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Optimized Parameters Prediction for Single-Pass Friction Stir Welding on Dissimilar Aluminium Alloys T- Joint

Dhanesh G. Mohan[1*] and Gopi S.[2]
[1]Institute of Materials Joining, Shandong University, Jinan, China.
[2]Department of Production Engineering,
Government College of Technology, Coimbatore, Tamilnadu, India.

(Corresponding author: Dhanesh G Mohan)
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ABSTRACT: A T–joint with dissimilar aluminium alloys was difficult to configurative by using a conventional fusion welding method. The double corner fillet welding method will increase the heat-affected zone and thereby reduces the strength. This work Taguchi method is adopted to optimize this single-pass friction stir welding (FSW) process parameters for welding dissimilar aluminium alloy AA5052 with AA6061. A T – joint was fabricated by AA 5052 – H32 as skin and AA 6061 – T6 as a stinger. Five levels three parameters are adopted for this single pass FSW process. The optimized parameter combination for this singles pass FSW T – joint fabrication is; welding speed 60 mm/min, plunger depth 0.05 mm and spindle speed 850 rpm, respectively. While comparing the predicted result with the experimental confirmation result, the confirmation result has 94.50 % accuracy, which is acceptable.

Keywords: Friction Stir Welding, T – joint, Taguchi, Optimization, Single-pass, Aluminium alloy.

I. INTRODUCTION

Single-pass Friction-stir welding (FSW) is a solid-state joining process, which means the welding metals does not undergo a liquid state while welding and the joining happen in the semisolidus state itself. This help to reduce the area of the heat-affected zone generation while joining. For welding metals like aluminium and its alloys, FSW is extensively employed; these metals are difficult to weld by conventional fusion welding methods. A non-consumable rotating tool is adopted for this single pass FSW process. This tool generates friction on the metal's weld surface by shoulder penetration, while the tool pin profile agitates the metals in the nugget zone. This penetration of the tool shoulder and stirring of the pin makes the metal into semi solidus state, and thus the metal joins.

In a conventional fusion welding method, a T – joint is configured by two-corner fillet welding; this method decreases the joint's strength due to an increase in the heat-affected zone and the low probing of the filler metals. While adopting single pass friction stir welding, the tool pin penetrates through the top skin metal and reaches the stinger; this single pass friction stir welding can fabricate a T – joint with better strength. This single-pass FSW's main advantage over the conventional method is: it increases the joint's strength by reducing heat affected zone, the production time is comparatively less, and it is economical. Fig. 1 shows the schematic representation of conventional arc welding for T – joint, and Fig. 2 shows the schematic representation of a single pass FSW T – joint. The other advantages of FSW over conventional welding are FSW does not require any filler metals for joining and also prevents porosity or oxidation while joining.

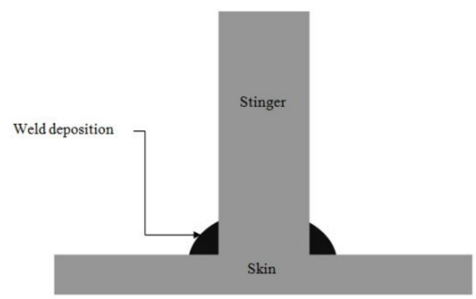

Fig. 1. Schematic representation of conventional arc welding for T – joint.

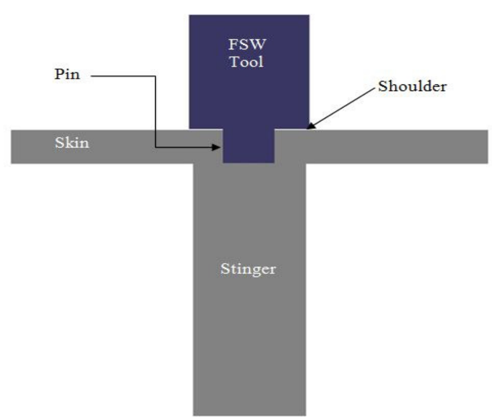

Fig. 2. Schematic representation of FSW for T – joint.

Taguchi method was adopted for predicting the better process parameters for this experiment. Taguchi method uses a lesser number of experiments in the orthogonal arrays to examine the entire parameter space. A signal-to-noise (S/N) ratio was then derived from these experimental results. To evaluate the quality characteristics evolved from the desired values, Taguchi uses the S/N ratios. Based on the S/N analysis, the S/N ratio for each level of process parameters is calculated. A greater S/N ratio relates to improved quality features. Therefore, the most significant S/N ratio represents the optimal level of the process parameters.

II. EXPERIMENTAL SETUP

This friction stir welding was conducted on an HMT FN2V conventional milling machine. The skin metal AA 5052, having 4mm thickness, has been cut into the required size (200×100×4mm), and the stinger metal AA 6061, having 10mm thickness, has been cut into the necessary size (200×60×10mm) by power hacksaw cutting and T – joint was configured. Before welding, the plates were undergone fine side and edge preparations. The schematic diagram is given in Fig. 3.

