OPTIMIZING THE PROCESS PARAMETERS OF FRICTION STIR BUTT WELDED JOINT ON ALUMINUM ALLOY AA6061-T6

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Abstract

This paper deals with Friction stir welding of AA6061-T6Aluminum Alloy by using H13 Tool at different rotational speeds and welding feeds &pin diameters. Experiments were conducted according to L9 Orthogonal array which was suggested by Taguchi. Optimum parameters for optimum Tensile strength, Hardness and ductility were found with the help of S/N ratios. Therefore optimization of input process parameter is required to achieve good quality of welding. In this experiment the effect of process parameters on welded joint was studied and optimizes the parameter by using Taguchi method for tensile strength, hardness, ductility. Assign the rank to each factor which are having more influence on the mean of tensile strength, hardness and ductility

Keywords: *FSW, Taguchi, DOE, Tensile Strength, Hardness, Ductility.*

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1. INTRODUCTION

To produce a joint stronger than the fusion arc welded joint, the Friction Stir Welding process (FSW) can be used. Many applications such as aerospace, automotive and ship building industries, [1] widely use the friction stir welding to weld the lightweight materials, such as aluminum, magnesium and titanium. More effective welding and joining techniques are essential, however for further usage of magnesium alloys. Commonly encountered defects in fusion welded joints [2] such as oxide inclusions, porosity, cracks and distortions surrounding the tool must be hot, so that a successful can be reduced using the joining technique of (FSW), because it has a great potential for magnesium alloys. To develop quality joints, the process variables like the rotational speed, travel speed and tool geometry are vital [3].

Friction stir welding is a solid state welding process invented by The Welding Institute (TWI) of UK in 1991. The work pieces that are to be joined are clamped together on a backing plate. A rotating non consumable tool with a profiled pin and large concentric shoulder slowly plunged in to the joint line between two plates which are clamped together. Here coalescence is created by the combined action of frictional heating between tool and work pieces and the plastic deformation of base metal due to the rotation of the tool. 95% of heat generated in the process is transferred to the work piece and only 5% flows in to the tool [4]. The friction heat generated softens the material around the pin and moves it from the front of the pin to the back due to the rotation and translation of the tool.

In conventional welding, dissimilar metals are very difficult to join because of different physical and chemical properties of base metals. The heat generated in the fusion welding process and the subsequent microstructure changes are the main reason for the decay of mechanical properties like strength, hardness and ductility of welded components. Similarly fusion welding of aluminum leads to poor solidification, microstructure and porosity in the fusion zone. Friction stir welding overcomes majority of the limitations of conventional fusion welding processes and in addition extensive thermo mechanical deformations induces dynamic recrystallization and recovery that refines the stir region. Therefore friction stir welded joints have improved mechanical properties such as tensile strength, ductility, hardness than conventional fusion welded joints [5]. Taguchi methods developed by Genichi Taguchi to improve the quality of manufacturing goods are recently applied to the field of engineering, biotechnology, marketing and advertising. The Taguchi method is a very powerful tool for carrying out experimental design. The main aim of the Taguchi methods is to produce an optimum result by analyzing the statistical data which have been given as an input function. This method allows limited number of experimental runs by utilizing a well balanced experimental design called orthogonal array design and signal to noise (S/N) ratio. Taguchi methods have been successfully utilized by Lakshminarayanan et.al.[6] for optimizing the process parameters of friction stir welding of RDE-40 aluminum alloy. The result shows that the rotational speed, welding speed and axial forces are the main parameters which affect the tensile strength of the joint. Vinod Kumar et.al.[7].

2. EXPERIMENTAL DETAILS

The specimens of the size of 80mmx75mmx3mm were machined from AA6061 aluminum alloy plates. The two plates of AA6061 aluminum alloy were Friction stir welded in the butt configuration by using conventional vertical milling machine. The base material's chemical composition is given in Table 1.The table 2 shows the chemical composition of the tool. The Ultimate Tensile Testing machine and hardness testing machine were used to test the tensile strength, elongation and hardness. The Table 3 below shows the identified process parameters and their levels. The L9 orthogonal array is selected as per standard suggested by Taguchi approach and is shown in table4.

