYSIS AND DISCUSSION

After conducting the experiments with different Settings of input factors, i.e., Tool rotation speed, welding speed and tool shoulder diameter, the values of output variable (Ultimate tensile strength) were recorded and plotted as per Taguchi design of experiments methodology. The analysis of the results obtained has been performed according to the standard procedure recommended by Taguchi. The detailed description of the analysis is given as under:

Analysis of Result for Single Response Optimization

The S/N ratio was obtained using Taguchi's methodology. Here, the term 'signal' Represents the desirable value (mean) and the 'noise represents the undesirable value (standard deviation). Thus, the S/N ratio represents the amount of variation present in the performance characteristic. The values of S/N ratio corresponding to different experimental runs have been tabulated in Table 5 along with the mean values of tensile strength.

Analysis of Variance (ANOVA)

The percentage contribution of various process parameters on the selected performance characteristic can be estimated by performing

Table 2: Control Variables and Their Levels

S. No	Parameters	Levels	Level 1	Level 2	Level 3
A	Tool rotation speed	3	1200	1950	3080
B	welding speed	3	20	25	30
C	Tool shoulder diameter	3	14	16	18

Table 3: Control Log for Experimentation

Experiment No.	Tool rotation speed (A)	Welding speed (B)	Tool shoulder diameter (C)
1	1200	20	14
2	1200	30	16
3	1200	40	18
4	2500	20	16
5	2500	30	18
6	2500	40	14
7	3500	20	18
8	3500	30	14
9	3500	40	16

Table 4: Taguchi's L9 Standard Orthogonal Array for Ultimate Tensile strength

Experiment No.	Column			Ultimate tensile strength(Mpa)
	1	2	3	
1	1200	20	14	231.76
2	1200	30	16	235.90
3	1200	40	18	240.50
4	2500	20	16	228.80
5	2500	30	18	230.20
6	2500	40	14	232.68
7	3500	20	18	227.70
8	3500	30	14	226.00
9	3500	40	2	228.70

analysis of variance test (ANOVA) as shown in Table 8.

Thus, information about how significant the effect of each controlled parameter is on the quality characteristic of interest can be obtained. The results of response of ultimate tensile strength for mean and S/N ratio are shown in Tables 6 and 7.

DISCUSSION OF THE RESULTS

It can be observed from Figure 2 that the Tool rotation speed affects the Ultimate Tensile strength very significantly. Moreover, the different input parameters used in the experimentation can be ranked in the order of increasing Ultimate tensile strength as welding speed, tool shoulder diameter and tool rotation speed. From the Figure 3, the highest Ultimate Tensile strength has been recorded with welding speed (at level 3). In Friction stir welding, the welding speed is most significant factor for increasing the Tensile strength, Tool shoulder diameter is the 2nd significant factor and tool rotation speed is the 3rd significant factor. It is also clear from the figure that the Ultimate tensile strength increases as the welding speed is increased. But when the tool rotation speed is increased, the Ultimate Tensile strength decreases.

With regarding to the S/N response, the values of S/N ratio have been found to be highest for those factor levels that correspond to highest average response. Hence, these factor levels can be termed as optimum from the point of view of average response as well as S/N response. As S/N response takes into account both the magnitude as well as the variation in response, the factor levels that correspond to highest S/N ratio are termed as optimum. The analysis of results showed that "$A_1B_3C_3$" is the optimal parameter setting for the Maximization of Ultimate tensile strength. Hence, it can be concluded from this discussion that "input parameters settings of tool rotation speed at 1200RPM, welding speed at 40 mm/min and tool shoulder diameter at 18 mm have given the optimum results for UTS; in Friction stir welding on AA 6082-T6.

