Nanotechnology Perceptions
ISSN 1660-6795
www.nano-ntp.com

An Analysis to Optimize the Process Parameters of Friction Stir Welded Aluminum Alloy (AA6101) Plates

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Friction stir welding (FSW) is a new and promising welding process that can produce low-cost and high-quality joints of aluminium alloys because it does not need consumable filler materials, and it can also eliminate some welding defects such as cracks and porosity. To demonstrate the friction stir weldability of the AA6101 aluminium alloy and determine optimum welding parameters, the relations between welding parameters and tensile properties of the joints have been studied in this paper. FSW trials were carried out using a vertical milling machine in which tool geometry was chosen and fabricated to have a nearly flat welded interface. Process parameters that we have considered are rotation speed (rpm) and traverse speed (mm/min). These parameters are analysed, and optimised results are obtained using the Taguchi method. It is observed that the rotational speed has a 23% contribution, and welding speed has a 16% contribution to the Tensile strength of welded joints.

Keywords: Friction stir welding, AA6101alloy, microstructure, mechanical properties, Taguchi Method, ANOVA.

1. Introduction

Friction Stir Welding was invented by Wayne Thomas at TWI Cambridge [1]. It is a solid-state process, which means the objects are joined without reaching melting point. In FSW, a cylindrical shouldered tool with a profiled pin is rotated and plunged into the joint area between two pieces of sheet or plate material. The parts have to be clamped to prevent the joint faces from being forced apart. Frictional heat between the wear resistant welding tool and the work pieces causes the latter to soften without reaching melting point, allowing the tool to traverse along the weld line. The plasticized material, transferred to the trailing edge of the tool pin, is forged through intimate contact with the tool shoulder and pin profile. On cooling, a solid phase bond is created between the work pieces. Friction Stir Welding can be used to join aluminum sheets and plates without filler wire. Material thicknesses ranging from 0.5 to 65 mm can be welded from one side at full penetration, without porosity or internal voids.

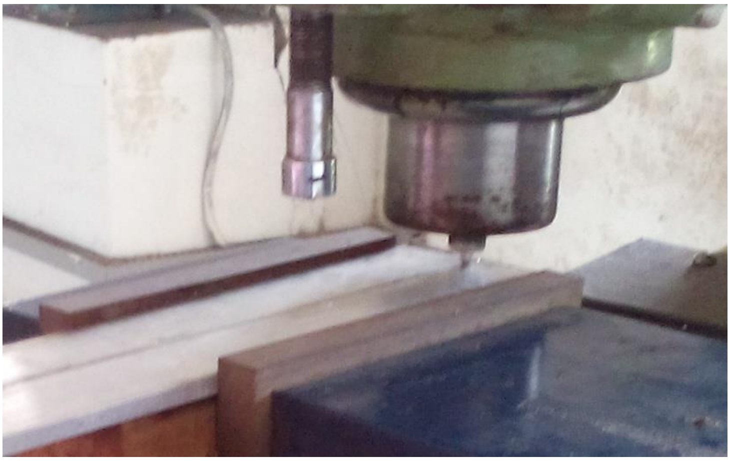


Fig.1. Friction stir welding

Friction stir weld has high fatigue strength and tensile strength. There is no fume, no porosity, no spatter and low

Shrinkage of the metal.

The friction stir welding technique has many advantages, such as high quality, low cost, low energy consumption, and environment friendliness, and there is no necessity for gas shielding for welding aluminium. Mechanical properties, as proven by fatigue and tensile tests, are excellent. There is no fume, porosity, spatter and low shrinkage of the metal. In particular, FSW is currently under extensive investigation for joining aluminium alloys in the aerospace industry.[2] Friction stir welding was considered the most significant development for metal joining in the past two decades.[3] Although it was a solid-state welding method, the FSW could still suffer from significant levels of residual stress and associated distortion, which could be similar in magnitude to that found in fusion welds.[4] Distortion can be a significant problem during fabrication, and expensive post-weld repair procedures are sometimes necessary to overcome it.[5] In order to reduce these defects, a liquid CO_2 cooling technique was applied during FSW process.[6] The cooling introduced a thermal tensioning effect on the cooling weld metal counteracting the forces which led to residual stresses and distortion.[7] However, with regard to local cooling, the cooling substances might contaminate the weld metal.[8] Thermal stress engineering techniques, global preheating and local thermal tensioning, were proposed.[9]

