Optimizing the Process Parameters of FSW for AA7075 to Enhance the Weldability

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Abstract: Friction stir welding is a solid state joining process for materials which is used welding of different alloys of aluminum, magnesium, copper, and also for hard materials like mild steels because it avoids the problems occurred in fusion welding processes. The fact that joining of alloys could be generally faced troubles in many sectors that includes aerospace, marine industries, automotive, railway industries, construction industries etc. where conventional welding is not possible due to large difference in physical and chemical properties of the components to be welded. Problems in conventional welding processes are solidification, shrinkage, cracking, porosity formation, distortion and chemical reaction may arise during joining of similar and dissimilar materials.

Taguchi technique has been used to determine the most important control variables that will result in greater mechanical characteristics of tensile strength of FSW joints of comparable AA 7075 material. To optimize process parameters including Rotational speed, Welding speed and Tool tilt angle, weld travel velocity on tensile strength and hardness of friction stir welded similar AA 7075 aluminum alloy, Taguchi Design of Experiment (DOE) and optimization method was used. The optimum levels of process parameters were identified by using the Taguchi parametric design concept. The results show that welding speed is more contributing process parameter than the rotation speed and tool tilt angle in getting optimum mechanical property of Ultimate Tensile Strength UTS.

Keywords: Taguchi Method, Signal to Noise (S/N) Ratio, Optimization, Process Parameters, UTS.

I. INTRODUCTION

Welding is a process of permanent joining of two similar or dissimilar metals through localized coalescence resulting from a suitable combination of temperature, pressure and metallurgical conditions. Depending upon the combination of pressure and temperature from a high temperature with no pressure to a high pressure with low temperature, a wide range of welding processes has been developed. In order to obtain the coalescence between two metals, there must be a combination of proximity and activity between the molecules of the pieces being joined, sufficiently to cause the formation of common metallic crystals. Proximity and activity can be increased by plastic deformation in solid-state welding or by melting the two surfaces so that fusion occurs in fusion welding. In solid- state welding, the surfaces to be joined are mechanically or chemically cleaned prior to welding whereas in fusion welding the contaminants are removed from the molten pool using fluxes.

Friction stir welding (FSW) is a rapidly maturing solid state joining process that appears as a promisingly ecologic weld method that enables to diminish material waste and to avoid radiation and harmful gas emissions usually associated with the fusion welding techniques. The main process parameters affecting material flow and weld quality contain the tool rotation speed, tool traverse speed, the vertical pressure on the tool, the tilt angle of the tool and the tool geometry. During processing, a no consumable tool attached with a specially designed pin was inserted to the butting edges of the plates to be joined. The tool shoulder had to touch the plate surface. Under this condition the tool was rotated and traversed along the bond line. Thus, frictional heat was generated. The tool rotation and traverse expedite material flow from the front to the back of the pin and welded joint were produced. The process was suitable for joining the plates and sheets; however, it can be employed for pipes and the hollow sections. FSW has several advantages such as energy savings, superior mechanical joint properties, no consumable requirements and lower process environmental impact as compared with fusion welding processes

II. EXPERIMENTATION

A. Methodology of Experiment

There are several optimization techniques to develop product, process or operation. Various techniques can be applied to optimize curing process. Sometimes different techniques are required integrate to get statistically significant results, which can lead to better conclusions and recommendations. Some extensively used methods in developing a process or a product are Build Test Fix (BTF), Design of Experiment (DOE) and One Variable at a Time (OVAT); BTF is very primitive and unorganized approach. It is iterative method of developing a process focused on improvement from last experiment. DOE is highly efficient method of investigating the effect of parameters as it varies multiple parameters at once. As more parameters are investigated, more number of new combinations is required. DOE cannot control individual parameters and more relies on statistical data. In one variable at a time (OVAT) approach, variation is done with one variable at a time and other parameters are kept constant until the effect of one parameter is studied.

