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Experimental investigation of joining of aluminum alloy 5083 by friction stir welding (FSW)

R.S. Mishra, Preety Rani

Department of Mechanical, Production, Industrial and Automobiles Engineering, Delhi technological University, Delhi, India

Abstract

This study represents the Friction stir welding of aluminum alloy 5083 with vertical milling machine as a machine tool and specially designed heat treated high carbon steel as a tool. In the present investigation, three different process parameters i.e. tool rotation speed, transverse speed and pin diameter are selected with their three different levels. The DOE by L9 array is consisted of nine trial runs. The analysis of the results obtained has been performed according to the standard procedure recommended by Taguchi. Analysis of Variance (ANOVA) is employed to analyze the influence of these parameters on % elongation during welding process

Keywords: Friction stir welding (FSW), Tool rotation speed (TRS), Welding speed (WS) .Green Technology

1. Introduction

In friction stir welding a rotating tool is slowly plunged between the parting line of the two plates that need to be weld. The friction between rotation tool and the work piece produces frictional heat which softens the work piece material without reaching its melting point. The material aluminum alloy 5083 is chosen for the optimization of friction stir welding process parameter, which finds widespread application in aerospace industry, shipbuilding industry, pressure vessel and cryogenic tank in space craft.

1.1 Literature Review

Uzun et al. [1] has joined, aluminum alloy 6013-T4 with stainless steel X5CrNi18-10 by using FSW techanique. The aluminum alloy 6013-T4 plates of 4 mm thickness were welded with the plates of X5CrNi18-10 stainless steel of 4mm using FSW using milling machine. Zhang et al. [2] optimized the parameters of welding magnesium AZ31 by using friction-stir-welded to get defect-free weld. The hot rolled AZ31 (5*100* 200) mm was used as parent metal. The plates were welded by friction-stir-welding at different WS from 40 to 600mm/min and TRS 1000 RPM was same. Zhang and Zhang [3] joined two plates of Al 6061-T6 by using FSW. The tool consisting of the pin and the shoulder of radii were 5 and 22.7mm, resp. The two plates were of (100* 40 * 8) mm. Zhang et al. [4] joined the plate of AA 6061-T6 using FSW having tool of pin radius of 3mm and the shoulder radius of 7.5 mm. The welding plates were of 100*30*3 mm in length, width and thickness respectively. Kulekci et al. [5] made lap joints by FSW of AA 5754 plates by using a semi-automatic conventional milling machine. The AA 5754 plates were of thickness 3 mm, length 200 mm and width 100 mm. Fratini et al. [6] studied the flow of materials using finite element analysis (FEA), which occurs in friction welding and forms a T-joint. A thin piece of brass is used as a marker and placed on the boundary of the two necessary plates for welding. Sakthivel et al. [7] joined two plates of aluminum of dimensions (300*150*6) mm by using friction stir welding at a constant TRS of 1,000 rpm with different WS. The tool having a cylindrical threaded (1mm pitch 6mm) pin of length 5.75-mm with 15 mm shoulder dia. Zimmer and others. [8] Optimized the friction welding process parameters for force and torque generated by AA 6082-T651 with a thickness of 6 mm. Aval et al. [9] found a relationship between heat input and the microstructures of thermo mechanically affected zone of the joint of AA 5086 by friction stir welding. Jonckheere et al. [10] investigated the effect of tool and friction welding tool dimensions on fracture and shear properties at the friction stir point. Husain Mehdi et. al., [11-15], analyzed that the mechanical properties of FSW joint are mainly dependent on chemical composition and processing parameters of alloying element. The

Corresponding author: R.S. Mishra
Email Address: hod.mechanical.rsm@dtu.ac.in
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microstructural analysis of FSW joints shows the formation of new grain size in the weld zone with different amount of heat input by controlling the processing parameter. Rajakumar et al. [16] predicted the value of hardness and grain size of nugget region of friction stir welded AA-6061 weld joints. AA 6061 has huge applications in the production of light weight structures with good corrosion resistance and high strength/weight ratio. Liu et al. [17] carried out welding of aluminum 2219-T6 alloy using FSW and investigated effects of transverse speed on mechanical and micro structural properties. Ravindra [18] studied the effect of the tool rotation speed (rpm) and the tool probe profile on Friction Stir Processing in AA5083 of 2.5 mm thick. The experimentation was carried out using five different cylindrical, straight, square, triangular and conical pin profiles and using three tool rotation speeds that were 900, 1400 and 1800 rpm with a constant transverse speed of 16 mm / min. Yuvral et al.[19] investigate the effect of parameters and reinforcement of TiC nano particles of size 10-30nm . Shuhan et al. [20] made defect-free butt welds of titanium alloy with steel by FSW. Wwas done at TRS varied at 600 and 950 rpm with a constant weld speed of 47 mm/min. the result showed that increment in TRS increase the thickness of intermetallic compound layer. Wenya et. al [21] improve the tensile properties of magnesium AZ31 joining by friction stir welding zone by using a stationary shoulder.