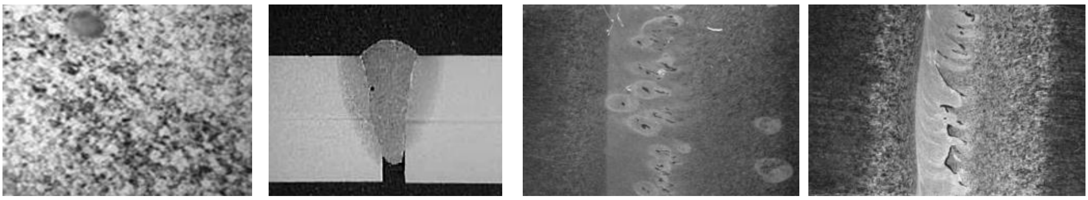
Experimental Work

A large number of trial were conducted on flat of 6 mm thickness AA 6101 aluminum alloy plate to find out feasible working limit of FSW process parameters. The parameters that are selected for study are tool rotational speed and transverse speeds. Chemical composition of AA 6101 alloy is given in table 1.

Table.1 chemical composition of AA 6101 alloy

Elements	Mn	Si	Zi	Cu	Cr	Al
Percentage	0.600	0.500	0.021	0.074	0.015	Balance

The working range of each parameter was decided by inspecting the macrostructure of AA6101 alloy and the capacity of the vertical milling machine. The following observations are made from the inspection: (1) when tool rotation speed was lower than 700 rpm, tunnel defect was observed (fig. 2a) due to insufficient heat generation and insufficient metal transportation. When tool rotation speed is higher than 1400 rpm, piping defect was observed (fig. 2b) due to excess turbulence caused by high tool rotation speed. (2) When tool transverse speed was lower than 14mm/min, tunnel defect was observed (fig. 2c) due to excess heat input per unit length. When tool transverse speed is higher than 30 mm/min, tunnel defect was observed (fig. 2d) due to inadequate flow of material caused by insufficient heat input. In this experiment, we applied the Taguchi method to optimise process parameters, as per the array selector and orthogonal table designed by Ross for two parameters and three levels (table 2). We have to conduct nine experiments, and three tensile tests are to be conducted for each experiment.



(2a) 700 rpm (2b) 1300 rpm (2c) 14 mm/min (2d) 30 mm/min

Fig.2 macrostructure of FSW joints

The plate of 6 mm thickness and 105 mm wide AA6101 aluminum alloy were cut into size 60 mm and these pieces are filed properly to have fine surface. The friction stir welding was obtained by securing two plates in butt position with the help of fabricated fixture of a milling machine. The direction of welding was normal to the rolling direction. Welding was carried out in a single pass using non-consumable tools made of HSS M2 having hardness 61 to 63 HRC, tool is having conical pin and flat shoulder. The three tensile specimens were prepared as per ASTM E8M-04 (fig. 3) from a single welded plate for an individual experiment. Parameter for each experiment and load obtained by performing tensile test on UTM are given in table. 3.

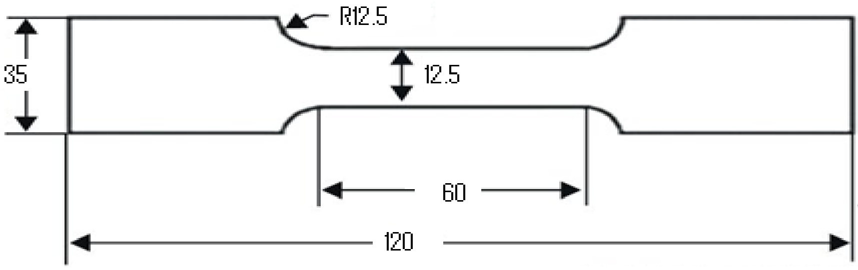


Fig. 3 dimension of flat tensile specimen

Table 2: Welding Parameters and Tool Dimensions

Level	Rotational speed (N in rpm)	Transverse speed (S in mm/min)
1	800	16
2	1000	20
3	1250	25

