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OPTIMIZATION OF FSW FOR7050 AL ALLOY WITH TAGUCHI METHOD

[1]V YOGESH, [2]T VAMSIKRISHNA, [3]P PAVAN KALYAN, [4]A PAVAN KUMAR, [5]N PAVAN KUMAR

[1,2,3,4,5] B.Tech Final Year Student
[1,2,3,4,5] Department of Mechanical Engineering
[1,2,3,4,5] Visakha Institute of Engineering and Technology, Visakhapatnam, A.P, India.

Abstract: Friction stir welding was invented by the Welding Institute, UK in 1991. It is a solid state joining process. The base metals are not melted and there is no requirement of filler metal. The plates are heated by frictional force and brought to plastic condition at the interface. The plasticized metal is then interspersed in the welding region from both sides of the base plate.

The purpose of the present work is to optimize process parameters of friction stir welding of aluminium alloy 7050 using Taguchi's approach. It is known that aluminium is found abundantly on earth and it has many applications. Aluminium and its alloys are used in many aspects of life, for example, duralumin is used in making aircrafts and kitchen appliances, Nickel alloy is used in aerospace manufacturing. The main parameters taken into consideration in this work are Tool Rotational Speed, Welding Traverse Speed and Tool Tilt Angle. Brinell hardness and Tensile strength of the joints are taken as response variables. The range of tool rotational speed, welding traverse speed and tilt angle are 1000 rpm to 2000 rpm, 16 mm/min to 33 mm/min and 0^o to 2^o respectively. The optimum values of tool rotational speed, welding traverse speed and tool tilt angle for tensile test are 1400 rpm, 25 mm/min and 2° respectively and for hardness test same are given as 2000 rpm, 25 mm/min and 1° respectively. The significance of process parameters has been decided by the ANOVA (Analysis of Variance). After analysis it has been observed that tool rotational speed is the most significant parameter for tensile strength and tool tilt angle for hardness.

Keywords: **Friction stir welding, AA 7050, Taguchi Method, Tensile test and Hardness test.**

I. INTRODUCTION

Friction stir welding was invented by the Welding Institute, UK in 1991. It is a solid state joining process. The base metals are not melted and there is no requirement of filler metal. The plates are heated by frictional force and brought to plastic condition at the interface. The plasticized metal is then interspersed in the welding region from both sides of the base plate.

The tool is made of hardened steel. It consists of a 'pin', a 'shoulder' and shank. The tool is held in a collet and placed in a spindle which rotates the tool at a high speed, as required. The tool is plunged into the base plate interface or the welding line. The pin is completely pushed into the metal such that the shoulder is a little bit sunk into the plate. The shoulder rubs against the plates causing frictional force which heats up the plate. The plate metal is then plasticized and the rotational action of the tool 'stirs' the metal pushing the metals one side from the other. The tool is then traversed along the weld line as shown in figure 1.1. The metal cools and solidifies as the tool moves ahead.

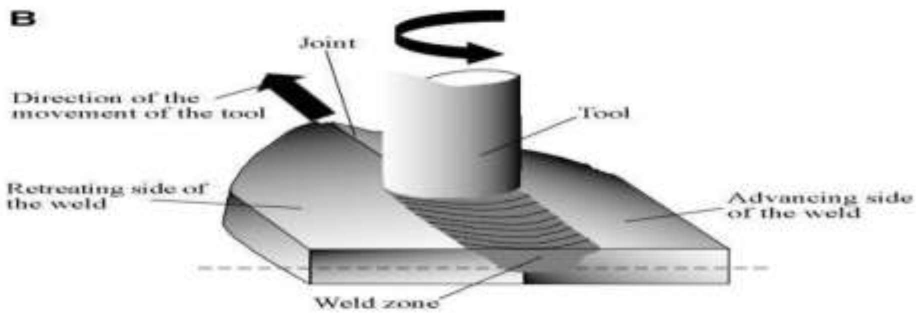

Figure 1.1: FSW process illustration

1.1 Selection of factors and levels

The controllable parameters for FSW like rotational speed, traverse speed and tilt angle which can potentially affect hardness and tensile of the welded joint obtained by FSW. The controllable parameters with their three levels are presented in Table 1.1

