IJRAME

ISSN (ONLINE): 2321-3051

INTERNATIONAL JOURNAL OF RESEARCH IN AERONAUTICAL AND MECHANICAL ENGINEERING

ANALYSIS OF MECHANICAL STRENGTH OF DISSIMILAR ALUMINIUM ALLOYS AA7075 AND AA2024 IN FRICTION STIR WELDING USING TAGUCHI'S TECHNIQUE

D.Muruganandam[1], D.Raguraman[2], Sushil Lal Das[3]

[1] *Assistant Professor, Department of production Engineering, Sri Sairam engineering College, Chennai, murudurai@gmail.com*
[2] *Assistant Professor, Department of production Engineering, Sri Sairam engineering College, Chennai, raguraman150807@gmail.com*
[3] *Professort, Department of Mechanical Engineering, Jeppiaar Engineering College, Chennai – 119.*
Author Correspondence: Plot No.28, Jega jeeva ram nagar, Selaiyur, Chennai – 600073. 9382780536, murudurai@gmail.com

Abstract

This paper deals with the experimental investigation of effects of geometrical parameters of friction stir welding of dissimilar Aluminium alloys and analysis of output responses such as tensile strength in the friction stir welding. Taguchi's Design of Experiment (DoE) is used to design the experimental array, based on which experiments were conducted. For four parameters and four levels of each parameter, L_{16} Orthogonal array is selected. To evaluate the output quality characteristics Taguchi's technique is used, based on which the optimum conditions are determined. An interaction effect of one input parameter over another parameter is studied to understand their influences on output performance characteristics. Analysis of Variance (ANOVA) is also performed to study the contribution of individual parameter on the output quality characteristics based on Signal-to-Noise ratio.

***Keywords**:* Taguchi's DoE, S/N ratio, Interaction effect, ANOVA, Geometrical parameters.

1. INTRODUCTION

In recent times, focus has been on developing fast, efficient processes that are environment friendly to join two dissimilar materials. The spotlight has been turned on Friction stir welding as a joining technology capable of providing welds that do not have defects normally associated with fusion welding processes[1-3]. Friction stir welding (FSW) is a fairly recent technique that utilizes a non consumable rotating welding tool to generate frictional heat and plastic deformation at the welding location, thereby affecting the formation of a joint while the material is in the solid state. Figure.1 shows the schematic drawing of friction stir welding representing all the relevant parameters of the process.

Vol.1 Issue.6,
October 2013.
Pgs: 13-22

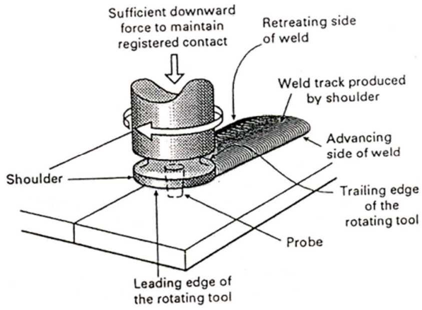

Figure.1: Schematic illustration of Friction Stir Welding

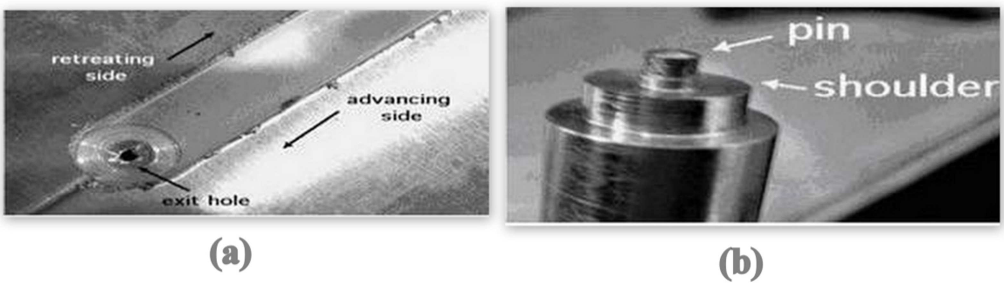

Figure.2: (a) Mode of weld (b) Tool profile for FSW

Figure.3: Typical cross section of the weld (300rpm, 60mm/min, 2.5kN, Taper cyl. threaded tool)

The principal advantages of FSW, being a solid-state process they have low distortion, absence of melt-related defects and high joint strength, even in those alloys that are considered non weld able by conventional techniques. Furthermore, friction stir welded joints are characterized by the absence of filler-induced problems/defects, since the technique requires no filler, and by the low hydrogen contents in the joints, an important consideration in welding steels and other alloys susceptible to hydrogen damage[4-6].

