Optimization of Process Parameters for Hardness of Aluminium Alloy 7068 During Friction Stir Welding by Taguchi Method

R.K.Suresh
Asst. Professor (Sr.) - Department of Mechanical Engineering ,
Srikalahasteeswara Institute of Technology, Srikalahasti(A.P)
rayakuntapalli@gmail.com

Abstract – **The effect of rotational speed, welding transversing speed and pressure applied against the joint on the hardness of AA7068 joints made by Friction Stir Welding are investigated. FSW is a solid state welding technique which treats metal to the temperature below re-crystallization. FSW avoids welding defects like porosity and hot cracking which are common in conventional welding technique due to alloy's low re-crystallization temperature and higher heat dissipating nature. For experimentation Taguchi Design of Experiments has been utilized. The results have been analyzed by using Analysis of Variance (ANOVA) statistical technique. Using ANOVA percentage contribution of each process variable on response has been calculated and the optimum operating conditions have been obtained.**

Keywords: Friction Stir Welding, Taguchi Method, Aluminium Alloy 7068, Brinell hardness number

I. INTRODUCTION

Compared to the many fusion welding processes that are routinely used for joining structural aluminium alloys, Friction Stir Welding (FSW) process is an emerging solid state joining process in which the material that is being welded does not melt and recast. The welding parameters and tool pin profile play a major role in deciding the weld quality.

Aluminium alloys are important for the fabrication of components and structures which require high strength, low weight or electric current carrying capabilities to meet their service requirements. Among all Aluminium Alloys, AA7068 alloy plays a major role in the automobile and aerospace industries in which Zinc is the principal alloying element. It is widely used in the automobile and aerospace applications because it is the strongest commercially available aluminium alloy, has good formability, weld ability, machinability and corrosion resistance compared to other aluminium alloys. In this investigation an attempt has been made to understand the influence of FSW parameters on resultant final mechanical properties such as hardness.

The basic concept behind FSW is simple: A non-consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of the two parts to be joined and traversed along the line of joint (**Figure 1**). The FSW tool primarily serves two functions: a. heating the work piece, and b. stirring the material to produce the joint. A detailed list of parameters controlling this joining process is given in as follows:

- Rotational speed (rpm)
- Welding speed (mm/s)
- Axial force (kN)

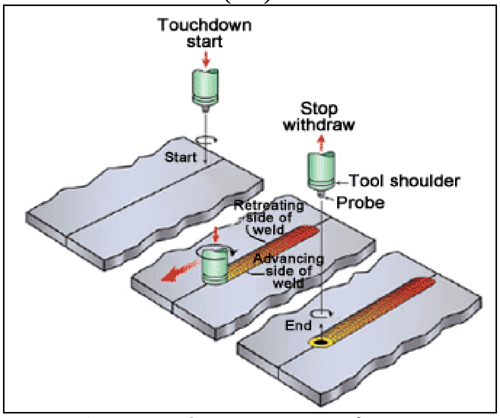


Figure 1 Schematic Diagram of FSW Process

This investigation analyses the effect of the tool rotational speed, Welding speed and Axial force for optimum hardness (BHN) of friction stir welded joints of AA7068 joints, by using full factorial experimental design (3^3) with Taguchi's robust design concept.

II. EXPERIMENTAL WORK

From primary and secondary process parameters (**Figure 2**), three primary process parameters [tool rotational speed (N), welding speed (S) and axial force kj (F)], which control the heat input and subsequently of aluminium alloy, were selected for this study.

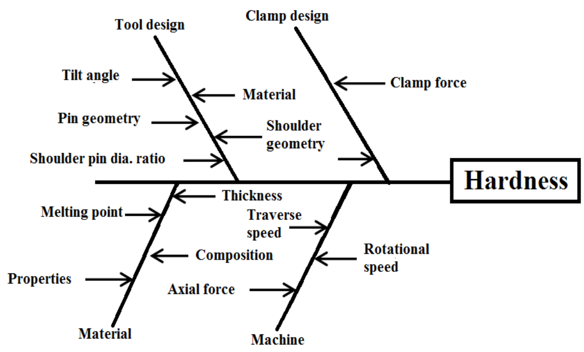


Figure 2 Cause and Effect Diagram of Factors influencing friction stir welded (FSW) joint hardness

A. Determination of the Limits of the Selected Parameters

TABLE I
PROCEESS PARAMETERS

Process Parameters	Range	Level 1	Level 2	Level 3
Rotational Speed (in rpm)	1000 – 2000	1200	1400	1600
Welding Speed (mm/min)	25 – 75	30	45	60
Pressure Applied (in kN)	0.5 – 2.5	1.0	1.5	2.0

The above range have been selected from the range after thorough study of the available literature on FSW and aluminium, and the three levels were selected based on the composition of the work material and tool material, i.e. Aluminium Alloy 7068 and Tungsten Carbide. The chemical composition of AA7068 is given the following tables:

TABLE II
CHEMICAL COMPOSITION OF AA7068

Weight %	Si	Fe	Cn	Mn	Mg	Cr	Zn	Fi	Zr	AI
Minimum			1.60		2.20		7.30		0.05	Remainder
Maximum	0.12	0.15	2.40	0.10	3.00	0.05	8.30	0.01	0.15	

B. Conducting Experiments

The aluminium alloy 7068 was made into cast rectangular plates (60 mm × 30 mm × 6 mm). Square butt joint configuration was prepared to fabricate FSW joints (**Figure 3**). A non- consumable, rotating tool made of tungsten carbide was used for fabricating the FSW joints. The TAL Vertimach V-350 vertical CNC machine is used to fabricate the required joints. The hardness test was calculated using the 500 kN Brinell hardness testing machine and the results are presented (TABLE III).

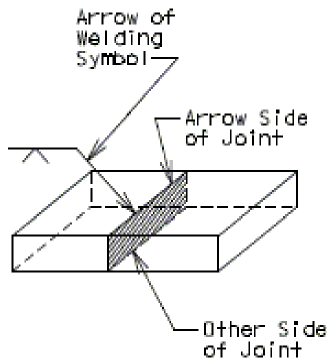


Figure 3 The Initial Joint Configuration

TABLE III
EXPERIMENTAL VALUES OF HARDNESS (BHN) AND S/N RATIO

S.No	Tool Rotational Spped (N) In r.p.m	Welding Speed (S) in mm/min	Axial Force (F) in KN	Brinell Hardness (BHN)	SNR $-10\log\left(\frac{1}{n}\sum\frac{1}{y_i^2}\right)$
1	1200	30	1	175	44.8607
2	1200	30	1.5	179	45.0571
3	1200	30	2	176	44.9102
4	1200	45	1	179	45.0571
5	1200	45	1.5	179	45.0571
6	1200	45	2	177	44.9594
7	1200	60	1	183	45.2490
8	1200	60	1.5	181	45.1536
9	1200	60	2	176	44.9102
10	1400	30	1	182	45.2014
11	1400	30	1.5	175	44.8607
12	1400	30	2	177	44.9594
13	1400	45	1	176	44.9102
14	1400	45	1.5	175	44.8607
15	1400	45	2	176	44.9102
16	1400	60	1	172	44.7105
17	1400	60	1.5	176	44.9102
18	1400	60	2	180	45.1054
19	1600	30	1	178	45.0084
20	1600	30	1.5	176	44.9102
21	1600	30	2	179	45.0571
22	1600	45	1	179	45.0571
23	1600	45	1.5	177	44.9594
24	1600	45	2	179	45.0571
25	1600	60	1	183	45.2490
26	1600	60	1.5	182	45.2014
27	1600	60	2	186	45.3902

III. RESULTS AND DISCUSSION

A. *Analysis of Variance (ANOVA)*

Means and signal-to-noise ratio (S/N) for each control factor are to be calculated, in order to assess the influence of the selected parameters on the response. Signals are indicators of effect on average responses and noises are measures of deviations from experimental output. The appropriate S/N ratio must be chosen using understanding of the process, previous knowledge and expertise. In this study, S/N ratio was chosen to meet the criterion, larger-the-better, in order to maximize response. In Taguchi method, S/N ratio is used to determine deviation of quality characteristics from desired value and can be expressed as

$$\mathrm{SNR} = -10\log\left(\frac{1}{n}\sum\frac{1}{y_i^2}\right)$$

where n is number of tests and y_i is the experimental value in i^{th} test. In the present study BHN data was analyzed to determine the effect of FSW process

Analysis of Variance (ANOVA) has been performed to identify statistically significant process parameters, which affect BHN of FSW joints (TABLE IV). The results of ANOVA indicate that the selected process parameters are highly significant factors affecting BHN of FSW joints.

TABLE IV
RESULTS OF ANOVA

Source	**Degrees of freedom**	**Sum of squares (SS)**	**Mean squares (MSS)**	**F-Ratio**	**% of contribution (Cr)**							
N	**2**	**49.2952**	**24.6476**	**1.98**	**32.086**							
S	**2**	**35.8507**	**17.9253**	**1.440**	**23.3355**							
F	**2**	**3.1652**	**1.5826**	**0.1272**	**2.06**							
N x S	**4**	**43.6252**	**10.9063**	**0.8764**	**28.3960**							
S x F	**4**	**18.0696**	**4.5174**	**0.3630**	**11.76168**							
N x F	**4**	**3.6252**	**0.9063**	**0.07283**	**2.3596**							
Residual	**8**	**99.5541**	**12.4443**	**----**	**------**							
total	**28**	**253.1852**	**72.9298**	**4.85943**	**100**							

B. *Optimizing Hardness*

Mean response refers to average value of performance characteristics for each parameter at different levels. Mean for one level was calculated as average of all responses that were obtained with that level. Mean response of raw data and S/N ratio of BHN for each parameter at level 1, 2 and 3 were calculated (TABLE IV). Analyzing means and S/N ratio of various process parameters (TABLE V) ,it is observed that a larger S/N ratio corresponds to better quality characteristics. Therefore, optimal level of process parameter is the level of highest S/N ratio. Mean effect (**Figure 4**) and S/N ratio (**Figure 5**) for BHN calculated using Minitab statistical software indicated that BHN was at maximum when: N (level 3), 1600 rpm; S (level 3), 60 mm/min; and F (level 1), 1 kN.

