

Parametric Analysis and Optimization of Friction Stir Welding OFAA 6111-T4

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Abstract

Friction Stir Welding is a well known solid state joining technology. Many processing conditions and materials properties affect the micro structural evolution and mechanical behavior of the produced joints. In this study , an experimentation are performed on FSW with and without preheating to study the effect of friction stir welding process parameters like Tool travel speed, tool rotational speed and shoulder diameter on mechanical properties of Friction stir welding joint of 6111-T4 studied by using statistical analysis tool. The Quantitative analysis has gives observations like the maximum responses such as Tensile strength ,Hardness, yield strength and percentage elongation at higher rotational speed of tool, medium tool travel, larger shoulder diameter. Factorial design ,Taguchi design, ANOVA and Regression analysis indicates an influence of individual parameters on Ultimate Tensile strength and other mechanical properties of welding joint. A mathematical relations are proposed for different process parameters which gives best welding joints in friction stir welding process.

Keywords: Quantitative Analysis; Factorial Design; Taguchi Design; Anova Analysis

I. INTRODUCTION

FSW is a solid state welding process, patented in 1991 by The Welding Institute (TWI), in which rotating tool is introduce into the adjacent edges of the work piece metal are welded and moved along length of the joint. The composition of the tool rotation and advancing velocity vectors induces a characteristic metal flow all around the tool adjacent surface. The tool travel determines heat creation due to friction forces and material deformation work. The process has been introduces to be effective and is currently industrially used for materials hard to be welded, normally when an aluminum and magnesium alloys. A large number of papers have been distributed over the most recent (FSW). The strong condition combination innovation is notable; total portrayal of handling, substantial and automatic conduct can be found in the ongoing writing, such innovation is capable in fixing innovation particularly on account of Al aeronautical structures [1, 2]. All

things considered, because of security and lawful choking influences and to support strategies, the examinations and the be in charge of welding parameters get elevated obstruction, identical micro formation and weakness exhibitions become central on account of such innovation [3]. The greater part of the documents are distributed in writing on micro formation, mechanical conduct of rubbing mix connected Al-composites, some of it focused on the impact of handling variables to got best.

EXPERIMENTAL PROCEDURE

FSW is a concrete condition welding procedure include the pin profile rotating tool penetrates into the adjacent the work piece metal which needed to welded with length of joint. Composition of the tool rotation induces a characteristic metal flow all around the tool adjacent surface. The tool travel determines heat creation due to friction forces and material deformation work. The process has been

demonstrated to be effective utilized for materials difficult to be welded, especially aluminum and magnesium alloys. The working principle of solid state friction stir welding would be understand with the help of following figure no.01.

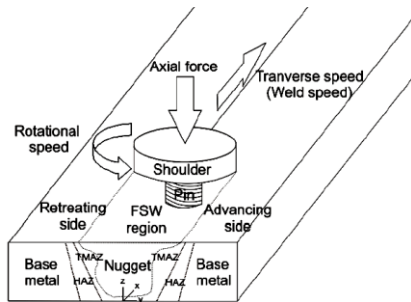


Fig 01 Schematic of the FSW process[4]

Friction stir welding process parameters tool travel speed, rotational speed and shoulder diameter of FSW Tool has selected on the basis of research papers and previous studies of FSW. The design of experiment has been done by using factorial design with 3 factor and 3 level of process parameter method to get a wide range in sample space as mentioned in table no.I.

Table I Process Parameter types and levels

| Factor Type | N(rpm) | | | F (Mm) | | | SD (mm) | | |
|-------------|--------|----|----|--------|---|---|---------|---|---|
| | Levels | 90 | 95 | 100 | 2 | 2 | 3 | 2 | 2 |
| | 0 | 0 | 0 | 5 | 8 | 0 | 5 | 8 | 0 |

With the basic parameter like rotational speed and transverse feed or tool travel was consider an effective and significant factor for making a quality joint in friction stir welding. For non-ferrous aluminium alloy metals are mainly joining by using FSW in several joint configurations. During FSW metals are joined in the solid state due to the heat generated by the friction and flow of metal by the stirring action of a pinned tool. In this investigation, the effect of friction stir welding process parameters like Tool Travel speed, Rotational speed and shoulder diameter on ultimate tensile strength, joint hardness and micro structural properties of Friction sir welding joint of AA 6111-T4.The

chemical composition of AA 6111-T4 as Al 95.6 % Cr 0.10 % Mg 1.0 % Mn 0.45 % Si 0.10 % Ti 0.10 % and Mechanical properties Tensile strength 200 MPa, Melting point 500-650°C Elongation at break 20%. As motioned in various research papers about a quality joint, the response parameter ie ultimate tensile strength was consider for this research. A set of process parameters and the response parameters are framed in typical ranges base on a literature data and hypothetical analysis. The sample random numbers was been used to run a best trial for a P value and R² values in Statistical Software Tool.

