APPLICATION OF TAGUCHI OPTIMIZATION TECHNIQUE ON DISSIMILAR AA6061-AA7075 FRICTION STIR WELDING

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Abstract. In this study, the Taguchi method was utilized to determine the optimum process parameters for dissimilar friction stir welding between AA6061 and AA7075 aluminium alloys. The Taguchi L9 orthogonal array and optimization approach was applied on three levels of three critical factors, namely rotational speed, transverse speed and tool tilt angle. The optimum levels of process parameters were determined through the Taguchi parametric design approach. Through the parameter analysis, the predicted value of the dissimilar joint's tensile strength was calculated to be 209.7 MPa, which is in close proximity to the experimental data (219.6 MPa) with 4.5% error. It can be concluded that a high tensile value of 219.6 MPa was achieved using 1000 rpm rotational speed, 110 mm/min travel speed and 3˚ tilt angle.

Introduction

Friction stir welding (FSW) is a solid state joining process whereby heat is generated through the friction between a rotating tool and the joint line of two plates to be welded, subsequently joining both plates together through the process. Since its invention in The Welding Institute, United Kingdom in 1991, FSW has become an increasingly important process in a wide area of research fields such as in ship building, aviation and automotive industry [1][2].

FSW has shown to be a promising technique since the welding is done under solid-state process, thus avoiding drawbacks from common fusion welding [3]. Defects such as spatter, hot cracking and distortion can be practically eliminated completely, and other defects such as voids, lack of penetration and surface breaking can be minimized by optimizing the process parameters.

Although approximately 99% of the present research on FSW focuses on similar aluminium sheets, a growing number of research have been conducted on dissimilar FSW, particularly between aluminium of different grades [4][5].

In order to bring forth a robust experimental design, a more systematic approach on parameter optimization is therefore crucial. Taguchi method is a powerful and preferable design of experiments tool to solve many engineering problems with significant reduction in time and cost [6][7]. Through statistical analysis, this method can determine the most influential parameters and predict the best parameters to yield the optimum quality.

However, presently only a handful of research studies are taking advantage of this engineering solution. Lakshminarayanan et al. and Yashar Javadi et al. have successfully applied Taguchi method on similar FSW of RDE-40 aluminium alloy and 5086 aluminium plates, respectively, with great success [8][9]. A recent paper have also reported the utilization of this technique on AA2219-AA5083 dissimilar FSW by Koilraj et al. [10].

In this study, the Taguchi method will be applied on dissimilar FSW of AA6061-AA7075 to predict the optimum parameters and subsequently produce a weld joint with the highest tensile strength value.

Materials and experimental methods

The base materials used in this experiment are AA6061 and AA7075 aluminium alloys. Both materials were cut into 2 × 50 × 100 mm dimensions. The chemical compositions of both materials are shown in Table 1.

Table 1. Chemical composition of base metal AA6061 and AA7075 (wt.%)

Composition	Mg	Si	Mn	Fe	Cu	Cr	Zn	Ti	Al
AA6061	0.84	0.54	0.01	0.40	0.24	0.18	0.006	0.031	97.7
AA7075	2.28	0.071	0.019	0.274	1.6	0.212	5.58	0.026	89.8

An H13 tool with pin length 1.7 mm as well as pin and shoulder diameter of 6 mm and 18 mm, respectively, was fabricated for the welding process. The rig used in this experiment is a mild steel backing plate. The backing plate functions as a support for the base metal during the friction stir welding process.

The welding process was performed by using a Milltronics VMM-3917 vertical milling machine. In order to promote better material mixing, the AA6061 plate and the AA7075 plate was placed on the advancing side and retreating side, respectively [3].

Table 2 shows the three levels of rotational speed, transverse speed and forward tilt angle that were set for the parametric design. The rotational speed and transverse speed's range was decided through its revolutionary pitch (rev/mm) by dividing rotational speed (rpm) over transverse speed (mm/min). Mishra and Ma [11] and Cavaliere et al. [12] have proposed that the revolutionary pitch should be in the proximity of 0.1 to produce optimum FSW condition.

The welded joints were cut into the dog bone shape using a cutting machine by following the American Society for Testing of Materials (ASTM E8-09) guidelines. For each of the experimental level, two tensile specimens were prepared.

Table 2. Three levels of rotational speed, transverse speed and tilt angle.