Table 1. Base material AA6061 Chemical composition:-

Mg	Si	Fe	Cu	Zn	Ti	Mn	Cr	Others	Al
0.8-1.2	0.4-0.8	0.7	0.15-0.4	0.25	0.15	0.15	0.04-0.35	0.05	98.7

Table 2. Tool H13 Chemical composition:-

Elements	C	Mn	Cr	Mo	V	Si	Fe
%	0.40	0.35	5.20	1.30	0.95	1.00	Remainder

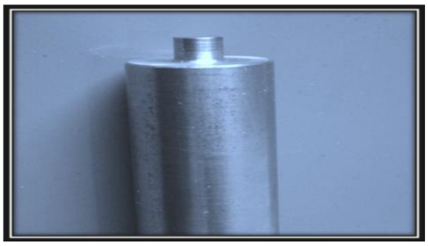

Fig 1A: Straight cylindrical tool

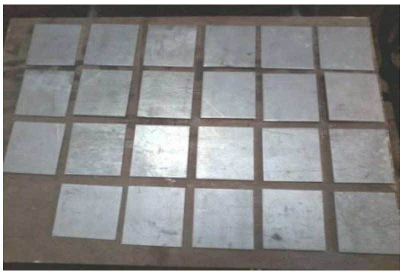

Fig (1B): Aluminum Work pieces

Fig (1C): FSW process

Fig 1. Illustration of FSW components

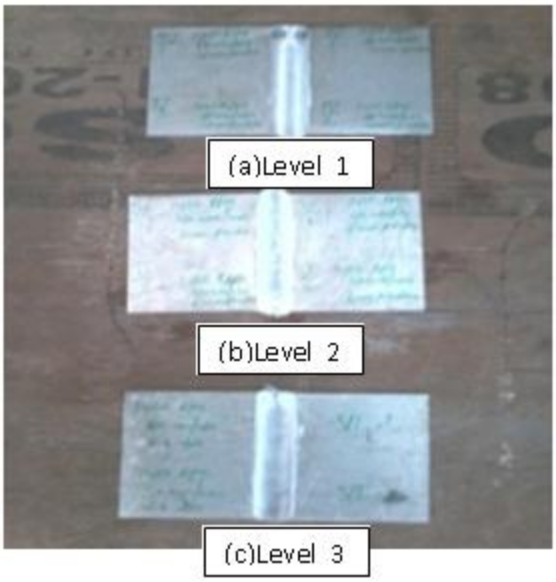

Fig 2 FSW Butt welded joints

3. OPTIMIZATION OF FSW:

3.1 Selection of FSW Parameters and Levels

To evaluate the optimum conditions of FSW process parameters with respect to FSW butt weld quality; in this study, there are three primary controllable factors and their three levels [8] and [9] are shown in Table 3. The plan of the experiments as shown in Table 4. As per Taguchi techniques, only 9 experiments for L9 orthogonal arrays are needed for percentage of elongation (%) and ultimate tensile strength (MPa) and hardness (Rockwell). By neglecting the values of the initial and the end pieces from each set of 2 piece trial under same experimental condition, averaged ultimate tensile strength and hardness are calculated and are shown in Table 5. The resulting averaged elongation rate is shown in Table 6.The objective of using Taguchi technique was to reduce the time and cost to evaluate the optimum welding conditions [9].

Table 3: FSW PROCESS PARAMETERS LEVELS

SI.NO.	Welding parameters	Level 1	Level 2	Level 3
1	Tool rotational speed N rpm	1120	1400	1800
2	Tool feed F(mm/min)	25	45	50
3	Pin diameter D (mm)	2.5	4	6

3.2 Selection of Orthogonal Array

Based on the number of factors and levels a suitable Taguchi orthogonal array for the experiment is selected by using MINITAB 16 statistical software. Since there are three factors having three levels each, L9 OA is chosen as shown in table 4 [10].

Table 4: Orthogonal array for L9 Taguchi Design

Sl. no	Tool rotational speed (N) (rpm)	Tool feed (F)(mm/min)	Pin diameter (D) (mm)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

3.3 Experiment Procedure

Taguhi analysis is performed according to the selected design of experiment table. The maximum tensile strength, hardness developed in each set of combinations is noted and tabulated in table 5[11]. For each experiment in the orthogonal array, signal to noise (S/N) ratio is calculated. The quality response is mainly divided in to three main types; the larger-the better (LTB), the smaller-the better (STB) and the nominal-the best (NTB) [12] and [13].

SNs = -10 $_{\log 10}(1/k \sum_{r=1}^{k}(y^2 i_r)$) $for\ STB$
SNs =10 $_{\log 10}(S_i^2/\bar{y}_i^2)$ $for\ NTB$
SNs =-10 $_{log10}$ $(1/k \sum_{r=1}^{k}(1/y^2 i_r)$) $for\ LTB$

Where y_i is the calculated average and S_i is the standard deviation.y_{ir} indicates at the i^{th} experiment or measured characteristic value. k denotes the number of measurements. The S/N ratio is calculated based on LTB criterion and tabulated in the table 5. The S/N ratio is calculated based on STB criterion and tabulated in the table 6[14] and [15].