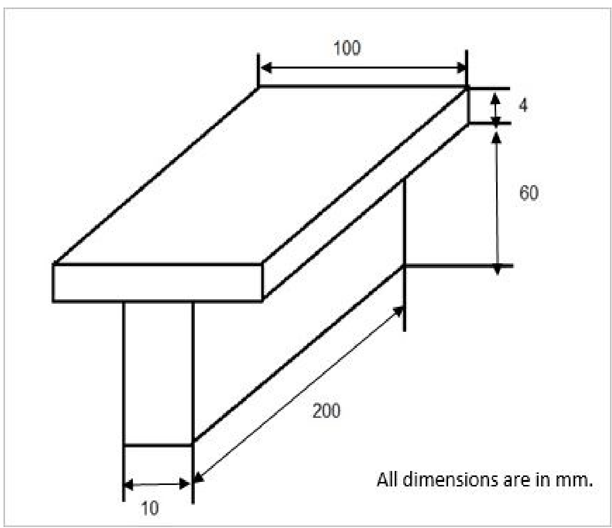

Fig. 3. Schematic diagram of the T-joint configuration.

The T – joint fabrication on the milling machine for the single-pass FSW process is shown in Fig. 4.

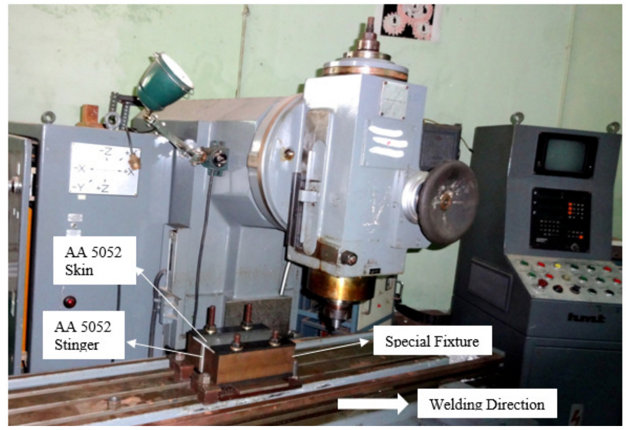

Fig. 4. T – joint fabrication on the milling machine.

The tool material selected for this FSW process is high carbon steel. The tool pin profile opted for this experiment is a hexagonal shape. The hexagonal profile tool pin with a flat shoulder profile is best for welding soft metals like aluminium and its alloys. This profile helps to attain maximum metal movements in the stir zone and helps to reduce wormhole defects. This hexagonal profile also benefits from achieving high metal stirring in the nugget zone and produces a good joint with a fine grain structure. The hexagonal pin profiled tool's dimension is shoulder diameter 25mm, pin diameter 8mm and pin length 7mm.

III. PROCESS PARAMETERS SELECTION AND DESIGN OF EXPERIMENTS

After conducting the trial runs, the levels for conducting the experiments are selected. The process parameters chosen for this work are welding speed, spindle speed and plunger depth. The level chosen is five. Table 1 shows the parameters with levels. The design of experiments was done by using the Taguchi method. The Taguchi experimental design reduces cost, Improves quality, and provides robust design solutions. The Taguchi method's advantages over the other methods are that numerous factors can be simultaneously optimized, and more quantitative information can be extracted from fewer experimental trials. Orthogonal array L_{25} (5^3) was designed for conducting the experiments. Table 2 shows the L_{25} (5^3) orthogonal array.

Table 1: Process parameters with levels.

Parameters	Level 1	Level 2	Level 3	Level 4	Level 5
Spindle speed (rpm)	700	850	1000	1150	1300
Welding speed (mm/s)	0.82	1.18	1.54	1.90	2.25
Plunger depth(mm)	0	0.05	0.1	0.15	0.2

Table 2: The L_{25} (5^3) orthogonal array.

Experiment Numbers	Spindle speed (rpm)	Welding speed (mm/s)	Plunger depth(mm)
1	700	0.8	0
2	700	1	0.02
3	700	1.2	0.05
4	700	1.5	0.1
5	700	2	0.2
6	850	0.8	0.02
7	850	1	0.05
8	850	1.2	0.1
9	850	1.5	0.2
10	850	2	0
11	1000	0.8	0.05
12	1000	1	0.1
13	1000	1.2	0.2
14	1000	1.5	0
15	1000	2	0.02
16	1150	0.8	0.1
17	1150	1	0.2
18	1150	1.2	0
19	1150	1.5	0.02
20	1150	2	0.05
21	1300	0.8	0.2
22	1300	1	0
23	1300	1.2	0.02
24	1300	1.5	0.05
25	1300	2	0.1

Fig. 5. Sample specimens produced by using the FSW method.

