EFFECT OF TOOL TILT ANGLE ON TENSILE STRENGTH OF FRICTION STIR WELDED DISSIMILAR ALUMINIUM ALLOY USING OPTIMIZATION TECHNIQUE

A. M.Deore[1], Prof. G. N. Kadam[2],

[1] *PG Student, Mechanical Engineering, JCOE, Kuran*
[2] *Assistant Professor, Mechanical Engineering, JCOE, Kuran*

ABSTRACT

Friction stir welding (FSW) as a solid state joining technology, is one of the environmental friendly fabrication techniques involving energy efficiency and versatility to provide satisfactory combination of microstructure and mechanical properties of the assemblies. In this work dissimilar aluminium (AA6061 & AA7075) plates were welded using Friction stir welding. In this work a Universal testing machine was used to carry tensile test of welded pieces. The optimization of different parameters is done by using Taguchi Approach. In this experiment L_9 orthogonal array is used with three controllable factors like Rotational Speed, Welding Speed and Tool tilt angle with three levels of each to find out optimum level of parameters for maximization of tensile strength. The ANOVA results used to find out significant factor and percentage contribution of individual factor. Optimum level of rotational speed (1200 rpm), welding speed (40mm/rev) and Tool tilt angle (2°) shows highest tensile strength of (130.12 Mpa). In this investigation Tool tilt angle plays a vital role and contributes 50.71% to the overall contribution.

Keyword: - *FSW[1], Taguchi method[2], Tensile strength[3], ANOVA[4], Minitab 16[5].*

1. INTRODUCTION

Friction stir welding is an advanced welding process and has emerged as an important solid state joining process. The technique was invented and patented in 1991 by The Welding Institute (TWI) of United Kingdom. The process was first used successfully by NASA to weld the super lightweight external tank for the space shuttle. Furthermore, a noteworthy factor is, the technique is used to join structural component of Delta IV, Atlas V and Falcon IX rockets. [13]

Friction stir welding (FSW) as a solid state joining technology, is one of the environmental friendly fabrication techniques involving energy efficiency and versatility to provide satisfactory combination of microstructure and mechanical properties of the assemblies. During processing, a nonconsumable tool attached with a desired designed pin is inserted to butting edge of the plates to be joined. Tool shoulder should touch the plate surface. Under this condition the tool is rotated and traversed along bond line. Frictional heat is generated, material gets softened locally and plastic deformation of the work piece occurs. Tool rotation and translation expedite material flow from front to back of the pin and welded joint is produced. The process is suitable for joining plates and sheets; however it can be employed for pipes, hollow section and positional welding. [1]

In contrast to conventional friction welding where two objects which are to be joined are rubbed with each other with high contact pressure, in FSW a third body is rubbed against two firmly clamped objects to be joined in the form of a nonconsumable rotating tool having probe at the tip. This tool is plunged into the joining region of two objects and subsequently translated along the joining line till the end and ultimately plunged out from the region. At one side where tool rotation direction remains same as the welding direction is called advancing side (A.S.) and the other side is called retreating side (R.S.). Further in FSW the microstructures are broken up into four distinct zones – (a) base metal (BM), (b) heat affected zone (HAZ), (c) thermo mechanically affected zone (TMAZ) and (d) nugget zone (NZ). [4]

The aim of this research is to find out the effect of friction stir welding process parameters on welded workpiece at the point of view tensile strength by employing Taguchi's orthogonal array design and analysis of variance (ANOVA). In this experiment L_9 orthogonal array is used with three controllable factors like Rotational speed (rpm), Welding speed (mm/rev), Tool tilt angle (Degree) with three levels of each to find out optimum level of process parameters for friction stir welding operation. The ANOVA results used to find out significant factor and percentage contribution of individual factor.

2. EXPERIMENTAL METHODOLOGY

2.1 Experimental Design

In this work 6 mm thickness Al 6061 & AA 7075 plates was used as base material. Three factors (Rotational speed, Welding speed, Tool tilt angle) at 3 levels each. The selected process parameter and their levels are shown in table 1. This is the design of experiment by which the works are done

Table -1: Control factors and their levels

Control Factors	Units	Level I	Level II	Level III
Rotational speed	rpm	800	1000	1200
Welding speed	mm/rev	40	50	60
Tool tilt angle	Degree	0	1	2

2.2 Taguchi Method

Taguchi technique is a remarkable factual outline of trial tool used to assess the impact of process parameters on output parameters. Orthogonal array is one of the Taguchi tool, which takes out the quantity of test required, decreases the cost, and reduce the time of trials.(5) The Orthogonal array L_9 is shown in Table 3. Taguchi gives three types of quality characteristics Smaller the better, Nominal the better and Larger the better.