It is highly precise method to study effect of each parameter at different levels. Air flow rate, cycle time and cycle time were identified as most predominant parameters affecting the Industrial oven. Based on the observation, Taguchi method has been used to optimize the process parameters. OVAT analysis has been conducted to find out effective range of parameters for optimization study. L9 orthogonal array (OA) has been selected from available designs. Standard notation for OA is given below

OA = Ln (Xm)

Where n= number of experiments, X= number of levels and m= number of parameters under study. From available designs for 3 levels 3 parameters, OA with least number of experiment required to conduct (L9) has been selected. ANOVA has been conducted to find out contribution of each parameter in the output. Minitab 19 software has been used for analysis.

B. Experimental Machine Selection

Table 1 states the specification of the Industrial oven used in this study. All the experiments were conducted at Pyramid Industries, L-29, MIDC Waluj, Aurangabad, M.S, India.

Figure 1. VMC Machine

Make and Model	**MCV-400**
Work Table Size	900x 450 mm
Working Table	450 x 500 mm
Max. Work piece Weight	400 kg
Machine Net Wt.	5100Kgf
Machine Dimensions	1900x3100x2150

Table 1. VMC Machine Specification.

C. Selection of material

Al 7075

- Superior Strength & Toughness
- Corrosion Resistant
- Can withstand Extreme Temperature
- Capable of being fabricated into a variety of parts

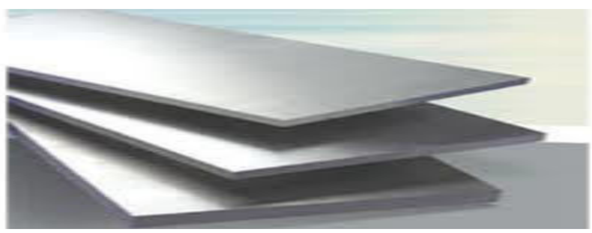

Fig. 2 Al 7075

Composition	**Zn**	**Mg**	**Cu**	**Fe**	**Zr**	**Si**	**Mn**	**Ti**	**Ni**
Percentage	5.6-.6.1	2.1-2.5	1.2-1.6	0.15	0.10-0.16	0.12	0.10	0.036	0.050

Table 2 Chemical Composition of Sisal material

Tool Material

Tool specification detail given in table 3 and shown in drawing as given below

Partic ular's	Total Tool Length	Headof tool	Shoulder Length	Pin Height	Pin Dia	Dia of Tool Head	Shoulder Diameter	Tool Material	Hardness of tool material
Value	72mm	60mm	12mm	5mm	6m m	16mm	18mm	H13	60-62 HRC

Table 3. Tool Specification

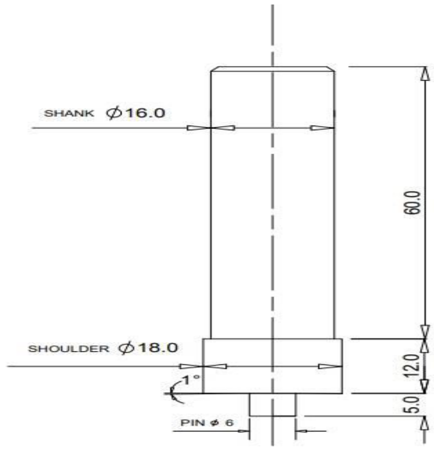

Fig. 3 Tool Drawing

III. RESULTS AND DISCUSSION

To get complete understanding of effects of input parameters rotational speed, welding speed and tool tilt angle on output UTS, you usually assess signal to noise ratio or main effects plot for means. For this purpose, Minitab 18 statistical software has been used. UTS has been done. ANOVA has been conducted to find out effect of each parameter on the UTS and linear regression model has been established to predict the values of UTS.

A. Experimental Result

Table 4 shows the L9 orthogonal array with measurement of UTS for runs one to nine. It also shows S/N ratio for all nine experiments.