2.1 Factorial for conventional Factorial for preheating

Factorial analysis carried out for this experiment with the help of random numbers so that the trials can successful up to 95 percent contribution. Individual parameter out of the process parameter could be identified and figure amongst the remaining parameter for best experimental conditions. The orthogonal array L27 selection for an experimental run has been selected from standard reference chart as mentioned in Taguchi method for 3 factor and 3 level as Rotational Speed (N) 900 rpm,950 rpm,1000 rpm, Transverse Travel (F) 20 , 25,30 Mm/rev and Shoulder Diameter 20,25,30 mm.

2.2 Tool Design

In most studies ,Authors figured the importance of role of shoulder diameter of tool geometry and its significance in heat generation at interface ie near welding edges. A welding tool including a shoulder diameter and Tool pin with half cone and half cylinder pin diameter of 25mm to 30 mm and4.8 mm respectively. And it has made up of from H30 Steel. The detail sketch as shown figure no.02 of FSW pin profile tool half cylinder and half cone threaded.

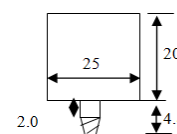


Figure no. 02 schematic diagram of FSW Tool geometry

2.3 Machine tool set up and experimental procedure

Experimentation for friction stir welding has carried out on VF-5 TR a Vertical Milling Center machine at FSW laboratory in advance manufacturing Tool Room. The tensile test samples were prepared in a perpendicular direction to the welding direction according ASTM –E8-04 Standard also the Tensile tests were performed using Universal Testing Machine -400D Machine. The material for friction stir welding joint by considering higher is the S/N ratio better will be the quality characteristic of FSW joint. An optimum conditions were identified for each level corresponding to each parameter. A best suited combination was been selected for higher S/N

ratio from the table.01. The means and S/N ratio were been closely observe and selected the levels for ANOVA analysis. A detailed ANOVA design for assessing the significance of the process parameters is also provided .The optimal combinations of the process parameters can be then predicted. The 5mm thickness of 6111-T4 Alloys plat was used as base materials.

2.3.1 Friction Stir Welding Factorial Design

Conventional friction stir welding has been conducted with conventional friction stir welding. A factorial design got selected to find the raw combinations for conduction of experiment. So the statistical tool Minitab 16 has used to find out probable combination for 3 level 3 factor process parameter.

Table I levels sample space for factorial design of FSW

| | | | | | | | | | |
|------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| N (Rpm) | 900 | 900 | 900 | 900 | 900 | 900 | 900 | 900 | 900 |
| F (mm/rev) | 15 | 15 | 15 | 18 | 18 | 18 | 20 | 20 | 20 |
| SD (mm) | 25 | 28 | 30 | 25 | 28 | 30 | 25 | 28 | 30 |

The factorial design for three level and three factors are consider in generalize model of factorial design for process parameters Rotational speed, feed and shoulder diameter as mentioned in above tableII. The predictive responses by assuming nominal mean and larger is the best tensile strength value as shown in following table

Delta 5.3 0.9
10.1
Rank 2 3

Table no. II Mean value and maximum tensile strength response values in Factorial design

| Response Table for Signal to Noise Ratios Nominal is best (10 * Log10(Ybar**2/s**2)) | | | | Response Table for Means Larger is finest | | |
|---|-------|-------|-------|--|-------|-------|
| Level | N | F | SD | rank | N | F |
| 1 | 40.49 | 42.51 | 43.11 | 1 | 170.2 | 168.3 |
| 2 | 45.93 | 43.32 | 43.34 | | | |
| 3 | 42.15 | 42.74 | 42.11 | 2 | 164.9 | 168.8 |
| Delta | 5.45 | 0.80 | 1.22 | | 169.1 | |
| Rank | 1 | 3 | 2 | 3 | 169.9 | 167.9 |
| | | | | | 162.9 | |

The factorial design for three level and four factors including preheating temperature at interface of welding plate edges of aluminium plates. Factors are consider in with generalize model of factorial design for process parameters Rotational speed (N), feed (F) and shoulder diameter (SD) as mentioned in above table. The predictive responses by assuming nominal mean and larger is the best tensile strength value as shown in following table for preheating friction stir welding.