Table 3 Experimental values of tensile strength (Mean) and S/N ratio

Exp.	Input		Load in KN			Tensile Strength in MPa			Mean	S/N ratio
	N	S	Trail 1	Trail 2	Trail 3	Trail 1	Trail 2	Trail 3		
1	800	16	32.4	34.6	31.8	154.29	164.76	151.43	156.83	43.89
2	800	20	40.8	42.2	43.4	194.29	200.95	206.67	200.54	46.04
3	800	25	34.2	32.8	30.2	162.86	156.19	143.81	154.29	43.73
4	1000	16	42.6	36.2	44.6	202.86	172.38	212.38	195.87	45.73
5	1000	20	44.2	41.4	41.8	210.48	197.14	199.05	202.22	46.11
6	1000	25	38.6	40.0	42.6	183.81	190.48	202.86	192.38	45.66
7	1250	16	36.4	34.6	37.8	173.33	164.76	180.00	172.70	44.73
8	1250	20	46.4	43.4	42.8	220.95	206.67	203.81	210.48	46.45
9	1250	25	42.8	46.8	47.4	203.81	222.86	225.71	217.46	46.72

The tensile strength is calculated by dividing individual load with cross-sectional area of specimen (35mm X 6mm) which is kept fixed given in Table 3.

Analysis of variance (ANOVA)

In order to assess influence of factors on response means and signal to noise ratio (S/N) for each control factor are to be calculated. Signals are indicators of effect on average response and noises are measures of deviation from experimental output. In this study S/N ratio is considered for criteria larger the better for maximum response. It is given by expression as follows, where n is total no of trial, Z_i is tensile strength of specimen in MPa.

S/N ratio = $-10 \text{ Log } \{1/n \, \Sigma \, (1/z_i^2)\}$

Analyzing mean and S/N Ratio of various process parameters (table 4); it is observed that a larger S/N Ratio corresponds to better quality. Therefore, optimum level of process parameter is the level of highest S/N Ratio. S/N Ratio (fig. 4) and Mean effect (fig. 5) for tensile strength calculated by software indicates that strength is maximum when N is 1250 rpm. (Level 3) and S is 20 mm/min (level 2).

Table 4. Main effect of tensile strength (means and S/N ratios)

Source	Mean			S/N Ratio		
	Level-1	Level-2	Level-3	Level-1	Level-2	Level-3
N	170.55	196.82	200.21	44.55	45.83	45.97
S	175.13	204.41	188.04	44.78	46.20	45.37

Table. 5 ANOVA for tensile strength (means and S/N ratios)

Source	DOF	SS		SS*		P %	
		S/N Ratio	Mean	S/N Ratio	Mean	S/N Ratio	Mean
N	2	3.67	1581.32	2.32	946.48	24.60	22.85
S	2	3.05	1291.96	1.70	957.12	18.03	15.86
Error	4	2.71	1269.68	5.41	2539.36	57.38	61.29
Total	8	9.43	4142.96	9.43	4142.96	100	100

DOF= Degree of freedom, SS= Sum of square, SS*=Pure sum of square, P% = Percentage contribution

With the help of analysis of variance (ANOVA), Percentage contribution of various process parameters in terms of S/N Ratio and mean are given in table.5. Graphical representation of mean percentage contribution of various parameters is shown in fig. 6.