2. Experimentation

A universal vertical milling machine used as the experimental machine in this study with a fixture used for clamping the workpiece with locking nut. The size of table is 254×1370 mm on which a fixture or backing plate is mounted which is used to hold the work-piece during welding. Two aluminium alloy 5083 plates of size 75mm×60mm×6mm are mounted on the fixture of vertical milling machine for making butt joint by using friction stir welding. The parameters which selected for this investigation are: tool rotation speed, transverse speed and tool pin diameter. Various experiments are conducted for optimize the response parameter i.e. %Elongation. Taguchi's robust design of experiments (DOE) methodology is used to plan the experiments statistically. Table 1 details the different control variables and their levels.

Table 1: Control variables and their levels

Parameters	Level 1	Level 2	Level 3
Tool rotation speed	1200 rpm	1950 rpm	3080 rpm
welding speed	20mm/min	25mm/min	30mm/min
Tool Pin diameter	5mm	6mm	7mm

All the selected parameters have equal levels. L9 and L27 orthogonal array has come out as the possible solutions for designing the experiments. Hence, L9 array was selected for the present investigation. The DOE by L9 array is consisted of nine trial runs as shown in table2.

The welding of two plates of AA 5083 is done according to the entire nine trail run. The joined plates after welding are shown in fig.1.

Figure 1: Plate after friction stir welding

Then two tensile test specimens are extracted from each welded piece. The dimensions of the test specimens are according to American Society for Testing of Materials (ASTM) standard and after extract from the welded plates are shown in fig.2**.** The values of % elongation were recorded and plotted as per Taguchi design of experiments methodology. Table.3 & Table .4 shows the values of % elongation against the input parameter setting for L9 orthogonal array.

Figure 2: Specimen for the elongation

The analysis of the results obtained has been performed according to the standard procedure recommended by Taguchi. The main effects are studied by the level average response analysis of % elongation raw data or of S/N data. The analysis is done by averaging the % elongation data and/or S/N data at each level of each parameter and plotting the values in graphical form. The factor effects of different input parameters with their corresponding levels on S/N ratio and average response for % elongation are tabulated in table-3 & table 4 respectively.

Table-2: Taguchi's L9 Standard Orthogonal Array for % Elongation

Experiment No.	Design of Experiment			% Elongation Sample 1	%Elongation	Average % Elongation
	Tool rotation speed (A)	Welding speed (B)	Tool pin diameter (C)		Sample 2	
1	1200	20	5	3.9	3.95	3.92
2	1200	25	6	3.74	2.98	3.36
3	1200	30	7	5.39	5.19	5.28
4	1950	20	6	4.41	4.4	4.4
5	1950	25	7	5.44	5.44	5.44
6	1950	30	5	7.3	7.27	7.28
7	3080	20	7	2.3	2.35	2.32
8	3080	25	5	2.67	2.77	2.72
9	3080	30	6	3.18	2.9	3.04

Table.3: Response Table for % Elongation (Means)

Level	A	B	C
1	4.187	3.547	4.640
2	5.707	3.840	3.600
3	2.693	5.200	4.347
Delta	3.013	1.653	1.040
Rank	1	2	3

Table.4: Response Table for % Elongation (S/N Ratio)

Level	A	B	C
1	-12.282	-10.682	-12.600
2	-14.941	-11.310	-11.018
3	-8.553	-13.784	-12.158
Delta	6.388	3.103	1.582
Rank	1	2	3

Table..5: Analysis of Variance for % Elongation (Means)

Source	DF	Seq SS	Adj SS	Adj MS	F	P	%Age contribution
A	2	13.6206	13.6206	6.81031	195.4	0.005	67.78
B	2	4.6692	4.6692	2.33458	67.00	0.015	23.24
C	2	1.7252	1.7252	0.86258	24.76	0.039	08.58
Resi. Error	2	0.0697	0.0697	0.03484			
Total	8	20.0846					

2.1 Analysis of Variance (ANOVA)

The purpose of ANOVA is to investigate the parameters, whose combination to total variation is significant. The ANOVA for Means of %elongation are given in table-5.