Table no III. Mean value and maximum tensile strength response values in Factorial design

| Response Table for Signal to Noise Ratios (10*Log10(Ybar**2/s**2)) | | | | Response Table for Means | | |
|---|---------|-------|-------|--------------------------|-------|-------|
| Nominal Level | is best | | | Level | N | F |
| 1 | 45.65 | 47.01 | 45.77 | 1 | 179.0 | 186.6 |
| 2 | 45.86 | 48.46 | 45.32 | 2 | 188.3 | 183.7 |
| 3 | 48.62 | 44.08 | 48.44 | 3 | 187.1 | 184.2 |
| Delta | 3.57 | 4.38 | 3.12 | | | |
| Rank | 2 | 1 | 3 | | | |
| | | | | Delta | 9.3 | 2.9 |
| | | | | Rank | 1 | 3 |
| | | | | | 2 | |

The predicted values of friction stir welding for preheating in factorial analysis for tensile strength by considering higher Signal to Noise ratio value 45.6589 and 191.704Mpa and N,F,SD as 950,25,25, respectively.

III. RESULT

The superiority of roughness stir welding mainly depends on the response values after experimentation. The design for an experimentation as mentioned in table no. The process parameters like speed, tool travel, feed and shoulder diameter for conduction of friction welding process on the material 6111-T4 Alloys. Following table I. shows the L27 trial tensile strength of an aluminum alloy. On the basis of mean signal to noise ratio the effective parameters can be selected for best possible results. Following table is the summary of the taguchi design performed for actual experimentation. The 27 trial results are sort on the best response value, Hence following table indicates the best solution of friction stir welding using taguchi design.

Table no. I Tensile strength with preheating

| N (rpm) | F(Mm /Min) | SD(mm) | T (°C) | T.S. |
|---------|------------|--------|--------|------|
| 900 | 25 | 25 | 160 | 184 |
| 900 | 30 | 28 | 170 | 175 |
| 900 | 28 | 30 | 180 | 178 |

| | | | | |
|------|----|----|-----|-----|
| 950 | 25 | 25 | 180 | 190 |
| 950 | 25 | 28 | 170 | 186 |
| 950 | 25 | 25 | 160 | 188 |
| 1000 | 15 | 30 | 180 | 186 |
| 1000 | 25 | 25 | 170 | 189 |
| 1000 | 20 | 28 | 160 | 188 |

Graphical representation of main effect of plot for S/N ratios by taking larger is the best value of tensile strength and nominal is the better for mean using taguchi analysis. the effect speed and shoulder diameter on S/N as shown in figure no.01.

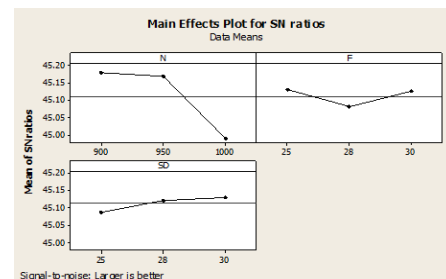


Figure no 01 .Main effect for S/N for tensile strength Vs N,F,SD

3.1 ANOVA analysis for Tensile strength with preheating

An ANOVA analysis has been carried out for the available taguchi design with the help of statistical tool one way ANOVA method. The rotational speed of tool has significant role in tensile strength value in an experimentation. Tukeys method allows single parameter at a time for effective cause for tensile strength value of a welding joint.

Table no II ANOVA for One-way ANOVA for Tensile strength

| One-way ANOVA: | | | | Grouping Information | | |
|----------------|----|-----------|-------------|----------------------|---|-----------|
| TS versus N | | | | Using Tukey Method | | |
| Source | DF | SS | | N | N | Mean |
| MS | F | P | | Grouping | | |
| N | 2 | 463.19 | | 950 | 9 | 188.333 A |
| | | 231.59 | 38.90 | 1000 | 9 | 187.111 A |
| Error | 24 | 142.89 | | 900 | 9 | 179.000 B |
| | | 5.95 | | | | |
| Total | 26 | 606.07 | | | | |
| | | S = 2.440 | R-Sq = | | | |
| | | 76.42% | R-Sq(adj) = | | | |
| | | 74.46% | | | | |

A normality test has found to be good and the box plot graph shows best results at 2nd level of speed at 950 rpm.

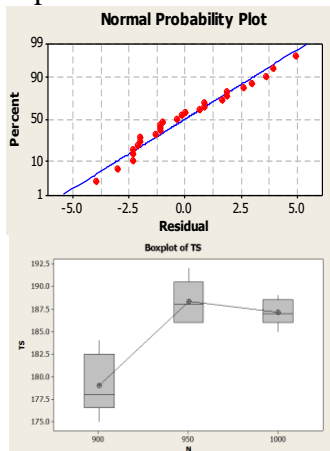


Fig no 02. Normality test and Box plot for Tensile test with preheating

3.3 Regression Analysis for Tensile strength with preheating

Regression analysis has used to identify the process parameters and response mathematical relationship the generalize model has been selected for prediction of tensile strength response value. The model for regression has estimated to predict the value of response value constant value as mention below table III.

