OPTIMIZATION OF FRICTION STIR WELDING PARAMETERS FOR DISSIMILAR ALUMINUM ALLOY

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Abstract

Friction stir welding is counted as one of the most significant development in welding techniques. It is also called as green technology as it requires less energy, flux or gas. As it does not require any filler material hence can be used to join dissimilar metals. The process has wide application of welding alloys of aluminium, magnesium and hard metal like steel etc. Investigation on geometrical and mechanical parameters used in friction stir welding needs to explore for different metal alloys. In present work parameters were studied for friction stir welding of aluminium alloys (AA8011 & AA3003). The welding was performed on vertical milling machine with AISI H13 tool. Three parameters rotation speed, welding speed and tilt angle were selected for study using cause and effect diagram. Welding character was evaluated on basis tensile strength, percentage elongation and hardness of welding joint. The results were optimized by Minitab software on the basis of Taguchis method. The results revealed that rotation speed emerged as the most significant process parameter that affects the mechanical properties of welded joint followed by tilt angle while welding speed emerged as non-significant factor.

Keywords: Friction stir welding, AA8011, AA3003, welding speed, rotation speed, Tilt angle
Taguchi’s method

1. Introduction

Friction Stir Welding (FSW) is perpetual method that utilizes a non-consumable rotating welding tool to develop frictional heat and plastic deformation at the welding region while the material is in a solid state. There are numerous elements which influence the weld quality. A sound weld quality must be accomplished by appropriate combination of process parameters. A large number of exploratory examinations on friction stir welding have been reviewed where welding conditions such as rotating speed, tool pin profile, transverse speed, tilt of the tool, depth of sinking, and the material properties of both the tool and work piece drastically radically impact weld quality created by FSW.

Factors which influence the weld quality are essentially separated into two major types: Controllable and uncontrollable parameters like machine tool vibration, ambience and metrology practice considered to be the uncontrollable parameters and rotating speed, tool pin profile, welding speed, tilt of the tool and depth of sinking are considered to be the controllable parameters. We can't have our hands on the uncontrollable parameters. One needs to focus in choosing the best combination which would result in exceptionally poor

weld quality. In this manner the incredible test lies in one choosing optimum combination of the procedure parameters to get the best weld quality.
The literature review reveals that the important factors affecting the mechanical properties of welded joints are:-

1. Tool rotational speed
2. Tool welding speed
3. Tilt angle of tool

From literature review we are able see that a part of work has been done in field of friction stir welding of Aluminium and its alloys, Magnesium, Brass, Zinc and various other materials but a very limited work was reported in the FSW of AA8011 and AA3003. So here an attempt has been made by welding aluminium alloy (AA8011-AA3003) using FSW and experiment has been outlined according to L9 Taguchi orthogonal array to study effects on Ultimate tensile strength and percentage elongations.

2. Experimental

2.1 Selection of hardware and their specifications

- **Vertical universal milling machine**

Programmable DRO vertical universal milling machine (Model 3KS) manufactured by "PACMILL," a brand of Taiwan was used in current investigation. A setup of vertical universal milling machine is shown in Fig.1.

Fig. 1 A vertical Universal milling machine

- **Work Piece Material**

A total of 9 sets of both AA8011 and AA3003 aluminum alloy were cut in size of 150mm × 100 mm using Shaper machine and Power hacksaw. The pairs of work piece are shown in Fig. 2.

Fig.2 Pairs of work piece

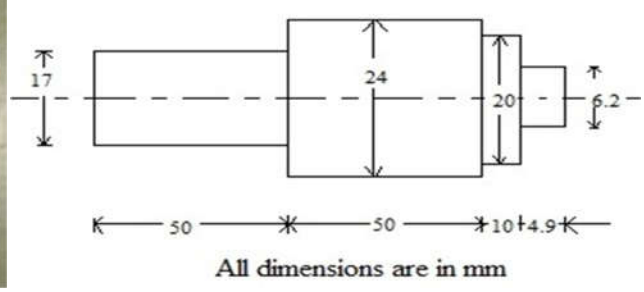
The Element composition has been has observed at Institute for Auto Part & Hand Tool Technology, Ludhiana and tabulated in table 1.