Experiments	**Inputs Factors**			**Output Responses**	
Trial No.	**Rotational Speed**	**Welding Speed**	**Tool Tilt Angle**	**UTS**	**S/N Ratio**
1	1400	20	1	175.45	44.8831
2	1400	30	2	169.25	44.5706
3	1400	40	3	152.78	43.6813
4	1600	20	2	168.23	44.5181
5	1600	30	3	160.78	44.1246
6	1600	40	1	162.89	44.2379
7	1800	20	3	173.02	44.7619
8	1800	30	1	158.47	43.9989
9	1400	20	1	175.45	44.8831

Table 4 L9 orthogonal array with response characteristic.

The S/N ratio values are calculated with help of Minitab 18 software. It can be seen that variation in S/N ratio is minimum for all experiment.

B. Main Effects of Moisture Content

Figure 4 shows the main effects plot from S/N ratios.

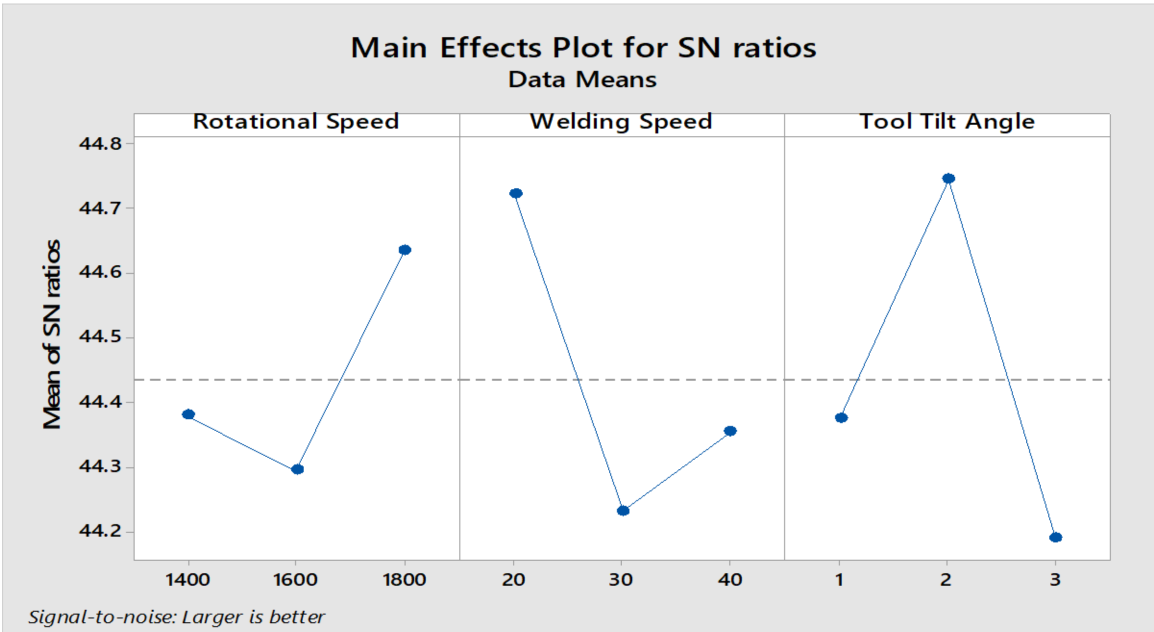

Figure 4 Main Effects Plot for S/N Ratio

From main effects plot for S/N ratio, parametric effect on response characteristic i.e. moisture content can be understood. Temperature 75oC at level 1, Air flow rate 0.047 at level 3, Cycle time 390 min at level 1 gives the highest signal to noise ratio values. The levels at which highest S/N ratio obtained from S/N ratio plot taken as optimum levels setting for machine parameters.