Table -2: Taguchi L_9 Orthogonal array

Run	Factor 1 Rotational Speed (rpm)	Factor 2 Welding speed (mm/rev)	Factor 3 Tool tilt angle (degree)
1	800	40	0
2	800	50	1
3	800	60	2
4	1000	40	1
5	1000	50	2
6	1000	60	0
7	1200	40	2
8	1200	50	0
9	1200	60	1

2.3 ANOVA Analysis

Analysis of variance (ANOVA) is similar to regression in that it is used to investigate and model the relationship between a response variable and one or more predictor variables. Analysis of variance (ANOVA) of the overall grade is done to show the significant parameters. If the P value for a factor becomes less than 0.05 then that factor is considered as significant factor at 95% confidence level. Statistical software with an analytical tool of ANOVA is used to determine which parameter significantly affects the performance characteristics.

2.4 S/N ratio

Taguchi introduced three types of quality characteristics Smaller is better, Nominal is better and Larger is better

The signal-to-noise (S/N) ratio is calculated for each factor level combination. The formula for the larger-is-better S/N ratio using base 10 log is:

$$S/N = -10*\log\left(\Sigma\,(1/Y^2)/n\right) \qquad \text{--------------- (1)}$$

Where Y = responses for the given factor level combination and n = number of responses in the factor level combination.

3. EXPERIMENTAL PROCEDURE

The Experiments were performed on Vertical Milling Machine to weld Al6061-AA7075 dissimilar material.

Fig -1: Photograph of experimental set up

The American Society for Testing of Materials (ASTM E8M-04) guidelines were followed for preparing the test specimens. The smooth tensile specimens were prepared to evaluate ultimate tensile strength. Tensile test was carried out in 100 kN, electromechanical controlled universal testing machine

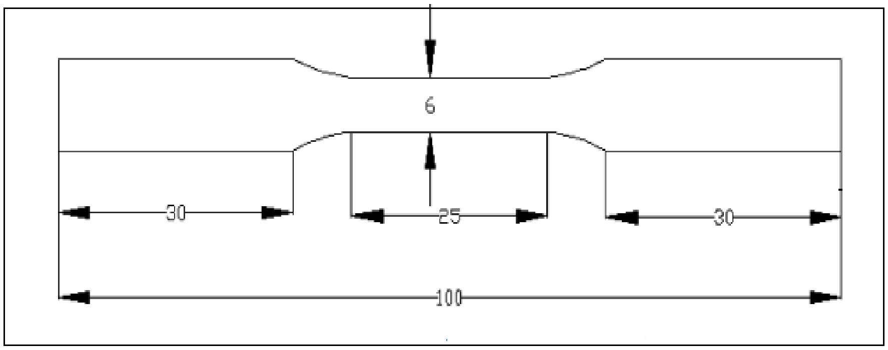

Fig -2: Dimension of Tensile specimen

After welding the tensile strength of welded component is measured using universal testing machine.. The Table 3 shows the results for Tensile strength (Mpa).

Table -3: Experimental result for Tensile strength

Run	Factor 1 Rotational Speed (rpm)	Factor 2 Welding speed (mm/rev)	Factor 3 Tool tilt angle (degree)	Tensile Strength (Mpa)
1	800	40	0	112.29
2	800	50	1	118.33
3	800	60	2	123.42
4	1000	40	1	124.85
5	1000	50	2	116.86
6	1000	60	0	112.20
7	1200	40	2	130.21
8	1200	50	0	119.08
9	1200	60	1	125.87

3. RESULT & DISCUSSION

The Signal to Noise (S/N) Ratio for Tensile strength is calculated by using Larger the better characteristic. The S/N Ratio result for Tensile strength is as shown in Table 4.

Larger the Better,

S/N Ratio = -10log [$\frac{1}{n}\sum_{i=1}^{n}(\frac{1}{Yi2})$] --------------- (2)

Table -4: Calculated S/N ratio for Tensile strength

Run	Factor 1 Rotational Speed (rpm)	Factor 2 Welding speed (mm/rev)	Factor 3 Tool tilt angle (degree)	S/N ratio Tensile Strength (Mpa)
1	800	40	0	41.00
2	800	50	1	41.46
3	800	60	2	41.83
4	1000	40	1	41.93
5	1000	50	2	41.35
6	1000	60	0	41.00
7	1200	40	2	42.29
8	1200	50	0	41.52
9	1200	60	1	42.00

3.1 Analysis of Tensile strength

From the result of ANOVA for Tensile strength the Tool tilt angle shows more contribution of 50.71 %, Rotational speed shows 32.13 % contribution and welding speed has lowest contribution of 8.40 %. Here the residual error was found as 8.76 %. The Analysis of variance result for Tensile strength as shown in Table 5.