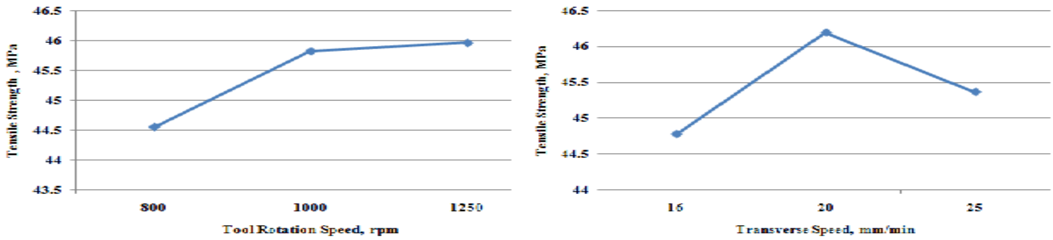


Fig 4.Response graph (S/N ratio) of tensile strength

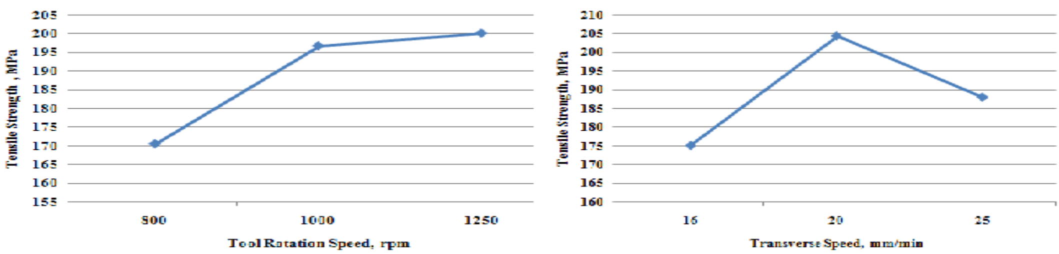


Fig 5.Response graph (mean) of tensile strength

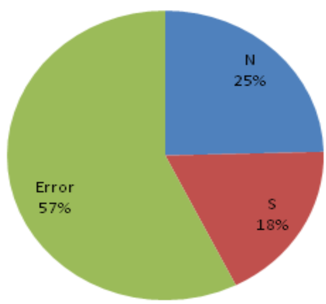


Fig 6. Percentage contribution of factors (mean) and their interactions

Calculation

1. DOF (Degree of freedom) = (n-1)

- $DOF_{(participant\ N)} = (3-1) = 2$
- $DOF_{(participant\ S)} = (3-1) = 2$
- $DOF_{(total)} = (9-1) = 8$
- $DOF_{(Error)} = DOF_{(total)} - DOF_{(participant\ N)} - DOF_{(participant\ S)} = (8-2-2) = 4$

2. SS (Sum of square) = $n_1(x_1-X)^2 + n_2(x_2-X)^2 + n_3(x_3-X)^2$

Where $X = (x_1 + x_2 + x_3) / 3$ and x_1, x_2 and x_3 are mean of parameter as per level.

(a) SS (for mean)

- $X_{(participant\ N)} = (170.55 + 196.82 + 200.21)/3 = 189.19$
- $X_{(participant\ S)} = (175.55 + 204.41 + 188.04) / 3 = 189.19$
- $SS_{(participant\ N)} = 3(170.55 - 189.19)^2 + 3(196.82 – 189.19)^2 + 3(200.21 – 189.19)^2 = 1581.32$
- $SS_{(participant\ S)} = 3(175.13 - 189.19)^2 + 3(204.41 – 189.19)^2 + 3(188.04 – 189.19)^2 = 1291.96$
- $SS_{(Total)} = \sum^{9}_{n=1}(mean)^2 – T^2/n$

Where T is total value of individual item in sample and n is trial number.

- $SS_{(Total)} = (326301.37 – 1702.77^2/9) = 4142.96$
- $SS_{(Error)} = SS_{(Total)} - SS_{(participant\ N)} - SS_{(participant\ S)} = 4142.96 – 1581.32 – 1291.96 = 1269.68$

(b) SS (for S/N Ratio)

- $X_{(participant\ N)} = (44.55 + 45.83 + 45.97)/3 = 45.45$
- $X_{(participant\ S)} = (44.78 + 46.20 + 45.37)/3 = 45.45$
- $SS_{(participant\ N)} = 3(44.55 - 45.45)^2 + 3(45.83 – 45.45)^2 + 3(45.97 – 45.45)^2 = 3.67$
- $SS_{(participant\ S)} = 3(44.78 - 45.45)^2 + 3(46.20 – 45.45)^2 + 3 (45.37 – 45.45)^2 = 3.05$
- $SS_{(Total)} = (18601.66 – 409.06^2/9) = 9.43$
- $SS_{(Error)} = SS_{(Total)} - SS_{(participant\ N)} - SS_{(participant\ S)} = 9.43 – 3.67 – 3.05 = 2.71$