C. ANOVA Result

ANOVA, the ratio between the variance of the welding parameter and the error variance is called Fisher's ratio (F). It is used to determine whether the parameter has a significant effect on the quality characteristic by comparing the F test value of the parameter with the standard F table value at the P significance level. If the F test value is greater than P test the cutting parameter is considered significant. Relevance of the models is tested by analysis of variance (ANOVA). It is a statistical tool for testing the null hypothesis for planned experiments, in which several different variables are studied simultaneously. ANOVA is used to quickly analyze the variances in the experiment using the Fisher test (F test). ANOVA table shown the result of the ANOVA analysis. ANOVA analysis makes it possible to observe that the value of P is less than 0.05 in the three parametric sources. It is therefore clear that rotational speed, welding speed and tool tilt angle of the material have an influence on the AA 7075 material. The last column of cumulative ANOVA shown the percentage of each factor in the total variance that indicates the degree of impact on the outcome. Table 5 shows results obtained from analysis of variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Rotational Speed	2	0.197789	0.098894	21.39	0.044	20.74
Welding Speed	2	0.567039	0.283515	61.29	0.017	59.50
Tilt Angle	2	0.178719	0.089359	19.33	0.048	18.77
Error	2	0.009252	0.004625			
Rotational Speed	2	0.197789	0.098894	21.39	0.044	20.74

Table 5 ANOVA Result.

It shows that the The table shows that the rotational speed (20.74%), the welding speed (59.50 %%) and the Tool Tilt Angle (18.77%) have a major influence on the UTS.

D. Development of Regression Model for UTS

Regression model has been developed using Minitab software. Substituting the experimental values of the parameters in regression equation, values for moisture content have been predicted for all levels of study parameters. Graphical representation also shows that a predicted and experimental value of moisture content correlates with each other.

Regression Equation –

S = 160.7+ 0.0123 [Rotational Speed]- 0.338 [Welding Speed] - 1.70 [Tool Tilt Angle]

Table number 4 gives comparison between experimentally measured and predicted moisture content by developed mathematical equation

Sr. No.	Experimental value	Predicted value	Error %
1	175.45	169.46	3.53
2	169.25	164.38	2.96
3	152.78	159.3	3.49
4	168.23	170.22	1.16

5	160.78	165.14	2.64
6	162.89	165.16	3.67
7	173.02	171.06	4.58
8	158.47	171.01	7.33
9	180.74	165.92	8.93

Table 6 Experimental and Predicted Values of UTS

Difference between UTS values calculated using regression equation and experimental values for each experience found less than 10%. Hence, we can say that the regression equation developed is valid. Figure 5 shows the graphical representation of experimental and values calculated using regression equation.

E. Confirmation Experiment Result

Table 5 shows the difference between value of moisture content of confirmation experiment and value predicted from regression model developed.

Parameter	Predicted value	Experimental value	Error %
UTS	172.68	181.63	5.18

Table 7 Confirmation Experiment Result

Confirmation experiment is conducted by keeping parameters at optimum levels suggested by Taguchi method and the UTS value obtained has been compared with value predicted by the regression model keeping the parameters at same levels. It can be seen that the difference between experimental result and the predicted result is 5.18%. This indicates that the experimental value correlates to the estimated value.

IV. CONCLUSIONS

This study covers the observations about the UTS over Al 7075 material by the process of Friction Stir Welding machine for the different input parameters to thoroughly study over the effect of FSW process on the Al 7075 material. Throughout the experimentation I got some results as under.

- The optimal solution obtained for UTS based on the combination of FSW parameters and their levels is (i.e. Rotational Speed 1800 rpm at level 3 Welding Speed 20 mm/min at level 1 and Tool tilt angle 2 degree at level 2). The Welding Speed more significant Parameters than rotational speed and axial load
- ANOVA results indicate that Welding Speed plays prominent role in determining the ultimate tensile strength. The contribution of Rotational Speed, Welding Speed, Tool tilt angle to the quality characteristics UTS is 20.74 %, 59.50% and 17.77% respectively.

- The optimal parameters are determined using Taguchi methods match with the experimental values by minimum errors i.e 4.52% .

- Through the developed mathematical models, any experimental results of ultimate tensile strength with any combination of FSW parameters can be estimated.

V. ACKNOWLEDGMENT

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