FSW can be used to produce butt, corner, lap, T, spot, fillet and hem joints, as well as to weld hollow objects, such as tanks and tubes / pipes, stock with different thicknesses, tapered sections and parts with three dimensional contours. Fig.2 (a) gives the idea of advancing and retreating sides in the traverse direction of welding. The advancing side (AS) is the side where the velocity vectors of tool rotation and traverse direction are similar and the side where the velocity vectors are opposite is referred as retreating side. Fig.2 (b) shows the tool with threaded cylindrical nib or probe pin.

The FSW process takes place in solid state and a permanent bond is obtained as a result of the stirring of plasticized and deformed material along the lines of contact between the pressure-welded elements. The plasticization and deformation of the material are effected during the translation of the rotating mandrel and rim of its back-up along the line of the joint.

2. Experimental procedure

The base materials used in this study are AA 7075 and AA2024 aluminium alloy[7-10] with thickness of 5 mm whose chemical composition is listed in the Table 1. Samples were butt welded using FSW machine along the rolling direction. A FSW tool made of M2 material, with cylindrical taper profile having pin diameter 6 mm and 10° taper, pin length 5.72 mm, and shoulder diameter of 20 mm was chosen for welding. The mechanical properties of the AA 2024 and AA7075 are shown in Table 2.

Table 1: Chemical Composition of base aluminium alloys

Material	Si	Fe	Cu	Mn	Mg	Zn	Cr	Al
AA2024	0.103	0.136	4.416	0.535	1.646	0.011	0.1	Remaining
AA7075	0.062	0.186	1.445	0.019	2.55	5.602	0.195	Remaining

The welding parameter like rotational and transverse speed, plunge depth, tool tilt, initial heating time and tool down speed are important input during the welding process. Rotational speed and transverse speed used are 300rpm and 60 mm/min. The plunge depth used during the welding process is 5mm and the tool tilt used is 2º towards the advancing side of weld. Initial heating time and tool down feed are 8 sec and 10 mm/min respectively. The FSW tools are shown in Fig. 2. In FSW the nugget zone is located in the middle and at each side three different zones can be detected. As shown in Fig.3, these regions are known as the HAZ, the thermo mechanical affected zone (TMAZ) and the base metal[11]. In the FSW process, parameter selection and tool geometry are among the key factors that determine the quality of the fabricated joint. The value of the different parameters such as welding speed, rotational speed, tilt angle and pin geometry could lower the force exerted from the TMAZ section to the tool which improves the quality of the weld and less thermal energy is needed for the process prompting both sheets to reach the plastic state. The plastic flow is responsible for obtaining the weld with high tensile strength and fewer defects and therefore the tool geometry plays a role in achieving a quality weld.

3. Methodology

3.1 Taguchi’s Technique

Taguchi's technique is a powerful tool in quality optimization. Taguchi's technique makes use of a special design of orthogonal array (OA) to examine the quality characteristics through a minimal number of experiments[12-13].Taguchi proposed the experimental design, which involves orthogonal arrays to organize the parameters affecting the process and the levels that should be varied. The orthogonal array allows for significant reduction in the number of experimental runs to find the optimal solution. The experimental results based on the orthogonal array are then transformed into S/N ratios to evaluate the performance characteristics. Taguchi's Design of Experiments is used to design the orthogonal array for four parameters varied through four levels. The control parameters and their levels chosen are shown in Table.3 and different combinations made for the analysis is shown in table.4.

Table.2: Mechanical properties of the base metal

Material	AA2024-T6	AA7075-T6
Yield stress (MPa)	327	498
Ultimate stress (MPa)	461	593
% of Elongation	29.5	17.7
Hardness (Vickers)	154	160

Table.3: Control Parameters and their levels in FSW

Parameter/Level	Level 1	Level 2	Level 3	Level 4
Rotational speed	600	800	1000	1200
Axial Force	1.5	1.5	2.0	2.5
Weld speed	62.5	70	70.5	80

Table.4: Combinations of Control Parameters in FSW

Trial No	Rotational Speed	Axial Force	Weld Speed
1	600	1.5	60
2	600	2	65
3	600	2.5	70
4	600	3	75
5	800	1.5	65
6	800	2	60
7	800	2.5	75
8	800	3	70
9	1000	1.5	70
10	1000	2	75
11	1000	2.5	60
12	1000	3	65
13	1200	1.5	75
14	1200	2	70
15	1200	2.5	65
16	1200	3	60

For analysis, there are three categories of performance characteristics, (i.e.)