3. SS^* (Pure sum of square) = $SS – (SS_{(Error)} / DOF_{(Error)}) X DOF_{(Participant)}$

(a) SS^* for S/N Ratio

- $SS^*_{(participant\ N)} = 3.67 – (2.71/4) X2 = 2.32$
- $SS^*_{(participant\ S)} = 3.05 – (2.71/4) X2 = 1.70$

- $SS^*_{(Total)} = SS_{(Total)} = 9.43$
- $SS^*_{(Error)} = SS^*_{(Total)} - SS^*_{(participant\ N)} - SS^*_{(participant\ S)} = 9.43-2.32-1.70 = 5.41$

(b) SS^* for mean

- $SS^*_{(participant\ N)} = 1581.32 – (1269.68/4)\ X2 = 946.48$
- $SS^*_{(participant\ S)} = 1291.96 – (1269.68/4)\ X2 = 657.12$
- $SS^*_{(Total)} = SS_{(Total)} = 4142.96$
- $SS^*_{(Error)} = SS^*_{(Total)} - SS^*_{(participant\ N)} - SS^*_{(participant\ S)} = 4142.6 – 946.48 – 657.12 = 2539.36$

4. P % (Percentage contribution) = (SS^* of participant / SS^* of total)

(a) P % for S/N Ratio

- $P\ \%_{(participant\ N)} = 2.32/9.43 = 24.60$
- $P\ \%_{(participant\ S)} = 1.70/9.43 = 18.03$
- $P\ \%_{(Error)} = 100 – 24.60 – 18.03 = 57.38$

(b) P % for mean

- $P\ \%_{(participant\ N)} = 946.48/4142.96 = 22.85$
- $P\ \%_{(participant\ S)} = 657.12/4142.96 = 15.86$
- $P\ \%_{(Error)} = 100 – 22.85 – 15.86 = 61.29$

2. Conclusion

As per experiment conducted on Aluminum alloy AA6101 plate rotational speed was the most dominant process parameters for weld strength followed by the welding speed. Percentage of contribution of FSW process parameters was evaluated and found that the rotational speed has 24.60% contribution and welding speed has 18.03% contribution to Tensile strength of welded joints.

The optimum process parameters for the weld strength are the rotational speed of 1250 rpm and welding speed of 20 mm/min. due to two parameter percentage of error rises to 57.38 %, which can be reduced by increasing number of parameters such as tool tilt angle, plate thickness, tool bit penetration etc.

References

1. W. M. Thomas, E. D. Nicholas, J. C. Needham, M. G. Murch, P. Templesmith and C. J. Dawes: ‘Improvements relating to friction welding’, International patent no. PCT/GB92/02203, WO/1993/010935,1992.
2. S. W. Williams: ‘Welding of airframes using friction stir’, Air SpaceEur., 2001, 3, 64–66.

3. R. S. Mishra and Z. Y. Ma: 'Friction stir welding and processing', Mater. Sci. Eng. R, 2005, R50, 1–78.
4. P. L. Threadgill, A. J. Leonard, H. R. Shercliff and P. J. Withers: 'Friction stir welding of aluminium alloys', Int. Mater. Rev., 2009, 54, 49–93.
5. J. Altenkirch, A. Steuwer, P. J. Withers, S. W. Williams, M. Poad and S. W. Wen: 'Residual stress engineering in friction stir welds by roller tensioning', Sci. Technol. Weld. Join. 2009, 14, 185–192.
6. P. Staron, M. Koc¸ak and S.Williams: 'Residual stress in friction stir-welded Al sheets', Appl. Phys. A, 2002, 74A, 1161–1162.
7. Q. Guan, C. X. Zhang and D. L. Guo: 'Dynamic control of welding distortion by moving spot heat sink', Weld. World, 1994, 33, 308–312.
8. D. Xu, X. S. Liu, P. Wang, J. G. Yang and H. Y. Fang: 'New technique to control welding buckling distortion and residual stress with noncontact electromagnetic impact', Sci. Technol. Weld. Join. 2009, 14, 753–759.
9. D. G. Richards, P. B. Prangnell, P. J. Withers, S. W. Williams, T.Nagy and S. A. Morgan: Efficacy of active cooling for controlling residual stresses in friction stir welds. Sci. Technol. Weld. Join. 2010, 15, 156–165.