3. Results and Discussion

The main effect of input parameters on the response parameters (% elongation) are discussed on the basis of mean of response, ANOVA and plots between response parameters and input parameters. The plots show that how response parameters are varying at different levels of input parameters. The plots for mean and S/N ratio for % elongation are shown in fig. 3-4. It can be observed from fig. 3 that the Tool rotation speed, welding speed and tool pin diameter affects the % elongation very significantly. Moreover, the different input parameters used in the experimentation can be ranked in the order of decreasing %elongation as tool rotation speed, welding speed and tool pin diameter.

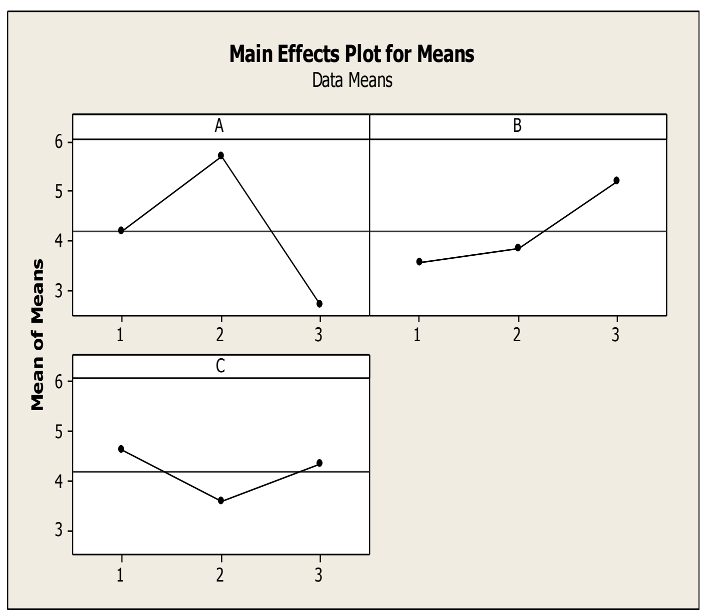

Figure 3: Effects of Process Parameters on % Elongation (Means)

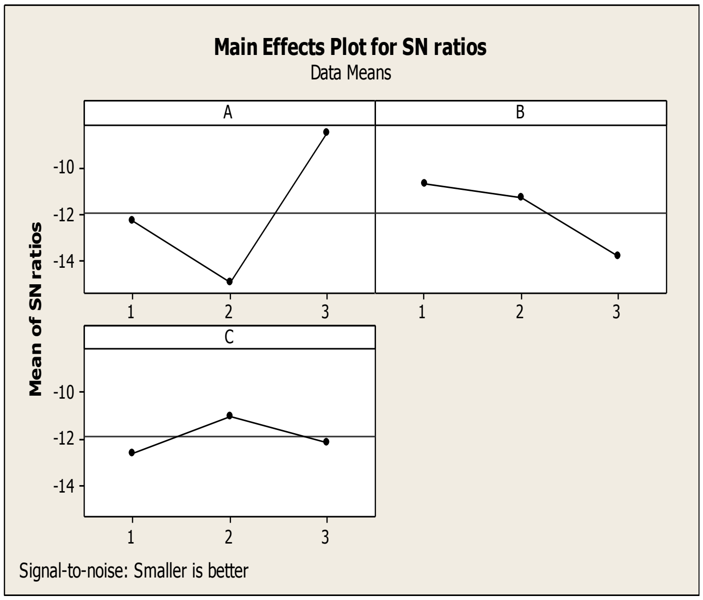

Figure 4: Effects of Process Parameters on % Elongation (S/N Ratio)

4. Conclusion

Following conclusions were drawn

1. In Friction stir welding, the Tool rotation speed is most significant factor for decreasing % elongation, welding speed is the second significant factor and Tool pin diameter is the third significant factor.
2. The most effective parameter with respect to %Elongation is tool rotational speed. Whereas the effect of welding speed and tool pin diameter on the %elongation was also significant.
3. By increasing the tool rotation speed, the %elongation first increases and then decreases. By increasing the welding speed, the %elongation is increased. By increasing the tool pin diameter, %elongation is first decreases and then increases increased.
4. The Computed results using ANOVA also showed that the tool rotational speed is the most effective factor with a percent contribution of 67.78%. The percent contribution tool shoulder dia. and welding speed is 23.24% and 08.58% respectively.
5. The input parameters settings tool rotation speed at 3080 rpm, welding speed at 20 mm/min, and tool shoulder dia. at 6 mm have given the optimum results for %elongation; in friction stir welding on AA 5083.

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