Table 1 Work piece compositions (in wt %)

Material	Si	Mg	Fe	Mn	Al
AA-3003	1.11	0.87	0.38	0.56	96.86
AA-8011	0.19	0.37	0.26	0.50	98.31

- **FSW tool material**

H13 die-steel has been utilized as a tool material for FSW of aluminum alloy (AA8011- AA3003). A carbide single point cutting tool is used to prepare the profiles of tool on Lathe machine. The cylindrical type of tool pin profiles has been used in present work. Fig.3 shows the pictorial and drafted view of FSW tool. Elemental composition of FWS tool is shown in table 2.



a) b)

Fig.3 a) Pictorial View of FSW tool b) Drafted View of FSW tool

Table 2 elemental composition (in wt %) of H13 die steel FSW tool

Element	C	Cr	Mn	Mo	P	Si	S	V
Wt%	0.32-0.45	4.75-5.5	0.2-0.5	1.1-1.75	0.03	0.8-1.2	0.03	0.8-1.2

- **FSW fixture**

A cast iron fixture was used to hold and clamp the work piece for FSW of aluminium alloy (AA8011-AA3003). The fixture is prepared in such a manner that it can hold up to a size of 150×100×25 mm as shown in Fig.4.

Fig.4 Work piece is mounted in the fixture

2.2 Experimental procedure

To carry out FSW of aluminium alloy, one plate of both AA3003 and AA8011 of size 150 mm × 100 mm × 5.1 mm is clamped in a fixture. These pieces are obtaining by cutting the sheet of this aluminium alloys with hydraulic press than to give them perfect dimension, shaper machine is being used. During the experimental analyses a vertical universal milling machine is utilized as FSW setup which has high rotation speed to rotate the stirrer.

FSW is done by taking three different values of rotational speed, welding speed, tool tilt angle. The parameters are chosen using quality tool cause and effect diagram. Design data handbook is used to know the maximum and minimum range of rotating speed and welding speed. Three different tool tilt angle are taken (0.5 degree, 0 degree and1degree). A total of 9 sets are prepared by the following the parameter combination of given set of orthogonal array by Taguchi L9 given in table 3. Further Tensile strength, % Elongation and Rockwell hardness testing of all specimens were performed at CITCO.

Table 3 Orthogonal Array Taguchi Design L9 FSW actual values

S. No.	Rotation speed	Welding speed	Tilt angle
1	1200	20	0°
2	1200	40	0.5°
3	1200	60	1°
4	1540	20	0.5°
5	1540	40	1°
6	1540	60	0°
7	1950	20	1°
8	1950	40	0°
9	1950	60	0.5°

3. Results and Discussion

3.1 Tensile Testing and percentage elongation

The testing for tensile strength and percentage elongation was performed on Universal Testing Machine. The specimens prepared as per dimensions shown in Fig. 5. Fig. 6 shows the plates from which the samples were taken. The Tensile test has been done on electro-mechanical controlled UTM at a room temperature. The specimen was stacked as per ASTM specifications, so that tensile specimen experiences distortion. The specimen was found to fail after necking and at that instance load displacement was noted. The ultimate tensile strength and percentage elongation were assessed given in table 4.

Specification of tensile specimen:

