Experimental Investigation in Friction Stir Welding of Dissimilar Aluminum Alloys AA2014 and AA6063 using Taguchi Technique

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Abstract - Aluminum alloys are broadly used in aerospace industry, automotive industry, railways and in marine industry due to its resistance to corrosion, light weight and high strength to weight ratio. The aim of the present research is to investigate and analyze the friction stir welding of dissimilar aluminum alloys AA2014 and AA6063.The effect of input process parameters such as Tool rotational speed, Tool transverse speed and Tool tilt angle are considered and the output responses like tensile strength, yield strength, % of elongation are calculated.. Taguchi L9 orthogonal array was formed to conduct the experiments. The optimum input process parameters were obtained by Taguchi S/N ratio calculations and their values are 700 rpm, 200mm/min and 0^0 respectively. The individual significance of each input parameter was evaluated by ANOVA method which indicates that tool rotational speed is having higher contribution of 42.72% followed by tool tilt angle and tool transverse speed.

Keywords : Friction stir welding, Taguchi method, ANOVA analysis, Tensile strength, yield strength, Percentage of elongation

1. INTRODUCTION

Many applications in automobile, aerospace and military purposes need to join dissimilar metals. The joining of dissimilar metals by using conventional methods faces with the problems like solidification cracking and intermetalic compounds formation [1]. Therefore, the solid state joining methods have received much attention. Solid state welding processes are ideally suited for welding of dissimilar aluminum alloys. These processes do not involve melting so that the weld solidification cracking does not occur. Similarly the problems such as porosity, segregation, brittle intermetallic formation and heat affected zone liquation cracking were avoided. As well as there is no need of filler metal this does not involve compatibility of composition between dissimilar aluminum alloys. Friction stir welding of dissimilar alloys has attracted extensive research interest [2].

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1.1 Principle of Friction Stir Welding

Friction Stir Welding is a solid state joining process, which means that the objects are joined before reaching the melting point. In FSW process, a cylindrical- shouldered tool with a profiled pin is rotated at a constant speed and fed at a constant transverse rate into the joint line between two pieces of sheet or plate material. The parts to be joined are clamped rigidly in order to prevent the joint faces from being forced apart. The tool pin length is kept slightly less than the weld depth required so that there should be an intimate contact of shoulder with the work surface.

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Fig -1: Sample Friction stir weld butt joint

Fig – 2: Plates in clamped position in FSW machine

There is generation of frictional heat between the wear resistant welding tool shoulder and pin with the material of the work pieces. This generated heat, along with the heat generated by the mechanical mixing process and the adiabatic heat within the material, cause the stirred to soften without reaching the melting point. As the pin is pushed toward welding, the primary face of the pin, assisted by an exceptional pin profile, forces plasticized material to the back of the pin while applying an substantial force to consolidate the weld metal. The welding of the material is empowered by plastic deformation in the solid state [3].

2. EXPERIMENTAL DETAILS

The aluminum alloys used for this research work are AA2014 and AA6063 of dimension 100*75*6 mm . The chemical properties of the material are shown in table 1.

Table – 1 : Chemical properties of AA2014 and AA6061

Element	Weight %	
	AA2014	**AA6063**
Si	0.5% - 1.2%	0.2% - 0.6%
Mg	0.2% - 0.8%	0.45% - 0.9%
Cu	3.9% - 5%	Maximim 0.10%
Mn	0.4% - 1.2%	Maximum 0.10%
Zn	0.25%	Maximum 0.10%
Cr	0.1%	0.10%
Al	Remaining	Remaining

Plates having dimensions of 100*75*6 mm in AA2014 which is placed on the advancing side[4] and AA6063 on the retreating side and weldments are done. In this investigation a H13 Tool steel of cylindrical pin shape was used. The tool possesses a shoulder diameter of 18mm and 6mm pin length of cylindrical geometry. The three input parameters such as rotational speed, transverse speed and tool tilt angle are taken into consideration. The parametric range and their levels are listed in Table 3.

Table – 3 Process parameter and their levels

Parameters	Level 1	Level 2	Level 3
Tool tilt angle (degree)	0	1	2
Rotational speed (rpm)	500	700	900
Transverse Speed(mm/min)	100	160	200

2.1 Taguchi's Method

The Taguchi method was used to optimize the welding parameters. This method is a time saving technique to optimize the process parameters. In this method, an appropriate orthogonal array should be selected depending on the total degree of freedom(DOF). The degree of freedom for the orthogonal array should be greater than or at least equal to those for the process parameters. So, L9 orthogonal array was selected which has a degree of freedom of 8[5]. Nine experimental runs were conducted as per Taguchi L9 orthogonal array.

