Investigate The Effect Of Welding Parameters On Mechanical Properties During The Welding Of Al-6061 Alloy

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Abstract: Friction welding is a solid state welding technique which is being used in recent times to weld similar as well as dissimilar metals for getting defect free weld. Many combinations like low carbon to stainless steel, austenitic to ferrite stainless steel, aluminium to copper and titanium to aluminium or steel have been tried out by various solid state welding processes with quite good results. In the present work the 3 level full factorial design has been employed to investigate the effect of welding parameters on tensile strength, toughness and heat generation during the welding of Al-6061 alloy. Mathematical relationships between friction welding parameters and mechanical properties like heat generation, tensile strength and toughness have also been developed. An attempt has also been made to examine the fracture surfaces of test specimens using SEM. It has been found that welding speed is the most significant parameter that's affect the heat generation, tensile strength and toughness. it has been found that tensile strength and toughness during welding increases with increased in welding speed, while tensile strength and toughness initially increased as the welding time increases, after that it decreased with increase in welding time. The difference in weight of alloying elements can be clearly seen by analyzing spectrum of elements.

Keywords: Composition of Al 6061 alloy, Friction welding, tensile strength, toughness, Rotary Friction Welding.

1. Introduction

Friction welding is a type of solid-state welding. It produces heat for the welding of two materials due to mechanical friction between the moving work piece and fixes work piece. In actual, friction welding is not a welding process in which for the joining of material first material melts due to the application of heat then it solidifies for making the joints. Friction welding is used for joining the metals, thermoplastics, etc. for different engineering applications like automotive applications [16]. Friction welding is being used in recent times to weld similar as well as dissimilar metals so we can get defect free weld. Many combinations like Low carbon to Stainless steel, Austenitic to Ferrite Stainless Steel, Aluminium to Copper and Titanium to Aluminium or steel have been tried out by various solid state welding processes with quite good results. Now a day's Al 6061 alloys are widely used for different applications like structural & marine applications. These alloys have the advantage of being lighter in weight with good tensile strength [17]. For the joining of two materials using conventional friction welding, a relative rotational motion between is requires between the work pieces to generate the heat. After the sufficient heat generation between the interfaces of work pieces, the work pieces have been joined together by applying forging force [14].

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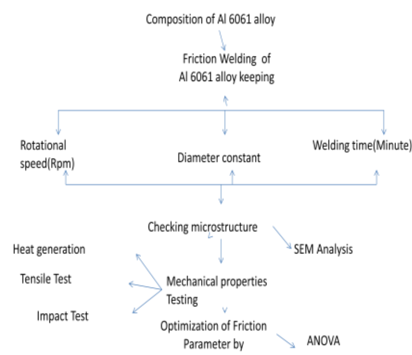
2. Methodology

The investigation is made to examine the effect of FW factors on heat generation, toughness & tensile strength of the weldments during the welding of Al 6061 alloy.



2. Objectives of present work

In this work, the 3 level factorial methodology is employed to investigate the effect of welding factors on responses during the welding of Al-6061 alloy. Thus objectives and the steps of the presents study are –

1) Determination of the working range for friction welding parameters (welding speed and welding time) using pilot experimentation.
2) Investigation of the effect of FW factors on heat generation, tensile strength and toughness of weldments during the welding of Al6061 alloy.
3) Development of mathematical relation between FW factors& responses (heat generation, tensile strength, and toughness).

3. Experimental details

3.1 Tiniusolsen materials testing machine

The tensile test of all specimen has been done at room temperature on specimens using Tinius Olsen materials testing machine with a cross head speed of 1mm/min The specimens have been prepared according to ASTM E8M-08 Standard with a length of 60 mm and thickness of 4 mm as indicated in fig.1.