Factors	Level 1	Level 2	Level 3
Rotational speed (rpm)	900	1000	1100
Transverse speed (mm/min)	90	100	110
Tilt angle	3˚	4˚	5˚

Results and discussion

Fig. 1 shows the welded product. All the specimens weld quality is sound with minimal defects. The results from the tensile tests show that all the joints failed at the AA6061 side, i.e. the weaker side.

Using the Taguchi method, the mean effect and Signal-to-Noise ratio (S/N) of each variations were calculated to analyse the influence of factors on the output (response). The tensile strength value was chosen to be the assessment basis of the joint quality. Since a higher tensile strength indicates better weld joint quality, the larger-the-better criterion was chosen. The larger-the-better S/N ratio can be calculated using Eq.1 below,

$$S/N = \eta_{dB} = 10log\left[\frac{1}{\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}}\right] = -10Log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right). \quad (1)$$

where the η represents the number of test and y_i is the experimental value [7].

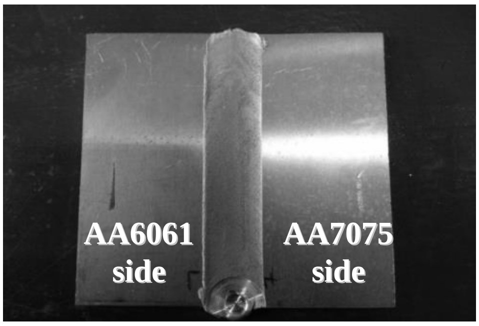

Fig. 1. The welded FSW product.

In this study, the L9 orthogonal array (OA) was selected. Thus, 9 means and 9 S/N ratios can be calculated in order to analyse the tensile strength for each level. The mean response can be referred to the average value of the tensile strength for each parameter at different levels.

The mean effect and S/N ratio for tensile strength was calculated by using a commercially available statistical software. As can be observed in Fig. 2, results from the software show that the tensile strength was at maximum when the rotational speed is at level 2, 1000 rpm (Fig. 2(a)); transverse speed at level 3, 110 mm/min (Fig. 2(b)); and tilt angle at level 1, 3° (Fig. 2(c)).

The analysis above has shown the best parameter in order to achieve a good tensile strength of FSW. The optimum value of tensile strength can be calculated based on these parameters. The optimum value of tensile strength can be computed as

$$RS_2 + TS_3 + TA_1 - 2T = \text{Tensile Strength (MPa)}. \quad (2)$$

where the RS_2 is the average tensile value at second level of rotational speed, 1000 rpm; TS_3 is the average tensile value at third level of transverse speed, 110 mm/min; and TA_1 is the average tensile value at first level of tilt angle, 3°. T indicates the overall mean of tensile strength in MPa.

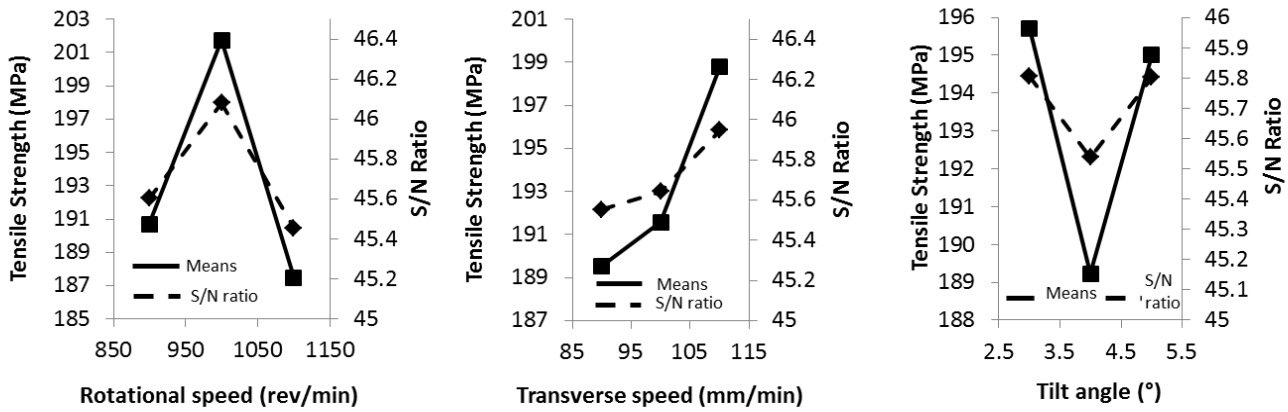

Fig. 2. Comparison of mean effect and S/N ratio of tensile strength.

