EFFECT OF SHOULDER TO PIN DIAMETER (D/d) RATIO ON TENSILE STRENGTH OF FRICTION STIR WELDED DISSIMILAR MATERIALS

S. B.Navale[1], Dr. B. R. Borkar[2],

[1] *PG Student, Production Engineering, AVCOE, Sangamner*
[2] *Assistant Professor, Production Engineering, AVCOE, Sangamner*

ABSTRACT

In this experimental work the effect of three controllable factors mainly Rotational speed (1000, 1500, 2000), Welding Speed (30, 50, 70) & Shoulder to pin diameter (D/d) ratio (4.5, 5.0, 5.5) on Tensile strength in FSW operation were investigated. The experiments were performed on dissimilar material Al-Cu plates Using Taguchi method. A three level, three Factor design of experiment prepared according to Taguchi orthogonal array L_9 using Minitab 16 software. The Analysis of Variance (ANOVA) and Signal to Noise (S/N) Ratio was carried to find out the most significant factor and percentage contribution of individual factor for Tensile strength. From result it is found that optimum level for Tensile strength is obtained as 2000 rpm of rotational speed, 70 mm/rev of welding speed and 5.5 of Shoulder to pin diameter. From result it is also observed that rotational speed is the most contributing factor with contribution of 70.44%. Finally a model for tensile strength values based on FSW parameters was calculated which was also confirmed by experimental results. Shoulder to pin diameter (D/d) ratio has the second highest influence on Tensile strength of Friction stir welded Al-Cu dissimilar materials.

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

1. INTRODUCTION

Friction stir welding is a new technology, of solid state joining for similar and dissimilar metals (soft metals). FSW was invented and patented in 1991 by TWI (The Welding Institute) in UK. FSW is based on a simple concept, which is based on frictional heat generated between the work piece and the tool.[9,10] 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. [2]

FSW has become a technology of widespread interest because of its numerous advantages, most important of which is its ability to weld otherwise unweldable alloys. Compared with many of the fusion welding processes that are routinely used for joining structural alloys, FSW is an emerging solid state joining process in which the material that is being welded does not melt and recast. [1] Friction stir welding (FSW) is a rapidly maturing solid state joining process that appears as a promisingly ecologic weld method that enables to diminish material waste and to avoid radiation and harmful gas emissions usually associated with the fusion welding techniques. The main process parameters affecting material flow and weld quality contain the tool rotation speed, tool traverse speed, the vertical pressure on the tool, the tilt angle of the tool and the tool geometry. During processing, a nonconsumable tool attached with a specially designed pin was inserted to the butting edges of the plates to be joined. The tool shoulder had to touch the plate surface. Under this condition the tool was rotated and traversed along the bond line. Thus, frictional heat was generated. The tool rotation and traverse expedite material flow from the front to the back of the pin and welded joint were produced. The process was suitable for joining the plates and sheets; however, it can be employed for pipes and the hollow sections and positional welding. [5] Parameters of friction stir welding process (FSW) such as geometry of tool and joint design have major influence on heat distribution, material flow pattern and created structures, which finally affects the quality of welded joints. Lots of researches have been done about the effect of FSW parameters on mechanical and metallurgical properties of similar and dissimilar aluminum alloys joints. [15]

This welding technique, attracting an increasing amount of research interest, is applied to the aerospace, automotive, and shipbuilding industries. [7] 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). [10]

From literature it is observed that very less work has been carried out on optimization of FSW process parameters on dissimilar Al-Cu material. 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), Shoulder to pin diameter (D/d) ratio 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 3mm thickness Al 6061-T651 & pure copper plates was used as base material. The parameters identified for investigation are tool rotation speed, welding speed, shoulder to pin diameter. The selected process parameter and their levels are shown in table 1. This is the design of experiment by which the works are done. The Nomenclature of FSW tool is as shown in Fig. 1.