TABLE V
MAIN EFFECTS OF HARDNESS (MEANS AND S/N RATIO)

Levels	**N**	**S**	**F**
1	45.0238	44.9805	45.0337
2	44.9365	44.9809	44.9967
3	45.0988	45.0977	45.0288

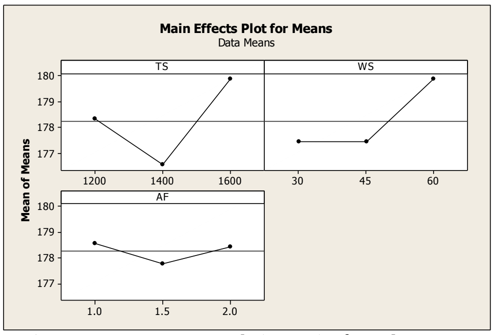


Figure 4 Response graph (means) of Hardness

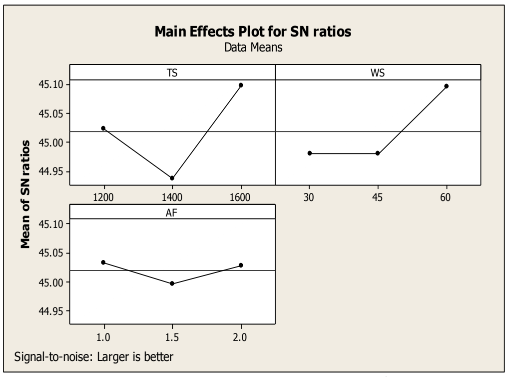
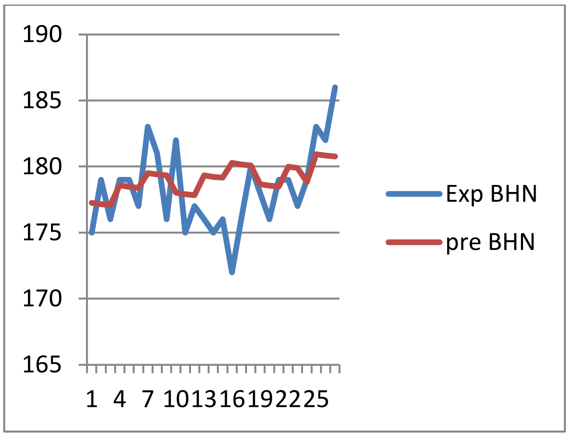


Figure 5 Response graph (S/N ratio) of Hardness



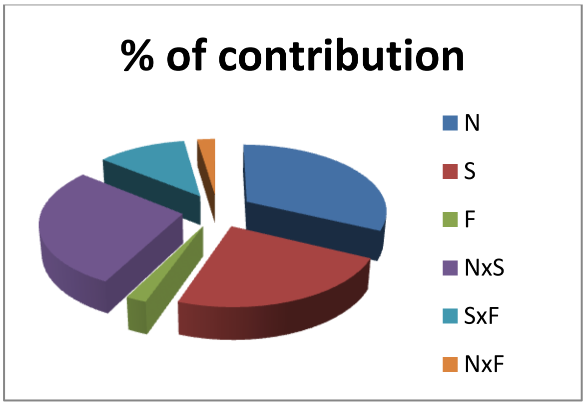


Figure 5 Percentage contributions of process parameters

IV. REGRESSION MODEL

In order to correlate the process parameters and BHN of welded joints, a nonlinear regression model was developed to predict BHN of FSW AA7068 alloy based on experimentally measured BHN. Regression coefficients were calculated using Minitab 16 statistical software. The final model developed using only these coefficients to estimate BHN as

$$BHN = e^{4.92} \times N^{0.0276} \times S^{0.0182} \times F^{-0.0014}$$

V. CONCLUSIONS

In the present work, FSW has been conducted over 27 odd pieces. The pieces were analyzed for mechanical properties like hardness by using Brinell hardness tester. The experimental results have been analyzed by using ANOVA statistical technique to get optimum process parameters. The weld joints made at rotational speed, 1600 rpm, traversing speed, 60 mm/min and axial force, 1 kN yielded maximum hardness when compared to other joints. Percentage of contribution of N, S and F are 32.08%, 23.34% and 2.06% for hardness. The regression equation was used to predict the hardness of the friction stir welds.

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