4. RESULTS AND DISCUSSIONS

In the present study the effect of process parameters on the tensile strength, hardness, ductility was examined. The experimental results of tensile strength, hardness were transferred to S/N ratio. The 9 S/N ratios were *tabulated in the table 5. The experimental results of ductility were* transferred to S/N ratio. The 9 S/N ratios were tabulated in the table 6. Statistical software MINITAB is used for calculating mean and S/N ratio by using the LBT and SBT criterion. Then the graphs are plotted as shown in the fig 3, 4 & 5. According to Taguchi's idea, maximizing signal to noise ratio will get maximum robustness. The main effects of all control variables are obtained from the graph.

Table 5 Experimental results for tensile strength, hardness and S/N ratios of FSW butt welds

Runs	N	F	D	Tensile strength (N/mm^2)	S/N Ratio	Hardness (RHN)	S/N Ratio
1	1120	25	2.5	112.65	41.03	46	33.25
2	1120	40	4	141.47	43.01	49.125	33.82
3	1120	50	6	129.83	42.27	52	34.32
4	1400	25	4	151.68	43.62	45	33.06
5	1400	40	6	157.66	43.95	45.125	33.08
6	1400	50	2.5	123.33	41.82	56.75	35.07
7	1800	25	6	153.83	43.74	47.125	33.46
8	1800	40	2.5	115.57	41.26	47.875	33.60
9	1800	50	4	136.78	42.72	49.25	33.84

Larger is better for tensile strength and hardness

$$S/N=-10_{log10} (1/k \sum_{r=1}^{k}(1/y^2 i_r))$$

From the above signal to noise ratios of each level of factor it is concluded that the optimum factor level to achieve Optimum tensile strength is 157MPa.which are having maximum s/n ratios i.e. speed is 1400 R.P.M and Feed is 40 mm/min and pin diameter is 6mm.Optimum factor level to achieve Optimum Hardness is 56.which are having maximum s/n ratios i.e. speed is 1400 R.P.M and Feed is 50 mm/min and pin diameter is 2.5mm.

Response Table for Signal to Noise Ratios Larger is better

Level	SPEED(N)	FEED(F)	PIN DIAMETER(D)
1	42.11	42.80	41.37
2	43.13	42.74	43.12
3	42.57	42.27	43.32
Delta	1.03	0.53	1.95
Rank	2	3	1

From the delta values it assigns the rank to each factor which are having more influence on the mean of tensile strength, from the results of S/N ratio also it is observed that pin diameter is the dominant factor for tensile behavior.

Response Table for Signal to Noise RatiosLarger is better

Level	SPEED(N)	FEED(F)	PIN DIAMETER(D)
1	33.80	33.26	33.98
2	33.74	33.51	33.58
3	33.64	34.42	33.62
Delta	0.16	1.15	0.40
Rank	3	1	2

From the delta values it assigns the rank to each factor which are having more influence on the mean of hardness, from the results of S/N ratio also it is observed that tool traverse feed is the dominant factor for hardness distribution.

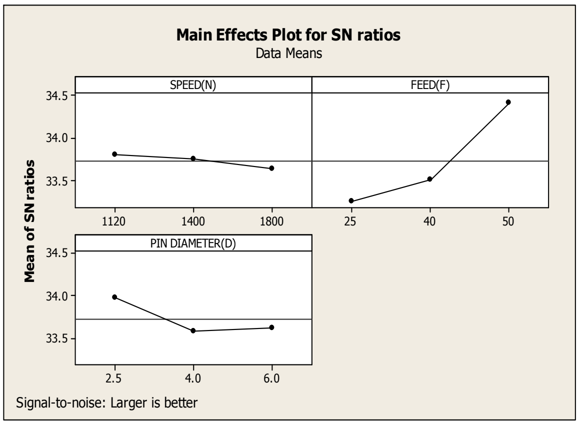

Fig 3. Graphical results for tensile strength

Based on the above graph, the optimum conditions for the tensile strength are (a): 1120rpm speed (b):50mm/min feed (c): 2.5 pin diameter.

