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OPTIMIZATION OF PROCESS PARAMETERS IN FRICTION STIR WELDING OF AL 6063

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ABSTRACT

Now a day's Friction Stir welding [FSW] has become very popular for joining of light weight materials like aluminum, magnesium and its alloys. This paper discusses about the use of Taguchi experimental design technique for maximizing tensile strength of friction stir welded Al 6063 alloy. The effect of process parameters on tensile strength of welded joints are evaluated using ANOVA and signal to noise ratio of robust design. From this investigation it is found that the joints fabricated at the tool rotational speed of 1400 rpm, welding speed of 1.2 mm/sec, and axial force of 7 KN yielded maximum tensile strength and joint efficiency of 92 Mpa and 70 % respectively. It was observed that the welding speed exhibits more influence on tensile strength of the welded joints followed by spindle speed and axial force.

Keywords: Al 6063, Friction stir welding, Taguchi experimental design, Tensile strength.

1. INTRODUCTION

Friction Stir Welding is a newly developed autogeneous welding technique in which the material that is being welded does not melt. FSW was invented at "The welding Institute" (TWI) of the Great UK in 1991 and was initially applied to aluminium alloys [1]. The basic concept to prepare the weld is remarkably simple. The process uses the non-consumable rotating tool which has two portions namely pin or probe and shoulder. During process the rotating tool is inserted in to the material till the bottom of the shoulder touches the top of the

work surface by giving the axial force normal to the joint line and then translated along the joint line to prepare the weld [2]. The basic concept is given in the Fig.1

Because of absence of complete melting, FSW offers several advantages over the conventional fusion welding process. The advantages are grouped as metallurgical advantages and environmental advantages. Metallurgical benefits includes good dimensional stability , repeatability, no loss of alloying elements, excellent mechanical properties in the joint area due to re crystallized micro structure in the stir zone. The process is a green one because it eliminates grinding wastages, no harmful emissions, required only minimum surface cleaning [3].

Due to the above mentioned advantages the process avoids some typical welding defects encountered such as loss of alloying elements, solidification cracking and porosity [4]. The technique has the limited process parameters need to control to produce the good welded joint. The most common process parameters are tool rotation speed, traverse speed and axial force and tool geometry [5].

Fig.1. Basic Concept of FSW [3]

Lot of efforts have been taken by the researchers to understand the effect of process parameters on mechanical properties of welded joint, material flow behavior and microstructure formation. In the present work, optimization of friction stir welding process parameters was done for getting maximum tensile strength. In addition to that ANOVA was performed to find the influence of each parameter on output response.

2. EXPERIMENTAL WORK

2.1 Selection of Work piece and tool

In the present investigation Aluminum 6063 plates were used to prepare the welded joint. The work piece was sliced to the dimension of 100mm (L) X 100mm (W) X 6.8mm (T) using power hacksaw. The Chemical properties of the base material are given in the table 1. The tool used in this investigation was made of HCHCr steel. The tool was designed with straight cylindrical pin which is shown in the Fig 2. and it has the following dimensions, tool shoulder diameter 18mm, pin diameter 6mm, and pin length 6.5 mm.

Table 1. Chemical composition of base material

Material	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Al 6063	0.2 – 0.6	0.35	0.1	0.1	0.45 – 0.9	0.1	0.1	0.1	Remainder

Fig.2. Designed tool

Fig.3. Computer Controlled FSW machine

2.2. Selection of process parameters

In the present study three process parameters such as tool rotation speed(N), Welding speed(S), axial force(F), which are mostly contribute to heat input and subsequently influence the mechanical properties of the welded joints were selected in two different levels. The table 2 shows the process parameters and their levels.

Table 2. Process parameters and their levels

S.NO	Parameter	Unit	Notation	Level 1	Level 2
1	Spindle Speed	Rpm	A	1000	1400
2	Welding speed	mm/Sec	B	1.2	1.8
3	Axial force	KN	C	7	8

2.3. Conducting the Experiments

Square butt joint configuration was prepared using computer controlled Friction stir welding machine which is shown in the Fig.3. Totally eight experiments were conducted for the selected process parameters. The prepared welded joints are shown in the Fig .4.

Fig.4. Prepared welded joints

Fig.5. Tensile specimens before test

In order to prepare the sample specimen, the welded joints were sliced in traverse direction using a power hacksaw. The standard tensile specimens were prepared as per the dimensions given by ASTM E8 – 04 standards. Three tensile specimens were prepared from each joint to evaluate tensile strength. The tensile specimens before and after test are shown in the fig.5 and 6 respectively. Tensile test was carried out by 100KN servo controlled Universal Testing Machine which is shown in the Fig. 7.