Table 5: Data Summary for Ultimate Tensile Strength

S.No.	Ultimate Tensile Strength (MPa)	Ultimate Tensile StrengthS/N Ratio
1	231.76	47.3008
2	235.90	47.4546
3	240.50	47.6223
4	228.80	47.1891
5	230.20	47.2421
6	232.68	47.3352
7	227.70	47.1473
8	226.00	47.0822
9	228.70	47.1853
Maximum	240.50	47.6223
Minimum	226.00	47.0822

Table 6: Response Table for Ultimate Tensile Strength (S/N Ratio)

Level	A	B	C
1	47.46	47.21	47.24
2	47.26	47.26	47.28
3	47.14	47.38	47.34
Delta	0.32	0.17	0.10
Rank	1	2	3

Table 7: Response Table for Ultimate Tensile Strength (S/N Ratio)

Level	A	B	C
1	236.1	229.4	230.1
2	230.6	230.7	231.1
3	227.5	234.0	232.8
Delta	8.6	4.5	2.7
Rank	1	2	3

Figure 2: Effects of Process Parameters on UltimateTensile Strength (Means)

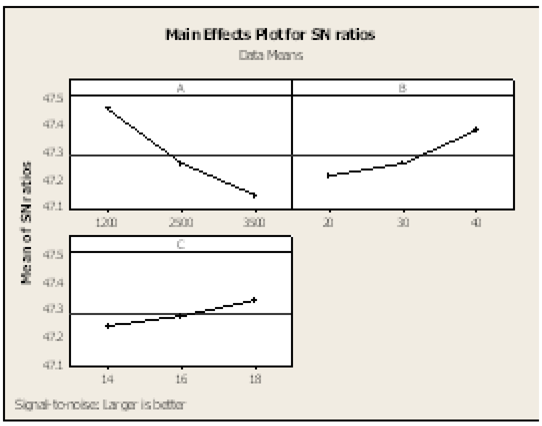


Figure 3: Effects of Process Parameters on Ultimate Tensile Strength (S/N Ratio)

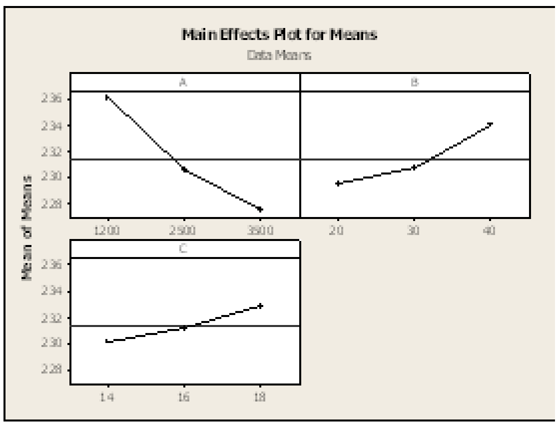


Table 8: Analysis of Variance for Ultimate Tensile Strength (Means)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	2	113.476	113.476	56.738	18.89	0.050
B	2	32.878	32.878	16.439	5.47	0.155
C	2	10.791	10.791	5.396	1.80	0.358
Residual Error	2	6.008	6.008	3.004		
Total	8	163.154				

CONCLUSION

Basically, this study evaluates the welding performance of friction stir welding by using vertical milling machine on aluminium alloy 6082 T-6. All the experiments trials, planning and analysis were executed using Taguchi design of experiment. The purposes of DOE method applied in this study were to determine the optimum condition of welding parameters and the significance of each parameter to the performance of welding characteristics. The total experiment runs performed in this study was 9 trials using randomized parameters which done by MINITAB 16 software.

The following conclusions are drawn based on the performance of welding characteristics studied in this research work namely, Ultimate Tensile Strength (UTS):

All the selected parameters, i.e., Tool rotation speed, welding/transverse speed and tool Shoulder Diameter significantly affect the Ultimate tensile strength in Friction stir welding on AA6082. With regarding to the average response, Tool rotation speed has emerged as most significant parameter and Welding speed is the second significant parameter. And tool shoulder diameter can be termed as less significant for Ultimate tensile strength. It can be concluded from the result that input parameters settings of tool rotation speed at 1200 RPM, welding speed at 40 mm/min and tool shoulder diameter at 18 mm have given the optimum results for UTS; in Friction stir welding on AA6082.

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