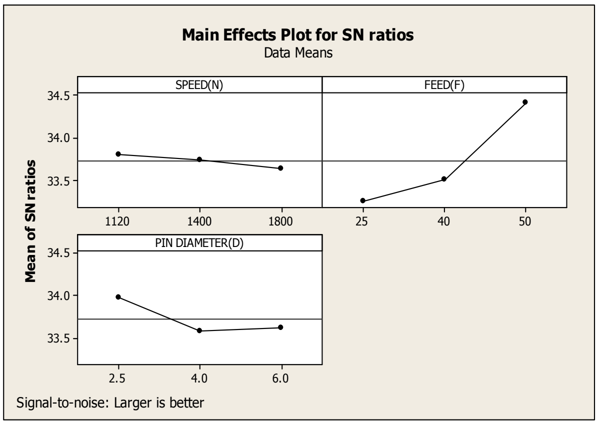

Fig 4. Graphical results for hardness

Based on the above graph, the optimum conditions for the hardness are (a): 1120rpm speed (b):50mm/min feed (c): 2.5 pin diameter.

Table 6 Experimental results for (%of elongation) and S/N ratios of FSW butt welds

Runs	N	F	D	Ductility(%)	S/N Ratio
1	1120	25	2.5	33.33	-30.45
2	1120	40	4	36.66	-31.28
3	1120	50	6	26.66	-28.51
4	1400	25	4	30	-29.54
5	1400	40	6	33.33	-30.45
6	1400	50	2.5	25	-27.95
7	1800	25	6	31.66	-30.01
8	1800	40	2.5	21.66	-26.71
9	1800	50	4	28.33	-29.046

Smaller is better for %elongation

$$S/N = -10 \log_{10}\left(1/k \sum_{r=1}^{k} (y^2 i_r)\right)$$

From the above signal to noise ratios of each level of factor it is concluded that the optimum factor level to achieve Optimum %of elongation is 21.66.which are having maximum s/n ratios i.e. speed is 1800 R.P.M and Feed is 50 mm/min and pin diameter is 4mm.

Response Table for Signal to Noise Ratios Smaller is better

Level	SPEED(N)	FEED(F)	PIN DIAMETER(D)
1	30.09	30.00	28.38
2	29.32	29.49	29.96
3	28.59	28.51	2966
Delta	1.50	150	1.58
Rank	2	3	1

From the delta values it assigns the rank to each factor which are having more influence on the mean of %of elongation, from the results of S/N ratio also it is observed that pin diameter is the dominant factor for ductility.

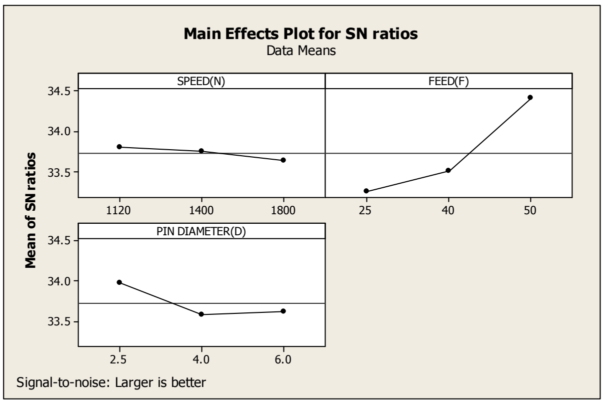

Fig 5: Graphical results for ductility

Based on the above graph, the optimum conditions for the hardness are (a): 1800rpm speed (b):25mm/min feed (c): 4mm pin diameter.

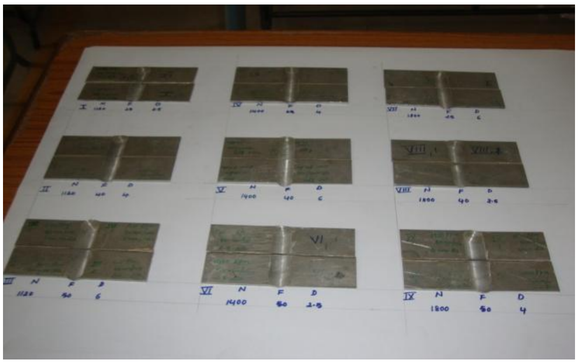

Fig: 6 Samples of testing pieces

5. CONCLUSION

The butt joining of Aluminum alloy was successfully carried out using FSW technique. The samples were characterized by mechanical properties like tensile strength, hardness, ductility. The following conclusions were made from the present investigation.

- I Observed that the tool traverse feed having more influence on the mean of tensile strength. And Mean of Hardness.
- Observed that the pin diameter having more influence on the mean of %elongation.
- Observed that the 1400 rpm, 40 mm/ min feed and 6mm pin diameter was best to maximize the tensile strength.
- Observed that the 1400 rpm, 50 mm/ min feed and 2.5mm pin diameter was best to maximize the hardness.
- Observed that the 1800 rpm and 50 mm/ min feed and 4mm pin diameter was best to minimize the ductility.

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