2.2 Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) test was performed to identify the process parameters that are statistically significant[6]. The purpose of the ANOVA test is to investigate the significance of the process parameters which affect the tensile strength, yield strength and hardness of FSW joints.

2.3 S/N Ratio

The SN ratio is calculated based on the quality of the characteristics intended. The objective function described in this investigation is maximization of the tensile strength so; the larger the better SN ratio is to be calculated[7]. The formula used for calculating the SN ratio is given below.
For larger-the-best:

$$s/n = -10\log_{10}(1/n) \sum n_{i=1} (1/y_{ij}^2)) \qquad - \quad (1)$$

Where, n represents number of reproductions, y represents corresponding quality characteristics value. larger-the-best, equation has been employed to find the S/N ratio values of output parameters.

Table – 4: Taguchi's L9 orthogonal array

S. No	Rotational speed (rpm)	Transverse Speed (mm/min)	Tool Tilt angle (degree)
1	500	100	0
2	500	160	1
3	500	200	2
4	700	100	1
5	700	160	2
6	700	200	0
7	900	100	2
8	900	160	0
9	900	200	1

2.4 *Tensile Testing of the Weld Joints*

All weld joints were prepared as per the design matrix and test specimens from these joints were prepared for mechanical testing. Trial experiments were conducted to determine the working range of welding parameters. The initial joint configuration was obtained by securing the plates in position using mechanical clamps on FSW machine. Tensile test samples were prepared from weld joints according to the ASTM E-8 specification[8]. A universal testing machine is used to test the tensile strength of the weld joints.

Figure. 3 : Tensile test conducted in UTM

3. Results and Discussion

Experimental data are used to find out S/N ratio values. The calculated S/N ratio values are tabulated in Table 5. The factorial design and Taguchi's Analysis were done by using MINITAB 16 software[9].

Table 6. Response Table for Signal to Noise Ratios Larger is Better

Level	Tool Rotational Speed (rpm)	Tool Transverse Speed (mm/min)	Tool tilt Angle (Degrees)
1	28.08	29.12	28.84
2	30.94	28.84	29.52
3	28.83	29.89	29.49
Delta	2.86	1.05	0.68
Rank	1	2	3

3.1 . Analysis of Variance (ANOVA)

ANOVA is a statistical tool which aims at evaluating the significant factor. It gives a clear picture as to how far the process parameter affects the tensile strength and the level of significance of the each factor involved in the analysis. Table 6. shows the ANOVA table for signal to noise ratio for tensile strength. The main effects for SN ratio are plotted in Fig. 4. The F test is being carried out to study the significance of the process parameter. The high F value indicates that the factor is highly significant in affecting the response of the process. In this investigation, tool rotational speed is a highly significant factor and plays a major role in affecting the tensile strength of the weld

Table – 5: Experimental Results

S.No	Tool Rotational Speed (rpm)	Tool Transverse Speed (mm/min)	Tool Tilt Angle (degrees)	Yield strength (MPa)	Ultimate tensile Strength (MPa)	% of Elongation	S/N Ratio
1	500	100	0	79	129	14.5	27.8019
2	500	160	1	75	124	155	28.3316
3	500	200	2	86	131	15	28.1080
4	700	100	1	78	135	19.5	30.2242
5	700	160	2	83	137	21.5	31.0388
6	**700**	**200**	**0**	**84**	**132**	**23**	**31.5708**
7	900	100	2	74	128	17.5	29.3194
8	900	160	0	76	94	13.5	27.1570
9	900	200	1	78	125	19	30.0022

Table 7. Analysis of Variance for Tensile Strength

Source	DF	Adj SS	Adj MS	F-value	p-value	%contribution
Tool Rotational Speed	2	557.56	278.78	3.16	0.240	42.72
Tool Transverse Speed	2	274.89	137.44	1.56	0.391	21.07
Tool Tilt Angle	2	296.22	148.11	1.68	0.373	22.70
Error	2	176.22	88.11			13.5
Total	8	1304.89				