Table -5: ANOVA for Tensile strength

Source	DF	Seq SS	Adj MS	F	P	% Contribution
Rotational speed	2	0.5131	0.25654	3.67	0.214	32.13
Welding speed	2	0.1341	0.06706	0.96	0.511	8.40
Tool tilt angle	2	0.8098	0.40492	5.79	0.147	50.71
Residual error	2	0.1400	0.06998			8.76
Total	8	1.5970				100

3.2 Response Table for Tensile Strength

From response table 6 it is observed that Tool tilt angle has the greatest influence on the S/N ratio also rotational speed has the next greatest influence followed by welding speed.

Table -6: Response of S/N ratio for Tensile strength

Level	RS	WS	TTA
1	41.43	**41.74**	41.17
2	41.43	41.44	41.80
3	**41.94**	41.61	**41.82**
Delta	0.51	0.30	0.65
Rank	2	3	1

From Figure 3 the optimum level of FSW process parameters are obtained at rotational speed of 1200 rpm, welding speed of 40 mm/min and Tool tilt angle of 2̊. From analysis it is also found that Tool tilt angle is the most influencing parameter for Tensile strength followed by rotational speed and welding speed

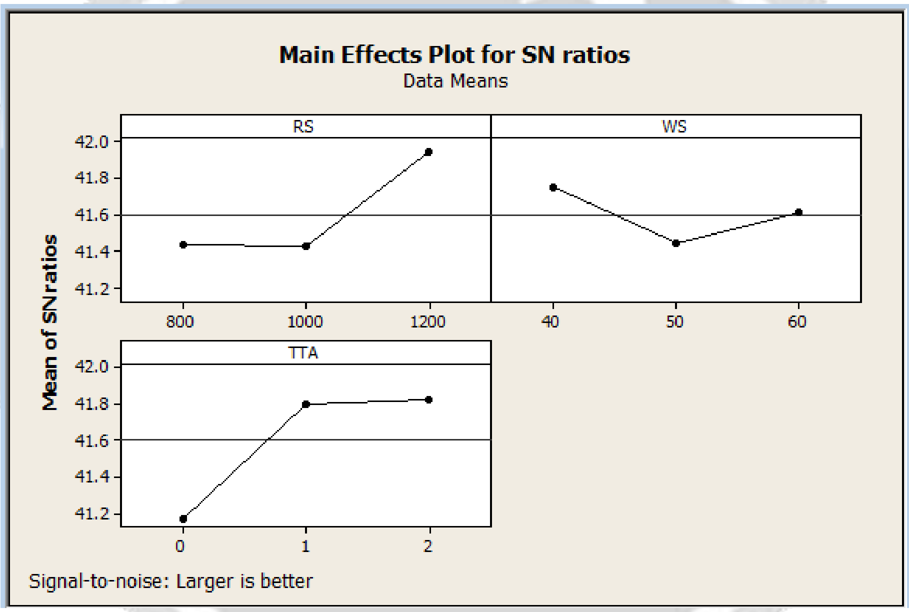

Fig -3: Main effect plot for S/N ratio of Tensile strength

3.3 Confirmation test

Confirmation test were carried out on parameters of Rotational speed 1200 rpm, welding speed 40 mm/rev and Tool tilt angle of 2̊. The result of confirmation test as shown in Table 7.

Table -7: Confirmation test for Tensile strength

Verification experiment No.	Verification experiment for	Predicted value	Experimental value
1	Maximum Tensile strength	130.12	130.309

4. CONCLUSIONS

In this study, the Taguchi method was used to obtain optimal condition for Friction Stir Welding of dissimilar metals (Al 60601-Al 7075).. Experimental results were evaluated using ANOVA and following conclusions are drawn:

1. Taguchi's design of experimental technique was used to find the optimum levels of process parameters in FSW. The optimum levels of the tool rotational speed, weld speed and Tool tilt angle are 1200 rpm, 40 mm/rev and 2˚ respectively.
2. In this investigation Tool tilt angle plays a vital role and contributes 50.71% to the overall contribution.
3. In this investigation rotational speed is second most influencing parameter contributes 32.13% to the overall contribution.
4. Welding speed has negligible influence on Tensile strength
5. Optimum level of rotational speed (1200 rpm), welding speed (30mm/rev) and Tool tilt angle (2˚) shows tensile strength of (130.12 Mpa)
6. Taguchi method successfully optimized friction stir welding process parameters shows the best result for tensile strength 130.12 Mpa.

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