Cross sectional area of test specimen =5mm x 15mm =75 mm^2

Gauge length = 50 mm

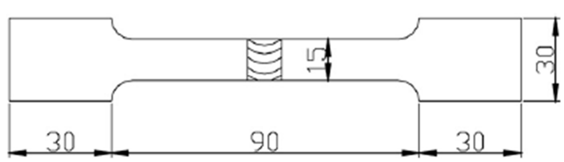


Figure 5 Dimensions of Tensile Specimen

Figure 6 Base from which the specimens were removed

Table 4 Test results obtained from universal testing machine

Job no.	Nomenclature of sample	Area (mm^2)	T.S (KN/mm^2)	% EL
22634	Sample-1,Dumble Size- 18.87×4.99mm	94.161	0.140	13.5
22635	Sample-2,Dumble Size- 18.13×5.3mm	96.270	0.091	5.2
22636	Sample-3,Dumble Size- 19.50×5.14mm	100.230	0.141	14.6
22637	Sample-4,Dumble Size- 19.55×5.06mm	98.923	0.141	14.3
22638	Sample-5,Dumble Size- 18.08×5.21mm	94.197	0.135	13.2
22639	Sample-6,Dumble Size- 18.07×5.11mm	92.338	0.136	13.3
22640	Sample-7,Dumble Size- 19.02×5.18mm	98.524	0.095	7.4
22641	Sample-8,Dumble Size- 19.05×5.30mm	100.965	0.135	12.9
22642	Sample-9,Dumble Size- 19.44×5.249mm	101.866	0.124	6.3

- **ROCKWELL HARDNESS**

Rockwell hardness testing machine with diamond spheroconical tool under a load of 150kgf was impacted on the surface of aluminium alloy welds and Rockwell hardness was measured on scale- C. The hardness of individual plates along with that of weld joint for all the samples has been tabulated in table 5.

Table 5 Results obtained from Hardness Testing

Sr No.	Hardness of plates (HRC)			Hardness at weld joint (HRC)
	Sample number	Al-3003	Al-8011	
1	Sample number-1	43	73	47
2	Sample number-2	47	72	33
3	Sample number-3	54	74	62
4	Sample number-4	50	74	57
5	Sample number-5	46	70	46
6	Sample number-6	44	74	27
7	Sample number-7	48	70	33
8	Sample number-8	60	75	53

9	Sample number-9	41	75	39

3.2 TAGUCHI DESIGN RESULT

- **Analysis of means and signal to noise ratio**

The delta values of each parameter are calculated for S/N ratio and means using Minitab. The delta value is the difference of maximum value of S/N ratio of one parameter to the minimum value of that parameter. The delta value helps to determine the rank of the parameter. The table 6, 7 and 8 show the response tables of means and S/N ratio for tensile strength, % elongation and Rockwell hardness.

Table 6 Response table for S/N & Means ratio for T.S.

Response table for signal to noise ratios Larger is better			
Level	Rotation Speed	Welding Speed	Tilt Angle
1	-18.30	-18.18	-17.27
2	-17.25	-18.54	-18.66
3	-18.66	-17.49	-18.28
Delta	1.41	1.04	1.39
Rank	1	3	2

Response table for means			
Level	Rotation Speed	Welding Speed	Tilt Angle
1	0.1240	0.1253	0.1370
2	0.1373	0.1203	0.1187
3	0.1180	0.1337	0.1237
Delta	0.0193	0.0133	0.0183
Rank	1	3	2

Table 7 Response table for S/N& Means ratio for %EL

Response table for signal to noise ratios Larger is better			
Level	Rotation Speed	Welding Speed	Tilt Angle
1	20.07	21.03	22.43
2	22.67	19.65	17.80
3	18.53	20.58	21.03
Delta	4.41	1.38	4.63

Response table for means			
Level	Rotation Speed	Welding Speed	Tilt Angle
1	11.100	11.733	13.233
2	13.600	10.433	8.600
3	8.867	11.400	11.733
Delta	4.733	1.300	4.633

Rank	2	3	1

Rank	1	3	2

Table 8 Response table for S/N& Means ratio for Hardness

Response table for signal to noise ratios Larger is better			
Level	Rotation Speed	Welding Speed	Tilt Angle
1	33.22	32.98	32.18
2	32.33	32.70	32.44
3	32.23	32.10	33.16
Delta	0.99	0.88	0.97
Rank	1	3	2

Response table for means			
Level	Rotation Speed	Welding Speed	Tilt Angle
1	47.33	45.67	42.33
2	43.33	44.00	43.00
3	41.67	42.67	47.00
Delta	5.67	3.00	4.67
Rank	1	3	2

Then from these entire response tables the parameters which affected most were identified and tabulated in table 9.