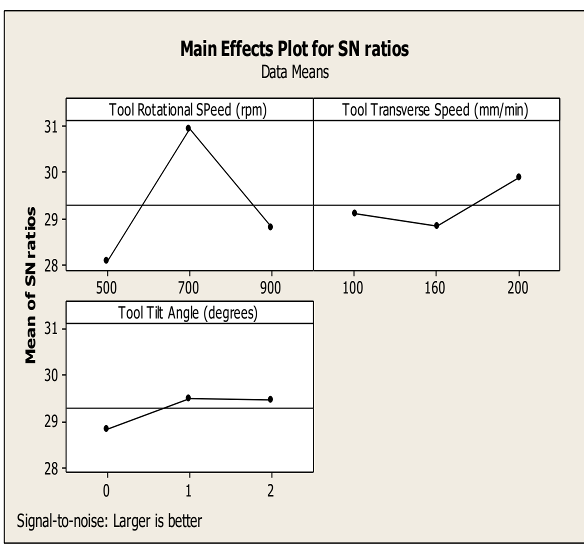

Fig .4 : S/N ratio graph

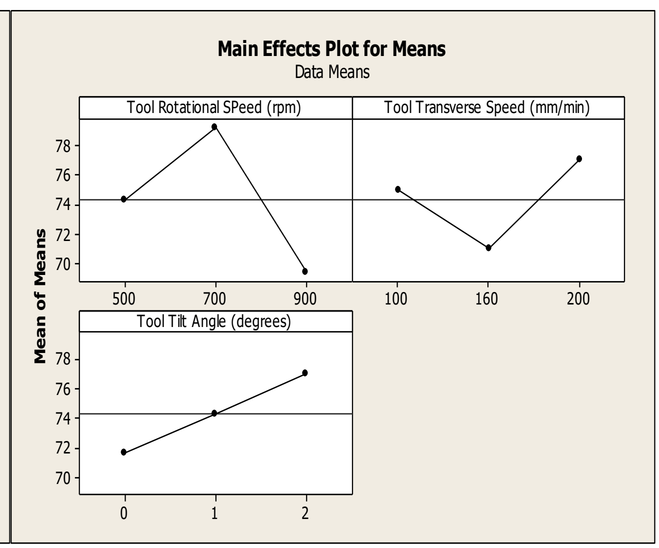

Fig 5 : Means Graph

3.2 Estimation of Optimum Performance Characteristics

Based on the highest values of the S/N ratio in table 5 and the signal-to-noise ratio plot obtained by Minitab software, it can be inferred that signal to noise ratio value is increased with increased tilt angle and tool rotational speed and then decreases. But when transverse speed increases the signal to noise ratio decreases and then increases.. The optimum friction stir welding parameters for joining dissimilar AA2014-AA6063 plates are

- Tool Rotational speed : 700 rpm
- Tool Transverse speed : 200 mm/min
- Tool Tilt Angle : 0 Degree

After the optimum condition was determined, the optimum performance of the response under the optimum condition was predicted[10]. The optimum value of the response characteristic is estimated as follows.

$\mu = T/N+(\delta_{RS2} - T/N) + (\delta_{TS3} - T/N) + (\delta_{TA3}-T/N)$

Where T/N is overall mean of tensile strength and δ_{RS2} is the average mean of tensile strength at second level , δ_{TS3} is the average mean of tensile strength at level 3,δ_{TA1} is the average mean of tensile strength at third level. Substituting the values for above terms we can find out the predicted value of tensile strength.

$$\mu = 130.11 \text{ MPa}$$

The experimental value for the optimum contribution is 132MPa. Hence the predicted value 'μ' is close to the experimental value with deviation of 1.43%.

4.0 Conclusion

Experimental work is done in friction stir welding of dissimilar aluminum alloys AA2014 and AA6063 to find the effect of important process parameters like tool rotational speed, tool transverse speed and tool tilt angle on determining mechanical properties like tensile strength, yield strength, % of elongation. It is found that tool rotational speed holds the main response in determining the signal to noise ratio followed by tool transverse speed and tool tilt angle. The optimum level of parameters in determining the output responses are tool rotational speed of 700rpm, tool transverse speed of 200mm/min and tool tilt angle of 0^o which gives tensile strength of 132MPa,yield strength of 84MPa, Elongation of 23% . The optimum parameter setting is applied in the prediction calculation which shows only 1.43% deviation. ANOVA analysis shows that tool rotational speed contributes by maximum 42.72 followed by tool tilt angle by 22.77% and tool transverse speed by 21.07%.The Friction stir welding of dissimilar alloys AA2014 and AA6063 is new and innovative one and the results obtained will be useful for further research.

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