The experiments were conducted as per the parameter combinations in the orthogonal array. The sample specimens produced by using the FSW method are given in Fig. 5.

IV. RESULTS AND DISCUSSION

The tensile testing was carried out in 0.25 kN; Servo controlled universal Testing Machine. The specimen is loaded at the rate of 0.25 kN/min so that the tensile model undergoes deformation. Tensile tests were performed to determine the strength of the weldments. The signal to noise ratio (S/N ratio) was found out by using the Taguchi method. The moto of this work is to find out the best parameter combinations for achieving good joint strength. This signal to noise ratio selected here is 'larger the better, that means the better parameter has a better response. The response taken here is the tensile strength. The relationship between the parameters and response can be predicted by using the signal to noise ratio. Table 3 shows the parameters with tensile strength and respected S/N ratios.

Table 3: Experimental values of tensile strength with S/N ratio.

S. No.	Spindle speed (rpm)	Welding speed (mm/s)	Plunger depth (mm)	Average Tensile strength (MPa)	S/N ratio
1	700	0.8	0	116	41.2892
2	700	1	0.02	120	41.5836
3	700	1.2	0.05	122	41.7272
4	700	1.5	0.1	105	40.4238
5	700	2	0.2	107	40.5877
6	850	0.8	0.02	123	41.7981
7	850	1	0.05	128	42.4115
8	850	1.2	0.1	101	40.0864
9	850	1.5	0.2	103	40.2567
10	850	2	0	112	40.9844
11	1000	0.8	0.05	123	41.7981
12	1000	1	0.1	115	41.214
13	1000	1.2	0.2	118	41.4376
14	1000	1.5	0	116	41.2892
15	1000	2	0.02	125	41.9382
16	1150	0.8	0.1	119	41.5109
17	1150	1	0.2	117	41.3637
18	1150	1.2	0	118	41.4376
19	1150	1.5	0.02	104	40.3407
20	1150	2	0.05	109	40.7485
21	1300	0.8	0.2	120	41.5836
22	1300	1	0	121	41.6557
23	1300	1.2	0.02	106	40.5061
24	1300	1.5	0.05	113	41.0616
25	1300	2	0.1	119	41.5109

Table 4: Main effects of the tensile strength (S/N ratio).

Mean S/N ratio							
Parameter	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**	**Delta**	**Rank**
Spindle speed (rpm)	41.12	41.11	41.54	41.08	41.26	0.43	3
Welding speed (mm/sec)	41.60	41.65	41.04	40.67	41.15	0.97	1
Plunger depth (mm)	41.33	41.23	41.55	40.95	41.05	0.60	2

From the above table, the experimental value of tensile strength being taken and shifted into MINITAB software and the result of the main effect of S/N ratio with mean was calculated, shown in Table 4. The graph showing the primary influence for S/N ratios with the mean is shown in Fig. 6. The main effect of tensile strength to mean was calculated using the same software, and the response table was shown in Table 5. The graph for tensile strength to mean value is shown in Fig. 7. This graph clearly shows that, while increasing the importance of the tensile strength parameters (TS), the spindle speed of 850 rpm, Welding speed of 60 mm/min and plunger depth was gradually increasing by 0.05mm, the strength got progressively decreased.

This result proves that the tensile strength of the specimen depends on the parameters. This graph clearly shows that in the initial stage, the joint's strength gradually increases while increasing the parameter values and later reaching a saturation point, the strength is reducing. While increasing the parameters' values, the material movements will gradually increase, and it plasticizes the joining region and sound joint were formed. Further increase in the parameters will drag the metals faster, and it causes higher material flow and resulting in wormhole defects formation. The higher welding speed and spindle speed causes an increase in the heat-affect zone and thus reduces the joint strength.

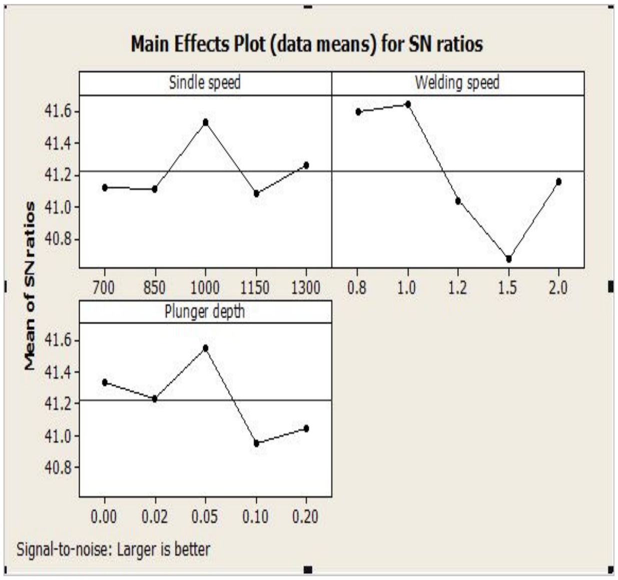

Fig. 6. Main effect plots for S/N ratios.