Table 1.1 Controllable Variables and Their Levels

Controllable Factors coded	Controllable Process Parameters	Level 1	Level 2	Level 3
A	Rotational Speed(rpm)	1000	1400	2000
B	Traverse speed(mm/min)	16	25	33
C	Tilt angle(°)	0	1	2

1.2 Selection of the response variables

From the literature review, it is observed that there are many factors which affect the quality of the weld and properties of materials. A good weld quality of the joint can only be achieved by proper combination of process parameters. Two response variables selected for the experiment are tensile strength and hardness of welded joint.

1.3 Choice of experimental design

Optimization of process parameter settings and calculation of response under optimum settings are the main objectives of parameter design. It is also to be made sure that values of responses obtained remain unaffected by the variations in environmental conditions and noise factors. The method developed by Fisher (1925) is very complex and not easy to follow. In this method a large number of experiments have to be carried out, which is always not feasible as there can be restriction on cost and availability of material (Lakshminarayanan K and Balasubramanian V, 2008). But in Taguchi method number of experiments is small and can easily be followed without much loss in accuracy. The difference between desired value and experimental value can be calculated by use of loss function. The loss function is further modified into S/N ratio (signal to noise ratio)

Three types of performance characteristics are used in this methodology: smaller the better, nominal the best and larger the better. Category of the performance characteristics does not matter as always highest S/N ratio is selected.

Now finally ANOVA (Analysis of Variance) is performed to see the significance of process parameters. Thus by analysis of ANOVA and S/N ratio values, optimum settings of process parameters can be obtained. The signal to noise ratio for different types of responses is obtained as given in equations 1.1 – 1.3.

1. The Smaller the Better: The target value for smaller the better case is zero. The signal to noise ratio equation for smaller the better category is,

$$SNR_s = -10 \log \sum_{i=1}^{n} \frac{y_i^2}{n} \quad \text{.....(1.1)}$$

2. The Larger the Better: This case is opposite of the smaller the better case. In this case yi is replaced by 1/yi , as a result, the SNR is given by,

$$SNR_l = -10 \log \sum_{i=1}^{n} \frac{1/y_i^2}{n} \quad \text{.....(1.2)}$$

3. Nominal is Best: In this case, to determine values of x that achieve a target value for the response, namely y = t. Deviations in either direction is undesirable. Thus, the SNR used by Taguchi is given by,

$$SNR_n = -10 \log \sum_{i=1}^{n} \frac{(y_i - y_o)^2}{n} \quad \text{.....(1.3)}$$

Where y_o = target value

1.4 Conduction of experiment

All the experiments are conducted under uniform conditions. It is assumed that the work-piece material is homogenous and tool wear effects are negligible. In this study, the controllable factors are the rotating speed, traverse speed and tool tilt angle which can potentially affect weld quality in FSW process. During testing, it has been observed that certain uncontrollable factors or noise factors are also present. These factors are the sources of variations for output results. They are impossible or difficult to control during experimentation. In this section, the use of orthogonal array to reduce the number of experiments for design optimization of the FSW parameters is reported. Table 1.2 gives the standard L-9 orthogonal array for conducting experiment in the present work.

Table 1.2 L9 Orthogonal Arrays

RUNS	A	B	C
1	1000	16	0
2	1000	25	1
3	1000	33	2
4	1400	16	1
5	1400	25	2
6	1400	33	0
7	2000	16	2
8	2000	25	0
9	2000	33	1

II. EXPERIMENTAL SETUP

Butt welds are produced in 6 mm thick plates of aluminium alloy 7050 using indigenously designed friction stir welding machine.

The machine can rotate the tool up to 3000 rpm, apply an axial load of up to 30 KN and the traverse speed can be as high as 500 mm/min. For welding of aluminium AA7050 alloy H13 die-steel tool is used. A carbide single point cutting tool is used to prepare the profiles of tool on Lathe machine. The tool pin profile has used in present work is cylindrical in shape.