***Fig 1**: Tiniusolsen materials testing machine*

3.2 Charpy V-notch impact test

The Charpy impact test for toughness has been carried out on Charpy V-notch impact test machine made by HMT as shown in figure 2 The all specimens for Charpy impact test have been prepared according to ASTM E23-07 Standard of dimension 10x10x55 mm as shown in fig. 2 and the test has been performed at room temperature

***Fig 2:** Charpy V-notch impact test machine*

4. Data analysis & Discussion

Required number of experiments depends on the selected methodology of D.O.E. In the present research work, 3 level full factorial design has been used to investigate the effect of two independent parameters for friction welding, i.e., RPM and welding time on tensile strength, toughness and heat generation. The welding factors & their levels are presented in table 1 the range of welding parameters has been decided using pilot experiments as represents in table 2 Table 3 shows the design matrix for experimentation

***Table 1** Factors and levels of independent variables according to factorial design*

Factors	symbol	units	Levels		
Welding speed	A	(RPM)	700	1000	1250
Welding time	B	(Minutes)	15	20	25

***Table 2** Pilot experiments for determination of range of factor*

Sample No.	Rotational Speed (rpm)	Friction Time (min.)	Remarks
1	750	10	Not welded
2	750	15	Welded
3	1000	10	Not welded
4	1000	15	Welded
5	1250	10	Not weld
6	1250	15	Weld

***Table 3** Complete design matrix for Experimentation*

S.No.	A:Welding speed (RPM)	B: Welding time (Minutes)
1	750	15
2	1000	15
3	1250	15
4	750	20
5	1000	20
6	1250	20
7	750	25
8	1000	25
9	1250	25

The selection of FS parameters and their levels, experimental details including testing of toughness, tensile strength and heat generation have been presented in the previous chapter. This chapter deals with the development of prediction models for heat generation, toughness and tensile strength. Also, describes the effect of welding parameters on responses
This analysis is based on two assumptions:
(1) Normally distribution;
(2) Homogeneity of variance.

Normal probability plot for residuals is shown in fig. 3 it is useful for checking the assumption of normal distribution. This plot shows that residuals for heat energy generation are normally distributed or not if residuals are normally distributed, then most of points will fall on straight line. The plot shows that mostly residuals following straight line, which indicates that residuals are, follow normal distribution

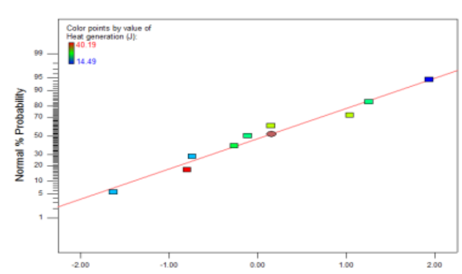


***Fig. 3** Normal probability graph for errors*

The fig.4 shows residuals v/s predicted graph for heat generation. This graph is useful for testing of the second assumption of ANOVA. The graph should not follow a notice able pattern. The figure represents that it shows unusual configuration. This shows that residuals follow constant variance assumption.

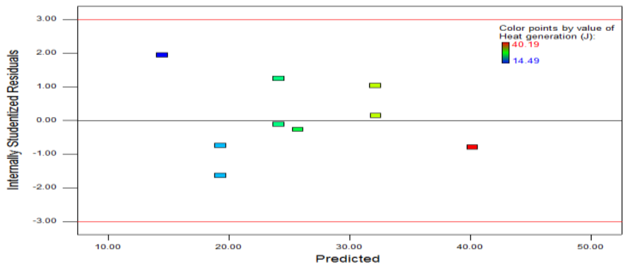


Fig. 4 *Plot of residuals v/s predicted response*

ANOVA analysis and development of heat generation prediction model

Table 4 shows ANOVA test for response surface model for heat generation. This investigation is done at confidence level of 95%.

Table 4 *ANOVA table for heat generation*

Source	Sum of Squares	Degree of freedom	Mean Square	F-Value	p-value Prob> F
Model	506.0898	3	168.697	8675825	< 0.0001
A-Welding speed	247.6838	1	247.684	12738021.43	< 0.0001
B-welding time	247.9408	1	247.941	12751242	< 0.0001
AB	10.4652	1	10.465	538211.5714	< 0.0001
Residual	0.0001	5	0.00002		
Cor Total	506.0899	8			
Std. Dev.	0.0044			R-Squared	1.00
Mean	25.7211			Adj R-Squared	1.00
C.V. %	0.0171			Pred R-Squared	1.00
PRESS	0.0005			Adeq Precision	8744.59