Table 5 indicates by the ranking method that the most predominant parameter that affects the joint's strength is the welding speed, and the least affecting parameter is the plunger depth. Examination of the mean for each of the experiments gives a better combination of parameter levels.

Means response denotes the average value of performance characteristics for each parameter at different levels. The mean for one level was calculated as an average of all responses obtained within that level. Mean response of raw data and S/R ratio of tensile strength for each parameter at level – 1, level – 2, level – 3, level – 4 and level – 5 were calculated, analyzed means and S/N ratio of various process parameters.

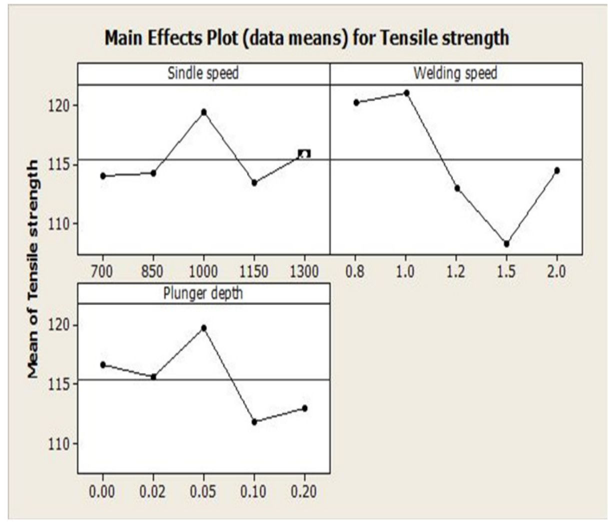

Fig. 7. Main effects plots for mean.

Table 5: Main effects of the tensile strength (means).

Mean S/N ratio							
Parameter	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**	**Delta**	**Rank**
Spindle speed(rpm)	114	114.2	119.4	113.4	115.8	6	3
Welding speed(mm/sec)	120.2	121	113	108.2	114.4	12	1
Plunger depth (mm)	116.6	115.6	119.8	111.8	113	6.8	2

It is observed that a larger S/N ratio corresponds to better quality characteristics. Therefore, the effect of the process parameter is the level of the highest S/N ratio. Mean effect and S/N ratio TS calculated by Minitab software indicated that TS was at maximum. The optimum parameter combinations predicted are welding speed 60 mm/min, plunger depth 0.05 mm and spindle speed 850 rpm. The optimum value of TS was predicted at selected levels of significant parameters. The most effective process parameter is Welding speed.

The estimated mean of response characteristics (TS) and the average values can be computed from tensile strength's primary effect.

Tensile strength (TS) = (A+ B + C) - D

Where,
A= Avg. tensile strength at the 2nd level of welding speed.
B= Avg. tensile strength at the 3rd level of plunger depth.
C= Avg. tensile strength at the 2nd level of spindle speed.
D= Overall mean tensile strength.
Therefore, Predicted TS = 129.48 MPa

The Minitab software predicted tensile strength from the given response was 129.48 MPa.

The confirmation test was conducted, and the experiment specimen provides a tensile strength of 122.36 MPa. The percentage of error calculated from the predicted with experimented one was 5.14%. The above result shows that the accuracy of optimum parameters is 94.50%, this error percentage is negligible, and these test results can be accepted.

V. CONCLUSION

a. The process parameters for single-pass friction stir welded dissimilar aluminium alloys AA 5052 with AA 6061 to make T – joint were optimized. After conducting this experiment with the Taguchi method of design, the following results were gained.
b. The highest tensile strength for friction stir welded T-joint aluminium alloys has been gained atthe optimum parameters combination of welding speed1 mm/s, plunger depth 0.05 mm, and spindle speed 850 rpm.
c. Welding speed has been the most dominant parameter which affects tensile strength. The other parameters, such as plunger depth and spindle speed, have minimal effect on tensile strength.
d. While increasing the welding speed, the strength gained for the specimen was also improved; after

reaching a speed of 1 mm/s, the specimen's strength got reduced. In contrast, a further increase in the welding speed drag the metals from the nugget zone and cause wormhole defects and result in low joint strength.

e. The confirmatory test has been carried out with the optimum parameter setting, and the results are validated. This work shows that the optimum parameter combination has 94.50 % accuracy over the predicted value.
f. This research output shows that this single-pass FSW is suitable for joining dissimilar aluminium alloys, and it provides a better tensile strength of 122.36 MPa; still, any fusion welding methods do not achieve this result.

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