2.1 WORK MATERIAL

Aluminium alloy 7050 is used as material for workpiece. 18 plates of 100mm × 50mm are cut using power hacksaw. There are total of 9 pairs of workpieces as shown in Figure. The chemical composition of aluminium alloy 7050 is given in Table 2.1.

Figure 2.1 Pairs of Workpieces

Table 2.1 Chemical Composition of Aluminium Alloy 7050

Al 7050	Composition %	Al 7050	Composition %
Al	87-90	Si	Max 0.12
Zn	5.5 – 6.5	Zr	Max 0.11
Mg	2 – 2.5	Mn	Max 0.1
Cu	2 – 2.5	Ti	Max 0.06
Fe	Max 0.15	Others	2.5

2.2 TOOL MATERIAL

To weld any material by FSW process it has to be made sure that the tool material used in process must have higher hardness in order to penetrate the workpiece. In this experiment H13 die steel tool is used. The tool profile is prepared by carbide single point cutting tool on lathe machine. Tool pin is of cylindrical shape as shown in the figure 2.2.

A cylindrical taper column tool without threads (H13 Die Steel) of hardness 470 BHN with shoulder diameter of 18 mm and pin diameter of 6 mm is used for this work. The length of the tool pin is 5.7 mm. The photograph of the tool is shown in Figure 2.2 (a). The tool profile is shown in Figure 2.2 (b). The chemical composition of H13 die steel is given in table 2.2.

Figure 2.2 (a) Tool Pin & (b) Cylindrical Tool Used for Experiment

Table 4.2 Chemical Composition of H13 Die Steel Tool

Element	C	Cr	Mn	Mo	Fe	Si	S	V
Wt%	0.32-0.45	4.75-5.5	0.2-0.5	1.1-1.75	90.53	0.8-1.2	0.03	0.8-1.2

2.3 MACHINE SETUP

A vertical milling machine has been used for friction stir welding process. Some components of the machine tool have been modified/ replaced in order to change speed 27 ratio and ensure smooth working of the machine tool. The vertical milling machine has been shown in figure 2.3.

Figure 2.3 Vertical Milling Machine Figure 2.4 Fixture Used For Experiment

2.4 CLAMPING DEVICE

A cast iron fixture is used to hold and clamp the work piece for FSW of aluminium alloy (AA7050). The fixture is prepared in such a way that it can hold up to a size of 100×100×6 mm. Figure 2.4 shows workpiece mounted in the fixture.

Three factors for FSW are studied (i.e. rotating speed, welding speed and tool tilt angle) in which three levels of each factor are considered. Therefore, an L9 orthogonal array is selected for the experiment.

In the present investigation, the base material AA7050 thickness of 6mm is employed. Rotational speed (1000, 1400 & 2000 rpm), traverse speed (16, 25 & 33 mm/min) and tilt angle (0, 1 &2 degree) were process parameters.

III. RESULT AND DISCUSSION

It is to discusses the results obtained and optimizes the FSW process parameters using Taguchi method. The objective function is to maximize the tensile strength and hardness of the FSW joint. The larger the better S/N ratio values are computed and analyzed. The optimum levels of the process parameters are ascertained. The effect of FSW process parameters such as rotational Speed, traverse speed, and Tool Tilt angle on tensile strength and hardness are discussed.

3.1 BRINELL HARDNESS TEST

Figure 3.1 shows the sample for hardness test.

Figure 3.1 Hardness Sample Specimens

Table 3.1 reports the experimental values of hardness expressed in terms of raw and S/N data.