Table no III Coefficients of Tensile strength

| Term | Coef | SE | T | P |
|----------|---------|---------|---------|-------|
| Constant | 188.346 | 17.4498 | 10.798 | 0.000 |
| N | 0.081 | 0.0151 | 5.35966 | 0.000 |

Table no 04. Comparison of Hardness ,Yield strength ,Percentage elongation

| Mechanical Properties | Taguchi method | ANOVA Method | Regression Model | Predicted levels | Predicted results | Experimental levels | Experimental Results |
|-----------------------|--|--|--|---------------------------|-------------------|---------------------|----------------------|
| Hardness | S/N Ratio Mean StDev Ln(StDev) 38.5183 84.3333 0.708092 -0.319132 | SD N Mean G 30 9 83.778 B 25 9 82.667 A 28 9 82.111 A | HRC = 76.7037 - 3.45165e-019 N + 0.0321637 F + 0.190058 SD (2) | N F SD 900 28 28 | 85.37 | N F SD 900 28 28 | 83.36 |

F -0.506
0.3007 -
1.68238
0.106
SD -
0.620
0.3007 -
2.06164
0.051

The General regression equation with 95 % confidence level for single factor at a time ie tensile strength for process parameters N,F, SD.

Regression

$$\text{Equation TS} = 188.346 + 0.0811111 \text{ N} - 0.505848 \text{ F} - 0.619883 \text{ SD} \quad (1)$$

As mentioned in table no.I ,the maximum value of tensile strength of a weld joint estimated regression value is 191.45 Mpa . the process parameters with the same levels has been applied on the experimental setup and results are found to be 187.45 mpa.

3.4 Comparison of Hardness ,Yield strength ,Percentage elongation with optimization models

The friction stir welding for half cone with threaded has been studied for various mechanical properties to form a good quality weld joint of aluminium alloy. The detail procedure of design of experiment , taguchi analysis , Anova analysis and regression equation for Tensile strength at various levels of process parameter has discussed. The analysis of remaining mechanical properties has summaries in table 04.

| | | | | | | | |
|---------------------|---|--|--|---------------------------|--------|---------------------|--------|
| Yield strength | S/N Ratio Mean StDev Ln(StDev) 43.0265 141.704 1.12118 - 0.138871 | SD N M G 30 9 135.556 A 25 9 134.889 B 28 9 132.889 A | YS = 142.184 - 0.0155556 N + 0.184211 F + 0.0701754 SD (3) | N F SD 950 28 25 | 139.52 | N F SD 950 28 25 | 137.89 |
| Percent. Elongation | S/N Ratio Mean StDev Ln(StDev) 22.3771 13.1852 1.34254 0.387977 | SD N M G 25 9 10.889 A 30 9 10.556 A 28 9 10.000 B | PEL = 23.0478 - 0.00777778 N - 0.102339 F - 0.0847953 SD (4) | N F SD 950 30 25 | 17.16 | N F SD 950 30 25 | 19.18 |

V. CONCLUSION

The parametric study of a friction stir welding tool profile with variable shoulder diameter and pin threaded has passed to learn the pressure of the pin geometry on the weld quality by using quantitative. Also, the influence of various process parameters are investigated in friction stir welding with and without preheating for Aluminium alloy 6111-T4 and The following conclusions can be summarize.

- The results shows an individual factor like speed and shoulder diameter has a majorly affecting the mechanical properties i.e. ultimate tensile strength and weld interface hardness in friction stir welding with and without preheating.
- An optimized process parameter after ANOVA and regression Analysis are 950 rpm, 25 mm/min, 24 mm for ultimate tensile strength and 950 rpm, 28 mm/min, 28 mm for hardness, 950 rpm, 28 mm/min, 25 mm yield strength and 950 rpm, 30 mm/min, 25 mm with the half cylindrical and half taper screw threaded tool.
- The quantitative results estimated and actual Tensile power, Hardness, capitulate power in addition to proportion elongation values are reaches to the 97.41% and 97% and 98.89 % and 89.87 respectively that of the base metal. The qualitative observation point towards the superior physical condition of weld joint of by

using selected optimized process parameters.

- The effect of tool geometry i.e. shoulder diameter has significantly contributed in weld surface texture and very less defect was observed.

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