Table 9 Results from parameters

Factors	Most effected parameter
Tensile strength	Rotation speed
% Elongation	Rotation speed and tilt angle
Hardness	Rotation speed

From response table it can be concluded that from all the three parameters (Rotation speed, welding speed and Tilt angle) which one is critical for different mechanical properties (Tensile Strength, % Elongation and Hardness) of Weld Joint

Figure 7 represents the S/N ratio and Means for % elongation. These graphs are on the basis of larger is better so from that the following results come out. For % Elongation the optimum combination of rotation speed, welding speed and tilting angle is 1540 rpm, 20mm/min and 0 deg respectively. Figure 8 represents the S/N ration and Means for tensile strength. By optimization of results for tensile strength it can be concluded that the value of rotation speed (1540 rpm) and tilting angle (0 deg).is same as in % elongation while the welding speed of

60mm/min is considering better result value in case of tensile strength. Figure 9 represents the S/N ration and Means for Hardness. The parameter value 1200 rpm (rotation speed), 20 mm/min (welding speed) and 1 deg (tilting angle) are the best suited parameter value for better hardness.

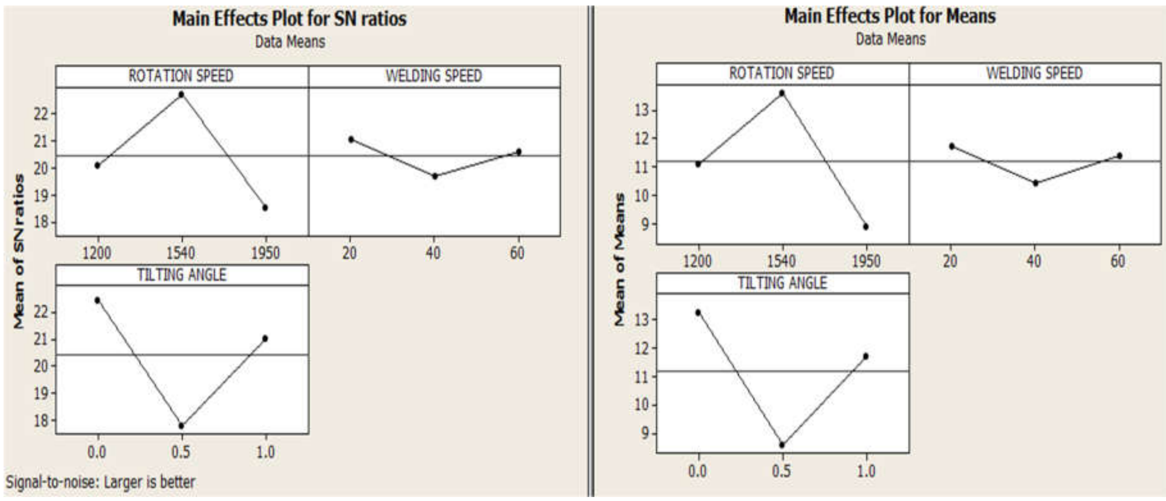


Fig.7 Result analysis of S/N ratio and Means for % EL

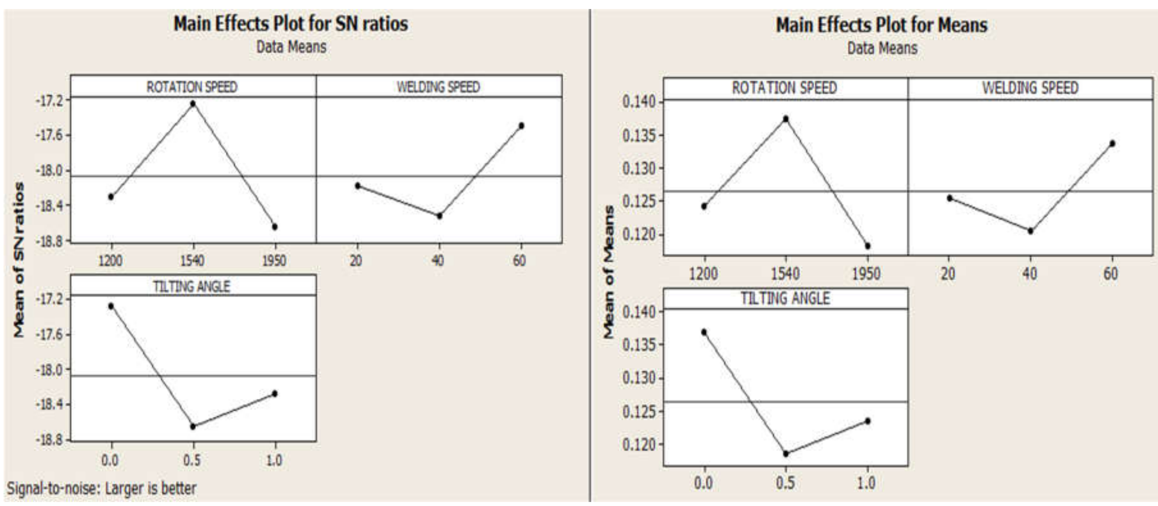


Fig.8 Result analysis of S/N ratio and Means for T.S.