Table 3.1 Brinell Hardness Test Result

Trial no.	Rotational Speed(rpm)	Traverse Speed(mm/min)	Tilt angle(°)	Hardness	S/N Ratio	MEAN
1	1000	16	0	88.2	38.9094	88.2
2	1000	25	1	96.3	39.6725	96.3
3	1000	33	2	92.0	39.2758	92.0
4	1400	16	0	98.5	39.8687	98.5
5	1400	25	1	102.7	40.2314	102.7
6	1400	33	2	90.0	39.0849	90.0
7	2000	16	0	98.0	39.8245	98.0
8	2000	25	1	93.5	39.4162	93.5
9	2000	33	2	100.0	40.0000	100.0

The quality characteristics, hardness, is of larger the better type and signal to noise ratio is accordingly calculated by using the following equation:

$$(S/N)LB = -10 \log (MSD)\ L\ B \quad \text{...(3.1)}$$

Where, MSD stands for mean square deviation and is given by:

$$MSD = 1/n \sum^{n} i=1\ 1/yi^{2} \quad \text{...(3.2)}$$

Brinell hardness is the major response factor considered in this experimental investigation which describes the quality of FSW joints. The delta values of each parameter are calculated for S/N ratio and means. The delta value is the difference of maximum and minimum value of Brinell hardness. The delta value helps to determine the rank of the parameters. Tables 3.2 and 3.3 represent the response tables of Brinell hardness S/N ratio and mean. It is seen from both the tables that tilt angle is having highest delta so rank 1 is given to tilt angle followed by rotational speed and traverse speed.

Table 3.2 Response Table for Brinell Hardness S/N Ratio

Level	Rotation Speed(rpm)	Traverse Speed(mm/min)	Tilt Angle(deg)
1	39.29	39.53	39.14
2	39.73	39.77	39.85
3	39.75	39.45	39.78
Delta	0.46	0.32	0.71
Rank	2	3	1

The optimal setting is RS3 TS2 TA2 based on S/N ratio.

Table 3.3 Response Table for Brinell Hardness Means

Level	Rotation Speed(rpm)	Traverse Speed(mm/min)	Tilt Angle(deg)
1	92.17	94.90	90.57
2	97.07	97.50	98.27
3	97.17	94.00	97.57
Delta	5.00	3.50	7.70
Rank	2	3	1

The optimal setting is RS3 TS2 TA2 based on the mean values.

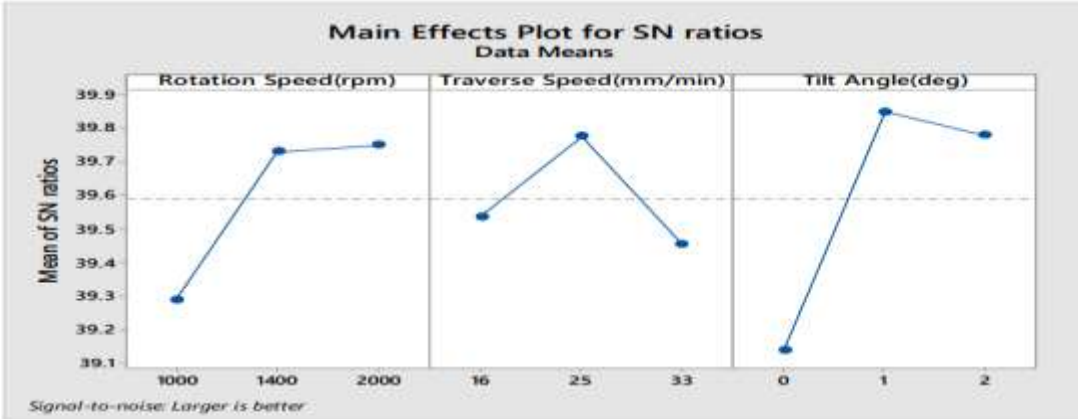

Figure 3.2 Main Effects Plot for Hardness (S/N Data)