Substituting the calculated values from Table 2 in Eq. 2 yields

$$\text{Highest tensile strength} = 201.640 + 198.935 + 195.700 - 2(193.27) = 209.735 \text{ MPa}.$$

Since the combination of factors level above has already been conducted (sample number 6), referring to Table 3, the experimental tensile strength mean value obtained was 219.585 MPa which is the highest tensile value. This tensile value is within acceptable range from the predicted value above with 4.5% error.

Table 3. Raw data and S/N ratio for L9 orthogonal array

No.	Input parameter			Response		Mean value	S/N ratio
	Rotation	*Transverse*	*Angle*	T1	T2		
1	900	90	3	187.69	182.02	184.855	45.338
2	900	100	4	193.84	195.80	194.820	45.793
3	900	110	5	193.52	191.24	192.380	45.683
4	1000	90	4	188.40	N/A	188.400	45.502
5	1000	100	5	195.14	199.39	197.265	45.902
6	1000	110	3	208.94	230.23	219.585	46.842
7	1100	90	5	193.71	196.99	195.350	45.817
8	1100	100	3	N/A	182.66	182.660	45.233
9	1100	110	4	182.59	186.37	184.480	45.319

Conclusion

Dissimilar butt joint friction stir welding between aluminium AA6061 and AA7075 alloy was conducted to perform parameter optimization analysis using the Taguchi method. All the joints fractured at the weaker AA6061 side. The highest tensile value from the experiment was measured to be 219.585 MPa using 1000 rpm rotational speed, 110 mm/min travel speed and 3˚ tilt angle. This is in accordance with the predicted value of 209.735 MPa with 4.5% error.

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References

[1] T. Sakiyama, G. Murayama, Y. Naito, K. Saita, Y. Miyazaki, H. Oikawa, T. Nose, Dissimilar Metal Joining Technologies for Steel Sheet and Aluminum Alloy Sheet in Auto Body, Nippon Steel Technical Report (2013) 91-98

[2] W. M. U. Thomas, E. D. Nicholas, Friction stir welding for the transportation industries, Mater. Design 18 (1998) 269-273.

[3] J. F. Guo, H. C. Chen, C. N. Sun, G. Bi, Z. Sun, J. Wei, Friction stir welding of dissimilar materials between AA6061 and AA7075 Al alloys effects of process parameters, Mater. Design 56 (2014) 185–192.

[4] P. Cavaliere, Friction Stir Welding of Al Alloys: Analysis of Processing Parameters Affecting Mechanical Behavior, Procedia CIRP 11 (2013) 139–144.

[5] B. T. Gibson, D. H. Lammlein, T. J. Prater, W. R. Longhurst, C. D. Cox, M. C. Ballun, K. J. Dharmaraj, G. E. Cook, A. M. Strauss, Friction stir welding: Process, automation, and control, J. Manuf. Process. (2013) 1–18.

[6] D. C. Montgomery, Design and analysis of experiments, forth ed., John Wiley & Sons Inc, New York, 2006.

[7] P. J. Ross, Taguchi techniques for quality engineering, second ed., McGraw Hill Professional, New York, 1996.

[8] A.K. Lakshminarayanan, V. Balasubramanian, Process parameters optimization for friction stir welding of RDE-40 aluminium alloy using Taguchi technique, T. Nonferr. Metal Soc. 18 (2007) 548-554.

[9] Yashar Javadi, Seyedali Sadeghi, Mehdi Ahmadi Najafabadi, Taguchi optimization and ultrasonic measurement of residual stresses in the friction stir welding, Mater. Design 55 (2014) 27-34.

[10] M. Koilraj, V. Sundareswaran, S. Vijayan, S.R. Koteswara Rao, Friction stir welding of dissimilar aluminium alloys AA2219 to AA5083 – Optimization of process parameters using Taguchi technique, Mater. Design 42 (2012) 1-7.
[11] R. S. Mishra, Z. Y. Ma, Friction stir welding and processing, Mater. Sci. Eng. R. 50 (2005) 1-78.
[12] P. Cavaliere, A. Squillace, F. Panella, Effect of welding parameters on mechanical and microstructural properties of AA6082 joints produced by friction stir welding, J. Mater. Process. Technol. 200 (2008) 364–372.