The table indicates that "Prob. > F" for model is 0.0001, which is < 0.05, i.e model is significant, that's necessary. In the same way, the "Prob. > F" for welding time, welding speed, and two-level interaction of welding speed are welding time are less than 0.05, so these terms are significant model terms. The R^2value is equal to one, that is required. The adjusted R^2value is also1. The adjusted R^2value is equal to ordinary R^2value. Adequate precision is 8744; a ratio > 4 is desired. Which shows the discrimination of the adequate model. The empirical relationship for heat generation in the form of actual parameters is represented as:

$$\text{Heatgeneration} = 0.19 - 0.00018 * \text{Welding speed} - 0.0084 * \text{welding time} + 0.0013 * \text{Welding speed} * \text{welding time}$$

Contribution of welding parameters on heat generation

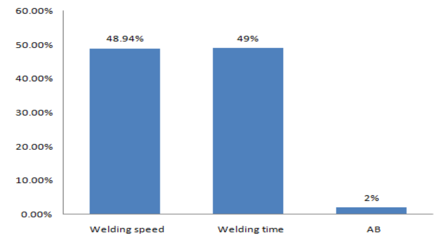


Fig: 5 *Percentage contributions of welding parameters on heat generation*

Figure 5 shows the percentage contribution of welding parameters on heat generation. From the figure, it is understandable that welding time has been found most significant factor that affects the heat generation during friction welding followed by welding speed and interaction effect of welding speed & welding time.

Effect of friction welding parameters on heat generation

Figure 6 shows the 3D plot for heat generation regarding welding time and welding speed. From the figure, it is clear that heat generation during welding increase with increase in welding speed, also with increase in welding time. The maximum heat generation is obtained at 1250 RPM welding speed and 25 minute welding time.

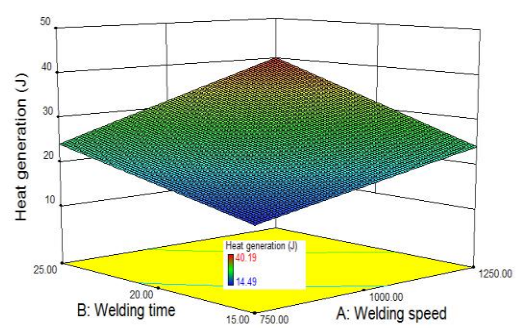


Fig: 6 *3D plot for heat generation*

5. Results

The all the friction welding on specimens having diameter 8 mm have been carried out at constant load (250N). The heat generation in Joule during welding has been calculated using equation 1

$$\bar{Q} = 2/3\mu.\pi.N.P.R^3.60.t \text{ (J)} \qquad (1)$$

Table 5 *Complete design layout with results*

S.No.	A:Welding speed (RPM)	B: Welding time (Minutes)	Heat generation (J)	Tensile strength (MPa)	Toughness (J)
1	750	15	14.47	108	14
2	1000	15	19.3	119	17
3	1250	15	24.1	124	23
4	750	20	19.29	122	19
5	1000	20	25.72	129	24
6	1250	20	32.15	136	30
7	750	25	24.11	117	18
8	1000	25	32.15	125	22
9	1250	25	40.19	131	25

Heat generation during welding increase with increase in welding speed, also with increase in welding time. The maximum heat generation is obtained at 1250 RPM welding speed and 25 minute welding time. Tensile strength during welding increase with increase in welding speed, while tensile strength initially increases as the welding time increases from 15 min to 20 min, after that it decreases as the welding time increases from 20 min to 25 min. The maximum tensile strength is obtained at 1250 RPM welding speed and 20 minute welding time. The toughness during welding increases with increase in welding speed, while toughness initially increases as the welding time increases from 15 min to 20 min, after that it decreases as the welding time increases from 20 min to 25 min. The maximum tensile toughness is obtained at 1250 RPM welding speed and 20 minute welding time

6. Conclusions

In the present work the 3- level full factorial design has been selected for investigation of friction welding parameters on heat generation, tensile strength and toughness and for development of prediction models for heat generation, tensile strength, and toughness regarding welding parameters. The significant conclusions for the current research are given as:

1. For the heat generation, welding speed is found a most significant parameter followed by welding time and interaction effect of welding speed and welding time.
2. For the tensile strength, welding speed is found most significant factor that affects the tensile strength followed by second order term of welding time, welding time and interaction of welding speed and welding time.
3. For the toughness, welding speed is found most significant factors followed by welding time, second order term of welding time, an interaction of welding speed and welding time & second order term of welding speed.

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