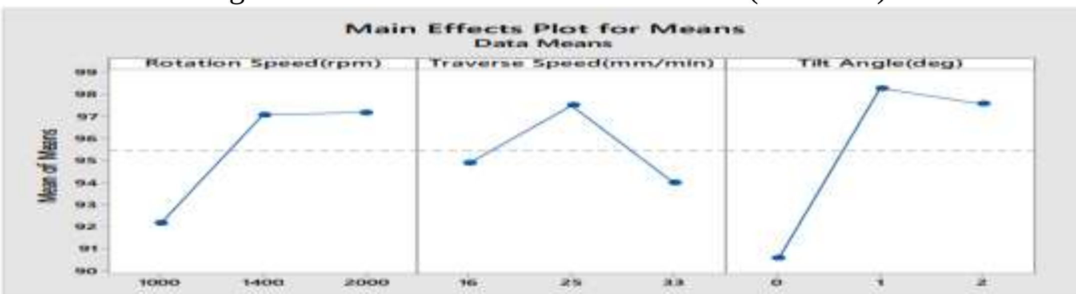

Figure 3.3 Main Effects Plot for Hardness (Mean)

3.2 TENSILE TEST

Table 3.4 reports experimental results for tensile strength.

Table 3.4 Analysis of Means & S/N Ratio For Tensile Strength

Trial no.	Rotational Speed(rpm)	Traverse Speed(mm/min)	Tilt angle(°)	Tensile Test (N/mm2)	S/N Ratio	MEAN
1	1000	16	0	250	47.9588	250
2	1000	25	1	280	48.9432	280
3	1000	33	2	258	48.2324	258
4	1400	16	0	282	49.0050	282
5	1400	25	1	323	50.1841	323
6	1400	33	2	298	49.4843	298
7	2000	16	0	270	48.6273	270
8	2000	25	1	275	48.7867	275
9	2000	33	2	285	49.0969	285

Figures 3.4 and 3.5 show the tensile specimen before and after testing.

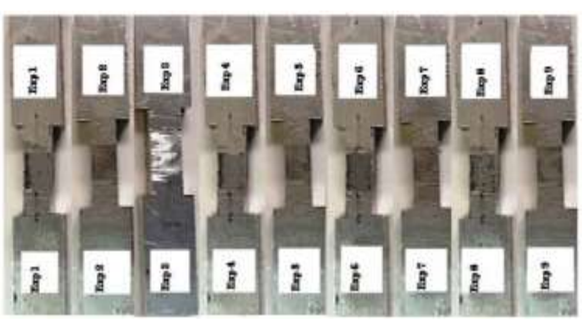

Figure 3.4 Tensile Samples Specimen

Figure 3.5 Photograph of Fracture Location

The tables 3.5 and 3.6 depict the response tables of tensile strength showing S/N ratio and mean values. The response tables reveal that rotational speed is having maximum delta value so rank 1 is given to rotational speed followed by traverse speed and tilt angle.

Table 3.5 Response Table for Tensile Strength S/N Ratio

Level	Rotation Speed(rpm)	Traverse Speed(mm/min)	Tilt Angle(deg)
1	48.38	48.53	48.74
2	49.56	49.30	49.02
3	48.84	48.94	49.03
Delta	1.18	0.77	0.27
Rank	**1**	**2**	**3**

The optimal setting is RS2 TS2 TA3 based on S/N ratio.

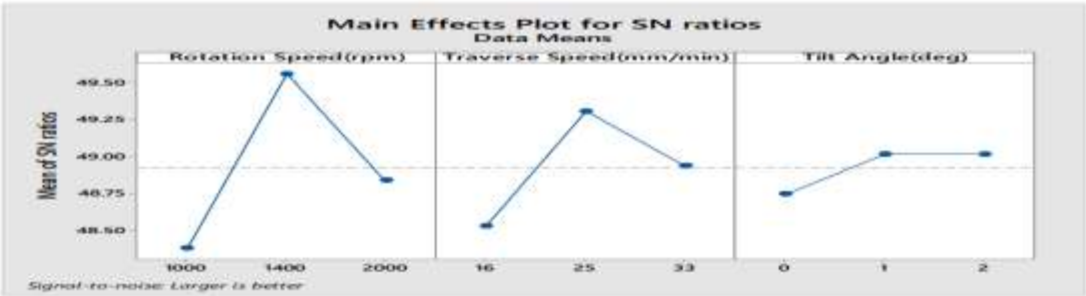

Figure 3.6 Main Effects Plot for Tensile Strength (S/N Data)

Table 3.6 Response Table for Tensile Strength Mean

Level	Rotation Speed(rpm)	Traverse Speed(mm/min)	Tilt Angle(deg)
1	262.7	267.3	274.3
2	301.0	292.7	282.3
3	276.7	280.3	283.7
Delta	38.3	25.3	9.3
Rank	**1**	**2**	**3**

The optimal setting is RS2 TS2 TA3 based on the mean.