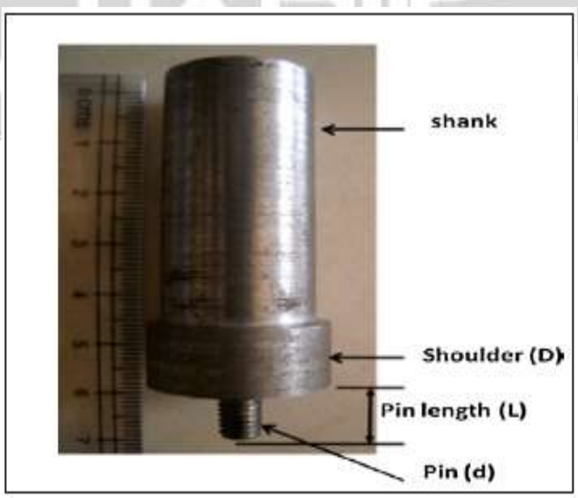

Fig -1: Nomenclature of FSW tool [11]

Table -1: Control factors and their levels

Control Factors	Units	Level I	Level II	Level III
Rotational speed	rpm	1000	1500	2000
Welding speed	mm/rev	30	50	70
Shoulder to pin diameter	-	4.5	5.0	5.5

Three different Shoulder diameter to pin diameter (D/d= 5.5, 5.0, 4.5) ratio tools of Tool steel material were prepared. The actual photograph of different tools is as shown in Fig. 2.

Fig -2: Three tools with shoulder to pin diameter (D/d= 5.5, 5.0, 4.5) ratio

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 Shoulder to pin dia ratio
1	1000	30	4.5
2	1000	50	5.0
3	1000	70	5.5
4	1500	30	5.0
5	1500	50	5.5
6	1500	70	4.5
7	2000	30	5.5

8	2000	50	4.5
9	2000	70	5.0

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

In Taguchi designs, a measure of robustness used to identify control factors that reduce variability in a product or process by minimizing the effects of uncontrollable factors (noise factors). Control factors are those design and process parameters that can be controlled. Noise factors cannot be controlled during production or product use, but can be controlled during experimentation. In a Taguchi designed experiment, you manipulate noise factors to force variability to occur and from the results, identify optimal control factor settings that make the process or product robust, or resistant to variation from the noise factors. Higher values of the signal-to-noise ratio (S/N) indicate control factor settings that minimize the effects of the noise factors. The signal-to-noise (S/N) ratio measures how the response varies relative to the nominal or target value under different noise conditions. You can choose from different S/N ratios, depending on the goal of your experiment. 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 Al-Cu dissimilar material. The actual photograph of Machine is as shown in Fig. 3.

Fig -3: 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 (Make: FIE-Bluestar, India; Model: UNITEK-94100).

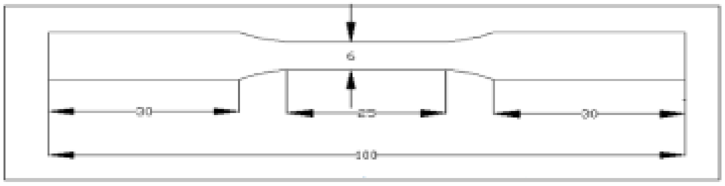

Fig -4: Dimension of Tensile specimen

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 Shoulder to pin dia ratio	Tensile Strength (Mpa)
1	1000	30	4.5	89.23
2	1000	50	5.0	112.38
3	1000	70	5.5	121.29
4	1500	30	5.0	135.27
5	1500	50	5.5	149.32
6	1500	70	4.5	129.36
7	2000	30	5.5	143.18
8	2000	50	4.5	138.26
9	2000	70	5.0	151.02

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 = $-10\log \left[\frac{1}{n} \sum_{i=1}^{n} \left(\frac{1}{Yi2} \right) \right]$ --------------- (2)

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

Run	Factor 1 Rotational Speed (rpm)	Factor 2 Welding speed (mm/rev)	Factor 3 Shoulder to pin dia ratio	S/N ratio Tensile Strength (Mpa)
1	1000	30	4.5	39.01
2	1000	50	5.0	41.01

3	1000	70	5.5	41.68
4	1500	30	5.0	42.63
5	1500	50	5.5	43.48
6	1500	70	4.5	42.24
7	2000	30	5.5	43.12
8	2000	50	4.5	42.81
9	2000	70	5.0	43.58

3.1 Analysis of Tensile strength

The Analysis of variance result for Tensile strength as shown in Table 5. From the result of ANOVA for Tensile strength the Rotational speed shows more contribution of 70.44 %, Shoulder to pin diameter (D/d) ratio shows 19.10 % contribution and welding speed has lowest contribution of 9.32 %. Here the residual error was found as 1.14 %.