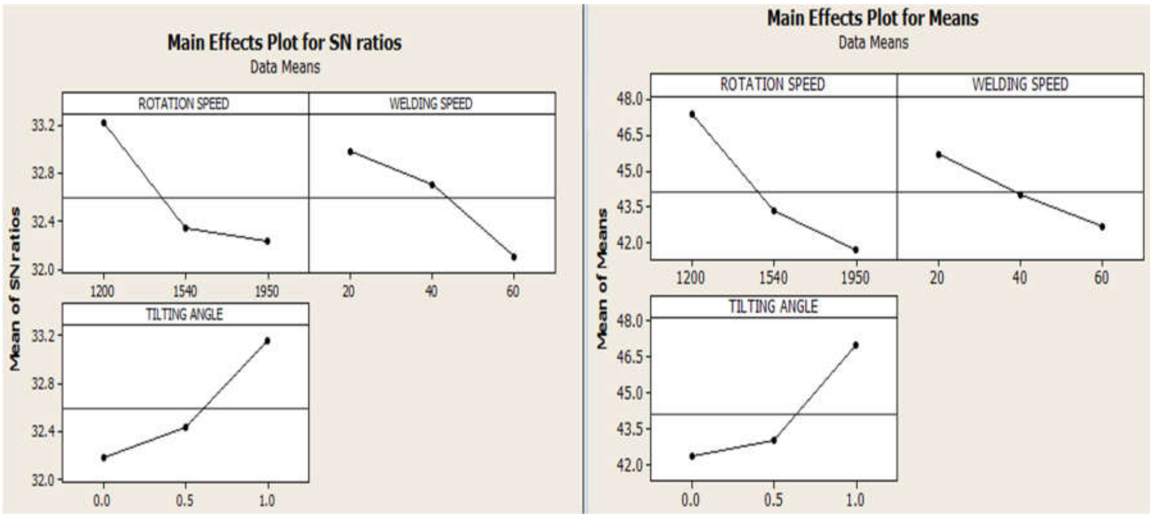


Fig.9 Result analysis of S/N ratio and Means for Hardness

4. Conclusion

Current work analyzes a potent way for finding the optimal FSW parameters for welding of aluminium alloy (AA8011- AA3003) with H13 tool under some carrying conditions. The study found that the control factors have varying effects on the response variable. Rotational Speed of the tool has highest effects. The numerous combinations of design parameter settings can easily be controlled by using DOE techniques.

The results can be concluded in the following points.

- Tool rotational speed is the most significant which contributes to all the Parameters (Rotation speed, welding speed and Tilt angle) subsequently followed by welding speed which contributes and tool pin profile has least significant factor contributes.
- Tensile strength is varying from 0.141(kN/mm^2) to 0.091(kN/mm^2)
- Variation in % Elongation is from 14.6 to 5.2
- Rockwell Hardness variation is from 62 HRC to 27 HRC
- In case of tensile strength and % elongation at rotation speed of 1950 RPM results are not satisfying, at 1200 RPM maximum variation in results was found and at 1540 RPM Results are found to be approximately constant. Whereas, in case of hardness results were varying.
- Tool pin profile has negligible influence on Rockwell hardness

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