Fig.6. Tensile test specimen after test

Fig.7. UTM with Welded Specimen

3. RESULTS AND DISCUSSION

The main quality characteristics considered in the present investigation was tensile strength which describes the quality of the FSW joints. In order to access the influence of welding parameters on the output response S/N ratio for each control factor were calculated. The S/N ratio was used to analysis the test run results because it represents both the average (mean) and variation (scatter) of the experimental results. The number of S/N ratios are available such as smaller the best, larger the best, nominal the best. Based on the previous knowledge, expertise and understanding of the process the appropriate S/N ratio was chosen.

In this investigation, maximum tensile strength was the objective function, so that larger the best S/N ratio was chosen. It is clear that a larger S/N ratio corresponds to better quality characteristics. Therefore the optimal level of process parameters is the level of highest S/N ratio.

The S/N ratio can be computed using the following equation (1).

$$\frac{S}{N} = -10 \log \left(\frac{1}{n} \sum \frac{1}{Y^2} \right) \text{----- (1)}$$

Where S/N is the signal to noise ratio, n is the number of measurements taken in the test and Y is the individual measured response value (experimental results). The table.3 shows the experimental results and corresponding S/N ratio values.

Table 3. Experimental Results

S.No	Process parameters			Experimental Results		
	A [Rpm]	B [mm/sec]	C [KN]	Ultimate tensile strength [Mpa]	Signal to Noise Ratio	Joint Efficiency [%]
1	1000	1.2	7	90	39.08	68.70
2	1400	1.8	7	80	38.06	61.06
3	1400	1.2	7	92	39.27	70.22
4	1000	1.8	8	64	36.12	48.85
5	1000	1.2	8	87	38.79	66.41
6	1400	1.8	8	72	37.14	54.96
7	1400	1.2	8	88	38.88	67.17
8	1000	1.8	7	69	36.77	52.67

Fig. 8 shows the main effects plot for S/N ratio indicating that the tensile strength is maximum when spindle speed, traverse feed, and axial load are at the level of 2, 1, 1 i.e. 1400 rpm, 1.2 mm/sec, 7KN respectively. In the present investigation joint efficiency was also calculated for each work piece. Joint efficiency is the ratio of ultimate tensile strength of the welded joint to the ultimate tensile strength of the base material. The maximum of 70% joint efficiency was achieved for the one of the above parameters.

Fig.8. Main Effects plot for S/N ratio

3.1 ANOVA: Analysis of Variance

The Analysis of Variance popularly known as the ANOVA can be used to identify the process parameters that are statistically significant which affect the tensile strength of the welded joints produced by FSW. ANOVA was performed using Minitab 16 statistical software. The results of ANOVA are summarized in the table 4.

Table 4. ANOVA Table for tensile strength

Source of Variation	Degrees of freedom (DOF)	Sum of squares (S)	Mean of squares (V)	F-ratio (F)	P-value (P)	Percentage (%) Of contribution
A	1	60.500	60.500	6.205	0.067	7.58
B	1	648.000	648.000	66.460	0.001	81.25
C	1	50.000	50.000	5.120	0.086	6.26
Error	4	39.000	9.75			4.88
Total	7	797.5				99.97

In addition, the F –test named after Fisher can also be used to determine which process parameter has a significant effect on the tensile strength. Usually the process parameters have a significant effect on the quality characteristics when F is large.

The results of ANOVA indicate that the considered process parameters are highly significant factors affecting the tensile strength of FSW joints in the order of welding speed, spindle speed, and axial force. The percentage of contribution is the portion of the total variation observed in the experiment attributed to each significant factors and/or interaction which is reflected. The percentage of contribution is a function of the sum of squares for each

significant item it indicates the relative power of a factor to reduce the variation [6, 7]. If the factor levels are controlled precisely, then the total variation could be reduced by the amount indicated by the percentage of contribution.

4. CONCLUSION

The butt joint configuration of Al6063 alloys was successfully prepared using non consumable rotating tool with straight cylindrical pin by friction stir welding technique. The samples were characterized for tensile strength of welded joints. ANOVA was performed to investigate the significance of the process parameters and following conclusions were made.

- The optimal FSW process parameter combinations are spindle speed at 1400 rpm, traverse feed at 1.2 mm/ sec and axial load at 7 KN.
- The maximum of 70% joint efficiency was achieved for optimum process parameters.
- The percentage of contribution of FSW process parameters was calculated. It was found that the welding speed has maximum contribution of 81%. Spindle speed and axial force showed minimum effect on tensile strength when compared to the traverse feed.

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