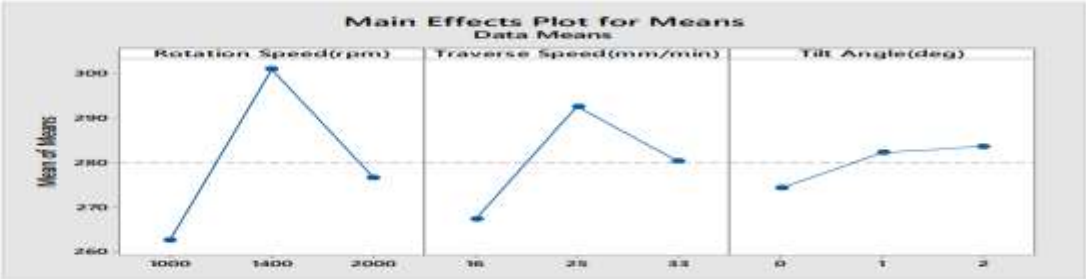

Figure.3.7 Main Effects Plot for Tensile Strength (Mean)

3.3 PREDICTED VALUE

The predicted mean values for both the responses are obtained from the optimal setting of the parameters.

3.3.1 Predicted Value of Brinell Hardness

Based on the investigation, the optimum level setting is RS3TS2TA2 for hardness. The average values of the hardness at optimal setting of the process parameters are taken from table 3.3. The predicted value of the Brinell hardness is given below: Hardness (predicted) = RS3+TS2 +TA2-2T, Where T is overall mean of raw data obtained from Table 3.3= 97.17+97.5+98.27-2(95.47) = 102

3.3.2 Predicted Value of Tensile Strength

Based on the investigation, the optimum level setting is RS2TS2TA3 for tensile strength. The average values of the response at these levels are taken from response Table 3.6 and the predicted value of the tensile strength is thus obtained as under: Tensile strength value (predicted) = RS2 +TS2+TA3-2T, Where T is overall mean of raw data obtained from Table 3.6. =301+292.7+283.7-2(280.11) =317.18

3.4 CONFIRMATION EXPERIMENT

Table 3.7 Results of Confirmation Experiments

Quality characteristics	Optimal setting	Predicted response	Average of three confirmation experiments	% error
Hardness (HB)	Rotational speed:2000 rpm, Traverse speed:25mm/min, Tool tilt angle: 1^o	102	98.35	3.71
Tensile strength	Rotational speed:1400 rpm, Traverse speed:25mm/min, Tool tilt angle: 2^o	317.18	311.20	1.92

Having predicted the mean values of the responses corresponding to the optimal setting of the process parameters, it is strongly recommended by Taguchi to verify the predicted results through conducting confirmation experiments. Three experiments are conducted at the optimal setting of the process parameters for each response and their average values are compared with the already predicted means.

3.5 CONCLUSIONS

The following conclusions may be drawn from the present study:

Tool tilt angle has maximum effect on hardness and rotational speed has maximum effect on tensile Strength among all the selected process parameters. The tool rotational speed and tool traverse speed are more dominating process parameters for the high quality welding. It has been observed by visual inspection that tool tilt angle is an important factor to minimize the defects. With an increase in rotational speed hardness always increases but with increase in traverse speed and tilt angle firstly hardness increases and then decreases. Increase in tilt angle increases tensile strength but with an increase in rotational speed and traverse speed firstly tensile strength increases and then decreases. The predicted mean of hardness corresponding to optimal settings of FSW process parameters is 102 BHN. The predicted mean of tensile strength corresponding to optimal settings of FSW process parameters is 317.18 N/mm^2

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