Smaller-is-better (Minimize): $\frac{S}{N} = -10\log(\frac{1}{n}\sum_{i=1}^{n} y_i^2)$ (1)

Larger-is-better (Maximize): $\frac{S}{N} = -10\log(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2})$

(2)

Nominal-is-best: $\frac{S}{N} = 10\log(\frac{\bar{y}}{s_y^2})$

(3)

where $\overline{y}_i$ represents the experimentally observed value of i^{th} experiment and n is the no of replications of each experiment.

3.2 Analysis a/Variance (ANOVA)

An important technique for analyzing the effect of categorical factors on a response is to perform an Analysis of Variance[14]. An ANOVA decomposes the variability in the response variable amongst the different factors. In order to determine the effect of each geometrical parameter, Analysis of Variance (ANOVA) is performed.

4. Results and Discussion

The tensile strength is measured for two different tools (Taper threaded and straight threaded) with 16 numbers of trials as shown in table.5.

Table.5: Measured Experimental values

Trial No	Tensile Strength (MPa)	
	Taper Thread	Straight Thread
1	116	110
2	112	116
3	126	122
4	120	123
5	121	126
6	130	132
7	125	120
8	100	124
9	111	105
10	100	110
11	115	112
12	117	120
13	120	119

14	122	125
15	130	129
16	135	136

4.1 Analysis of Tensile strength for Taper threaded

The tensile strength of the welded component has to be maximum for a given set of input parameters. Hence, the larger-is-the-better condition is chosen as given in Eqn.(2). Table.6 shows the S/N ratio for tensile strength values measured on the work piece surface which is welded using taper threaded tool.

Table.6: S/N Ratio for Tensile Strength combination of Taper Threaded

S. No	Experimental TT	S/N Ratio
1	122	41.7272
2	129	42.2118
3	132	42.4115
4	142	43.0458
5	121	41.6557
6	130	42.2789
7	129	42.2118
8	120	41.5836
9	111	40.9065
10	113	41.0616
11	115	41.2140
12	127	42.0761
13	124	41.8684
14	122	41.7272
15	130	42.2789
16	133	42.4770

Figure 4 shows the main effects plot for taper threaded tool, the optimum conditions being rotational speed of 600 rpm, axial force of 3 KN and weld speed of 65 mm/min. The best levels of various parameters are identified by calculating the average values of S/N ratio, corresponding to every level of parameters of tensile strength, which are consolidated in Table 7 and Table 8 the ANOVA table.

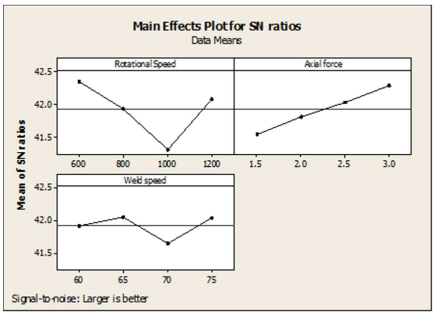

Figure. 4: Main effects plot of S/N ratio for Tensile strength for taper threaded tool

Table. 7: Response for Signal to Noise Ratios (Larger is better)

Level	Rotational speed	Axial force	Weld Speed
1	42.35	41.54	41.92
2	41.93	41.82	42.06
3	41.31	42.03	41.66
4	42.09	42.30	42.05
Max - Min	1.03	0.76	0.40
Rank	1	2	3

S=0.3724 R-sq = 82.6% R-sq(adj) = 56.6%

Table.8: ANOVA table for Tensile strength

Source	DF	SEQ SS	ADJ MS	F	P
Rotational speed	3	2.3162	0.7721	5.57	0.036
Axial force	3	1.2313	0.4104	2.96	0.120
Weld Speed	3	0.4143	0.1381	1.00	0.456
Residual Error	6	0.8323	0.1387		
Total	15	4.7941			

4.2 Analysis of Tensile strength for Straight Threaded

The tensile strength of the welded component has to be a maximum for a given set of input parameters. Hence, the larger-is-the-better condition is chosen as given in Eqn.(2). Table.9 shows the S/N ratio for tensile strength values measured on the work piece surface which is welded using straight threaded tool.

Table.9: S/N ratio of Tensile strength values for straight thread

S. No	Experimental ST	S/N Ratio
1	110	40.8279
2	116	41.2892
3	122	41.7272
4	123	41.7981
5	126	42.0074
6	132	42.4115
7	120	41.5836
8	124	41.8684
9	105	40.4238
10	110	40.8279
11	112	40.9844
12	120	41.5836
13	119	41.5109
14	125	41.9382
15	129	42.2118
16	136	42.6708

Figure 5 shows the main effects plot for straight threaded tool, the optimum conditions being rotational speed of 1200 rpm, axial force of 3 KN and weld speed of 65 mm/min. The best levels of various parameters are identified by calculating the average values of S/N ratio, corresponding to every level of parameters of tensile strength, which are consolidated in Table 10 and Table 11 the ANOVA table.