Table -5: ANOVA for Tensile strength

Source	DF	Seq SS	Adj MS	F	P	% Contribution
Rotational speed	2	11.8341	11.8341	61.61	0.016	70.44
Welding speed	2	1.5658	1.5658	8.15	0.109	9.32
Shoulder to pin diameter	2	3.2080	3.2080	16.70	0.056	19.10
Residual error	2	0.1921	0.1921			1.14
Total	8	16.8001				100

The response tables show the average of each response characteristic (S/N ratios) for each level of each factor. The tables include ranks based on Delta statistics, which compare the relative magnitude of effects. From response table 6 it is observed that Rotational speed has the greatest influence on the S/N ratio also Shoulder to pin diameter (D/d) ratio has the next greatest influence followed by welding speed.

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

Level	RS	WS	D/d Ratio
1	40.57	4158	41.35
2	42.78	42.44	42.41
3	**43.17**	**42.50**	**42.76**
Delta	2.60	0.91	1.41
Rank	1	3	2

Fig. 5 shows the main effect for S/N Ratio of Tensile strength. From fig. 3 the optimum level of FSW process parameters are obtained at rotational speed of 2000 rpm, welding speed of 70 mm/rev and Shoulder to pin diameter (D/d) ratio of 5.5.

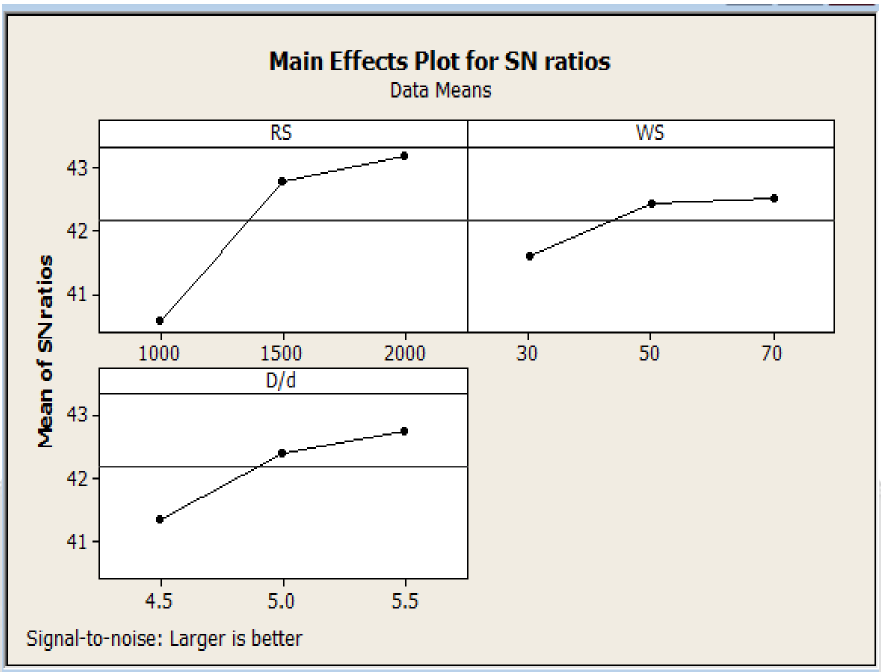

Fig -5: Main effect plot for S/N ratio of Tensile strength

3.2 Confirmation test

Confirmation test were carried out on parameters of Rotational speed 2000 rpm, welding speed 70 mm/rev and Shoulder to pin diameter (D/d) ratio of 5.5. 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	156.13	154.27

4. CONCLUSIONS

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

1. Shoulder diameter to pin din diameter (D/d) ratio has the second greatest influence on Tensile strength of Friction stir welded Al-Cu materials.
2. 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 shoulder to pin diameter (D/d) ratio are 2000 rpm, 70 mm/rev and 5.5 respectively.

3. In this investigation tool rotational speed plays a vital role and contributes 70.44 % to the overall contribution.
4. Welding speed has negligible influence on Tensile strength
5. Maximum tensile strength (151.02 Mpa) is observed at tool rotational speed (2000 rpm), weld speed (70mm/rev) and shoulder to pin diameter (D/d) ratio (5.0).
6. Optimum level of rotational speed (2000 rpm), welding speed (70mm/rev) and shoulder to pin diameter (D/d) ratio (5.5) shows tensile strength of (154.27 Mpa)
7. Taguchi method successfully optimized friction stir welding process parameters.

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