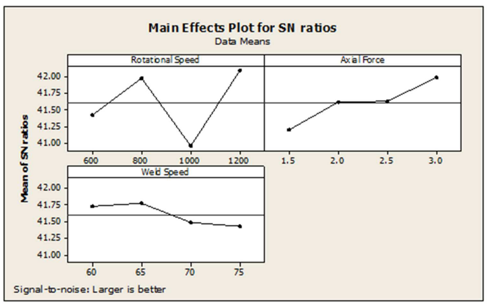

Figure. 5: Main effects plot for Tensile strength for straight thread

Table. 10: Response Table for Signal to Noise Ratios (Larger is better)

Level	Rotational speed	Axial force	Weld Speed
1	41.41	41.19	41.72
2	41.97	41.62	41.77
3	40.95	41.63	41.49
4	42.08	41.98	41.43
Max - Min	1.13	0.79	0.34
Rank	1	2	3

S=0.3592 R-sq = 86.3% R-sq(adj) = 65.7%

Table.11: ANOVA table for Tensile strength of straight threaded

Source	DF	SEQ SS	ADJ MS	F	P
Rotational speed	3	3.2816	1.0939	8.48	0.014
Axial force	3	1.2463	0.4154	3.22	0.104
Weld Speed	3	0.3449	0.1150	0.89	0.498
Residual Error	6	0.7741	0.1290		
Total	15	5.6469			

From ANOVA table, it is observed that for taper threaded friction stir welded components; the most influencing parameter is the rotational speed contributing by 48.31% followed by axial force by 25.68% and weld speed by 8.64%. For straight thread weld components, rotational speed contributes by 58.11% followed by axial force by 22.07% and weld speed by 6.10%. From the results obtained, it is observed that the rotational speed is the most significant parameter for both taper threaded and straight threaded weld component.

5. Conclusion

Analysis of friction stir weld components are carried out using Taguchi's technique for taper threaded and straight threaded tool for joining two dissimilar materials. The results obtained is, for taper threaded, the optimum condition is rotational speed of 600 rpm, axial force of 3 KN and weld speed of 65 mm/min and for straight thread, the optimum conditions being rotational speed of 1200 rpm, axial force of 3 KN and weld speed of 65 mm/min. The most influencing parameter for both taper threaded and straight threaded weld components is rotational speed followed by axial force and weld speed. Hence, by controlling the rotational speed, we can obtain a very good friction stir weld components of higher tensile strength.

References

1. Terry Khalid., 2005, An outsider looks at friction stir welding, *Report #ANM-112N*-05.
2. P. L. Threadgill., 2007, Terminology in friction stir welding, *Science and Technology of Welding and Joining*, Vol 12 , No 4357, 360.
3. R.Nandan, T. DebRoy, H.K.D.H. Bhadeshia., 2008, Recent advances in friction-stir welding – Process, weldment structure and properties, *Progress in Materials Science*, 53, 980–1023.

Vol.1 Issue.6, October 2013. Pgs: 13-22

4. R.S. Mishra, Z.Y. Ma., 2005, Friction stir welding and processing, *Materials Science and Engineering*, R 50, 1–78.
5. Y.D.Sato & H.Kokawa., 2003, Friction stir welding (FSW) process, *Welding International*, 17 (11), 852-853.
6. M.Kumagai., 2003, Recent technological developments in welding of Aluminium and its alloys, *Welding International*, 17 (3), 173-181.
7. M.Enomoto., 2003, Friction stir welding:Research and industrial applications, *Welding International*, 17 (5), 341-345.
8. M. Kimura, M. Kusaka, K. Seo and A. Fuji., 2005, Joining phenomena during friction stage of A7075-T6 aluminium alloy friction weld, *Science and Technology of Welding and Joining*, Vol 10, No 3, 378.
9. M.A.Sutton, B.Yang, A.P.Reynolds, R.Taylor., 2002, Micro structural studies of friction stir welds in 2024-T3 aluminium, *Materials Science and Engineering*, A 323 , 160–166.
10. Y.J.Chao, Y.Wang,K.W.Miller., 2001, Effect of friction stir welding on dynamic properties of AA2024-T3 and AA7075-T7351,*Welding research supplement* ,196-200.
11. W.N. dos Santos, P. Mummery, A. Wallwork., 2005, Thermal diffusivity of polymers by the laser flash technique, *Polymer Testing*, 24, 628-634.