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EXPERIMENTAL INVESTIGATION OF FRICTION STIR WELDING PROPERTIES OF AL 6063 ALLOYS WELDED JOINTS

Truman Edisonraj J[1] and P.Sathyabalan[2]

[1]PG Student, [2]Professor

Department of Mechanical Engineering, Kumaraguru College of Technology, Coimbatore, Tamil Nadu

***Abstract* - Friction stir welding (FSW) is a solid state welding process for joining metallic alloys. FSW has been employed in several industries such as aerospace and automotive for joining aluminium, magnesium and copper alloys. The various parameters such as tool rotational speed, welding speed, axial force play a vital role in the FSW process. The aim of this study is to investigate the effect of tool rotational speed/spindle speed, welding speed, on welding strength at 6mm thicknesses of 6063 aluminium alloy. In this work the weld tensile strength was measured and the parameters are optimized by Design of experiments. The optimized results show that the thickness depends on spindle speed and weld speed to obtain the good weld. Increasing the size of the plate may require to increase the number of sides of the polygon for effective stirring process. For a smaller plate size it generally requires less number of sides of the polygon for the effective stirring. Double side weld reduces the weld bead size to half of its original; consequently the thermo-mechanically affected zone and heat affected zone are reduced. This is because of the material softening obtained at higher temperatures. Excess heat energy in hot welding causes material softening and produces fine grains in a disturbed manner.**

***Keywords* - Friction Stir Welding, Tensile Strength, Spindle Speed, Welding Speed, Plunge Depth**

I. INTRODUCTION

The friction stir welding (FSW) [1] is a solid state joining process, developed by The Welding Institute (TWI). The material to be joined is plasticized by friction between surface of the plates and the contact surface of the tool. The tool consists of two main parts namely the shoulder and pin [2-4].

The generation of heat is done by shoulder while the pin mixes the material of the components to be welded, thus creating the joint. The FSW machine parameters are spindle / tool rotation speed, welding speed and plunge depth. Tool shoulder penetration is considered as the axial force in FSW machine. The main objective of the work is to perform tensile test on friction stir welded AA 6063, which has been welded by following the Taguchi experimental design matrix . An attempt has been made to optimize the parameters in order to maximize the tensile strength of FSW joint made up of 6mm thickness AA6063 material.

FSW has advantages in that it can weld high strength materials and high melting temperature materials with low part distortion and residual stresses.

II. EXPERIMENTAL WORK

The experiments were carried out on conventional vertical milling machine. Process parameters such as spindle speed, welding speed, plunge depth were considered. After several trials, the range of tool rotational speed and welding speed were taken from 700 rpm to 2000 rpm and 0.8 mm/sec to 4 mm/sec respectively. Shoulder penetrations are 0.0 mm, 0.1 mm and 0.2 mm. Non-consumable tools made of high speed steel were used to fabricate the joint.

This study uses circular tool profile of high speed steel. Friction stir tool of above pin profile were shown in the Figure 1. In this study shoulder diameter of 25 mm and length of 100 mm was used. The 6xxx-group is high strength AL-Mg-Si alloys that contain manganese to increase ductility and toughness. Aluminum alloy 6082 has the highest strength among the 6000 series alloys with excellent corrosion resistance property.

Trial runs were conducted to find the upper and lower limit of process parameters, by varying one of the parameters and keeping the rest of them at constant values.

Fig 1 Friction stir tool

Feasible limits of the parameters were chosen in such a way that the joint should be free from visible defects. The selected process parameters with their limits, units and notations are given in Table 1. Taguchi Experimental Design Technique (Orthogonal Array) assesses the influence of process factors on response, the means and the signal-to-noise ratios (S/N) for each control factors are to be calculated.

Signals are indicators of effect on average response and noises are the measure of deviations from experiment output. In this study, S/N ratio was chosen according to correction, 'larger-the-better' in order to maximize the response. In Taguchi Method, S/N ratio can be expressed as $\frac{S}{N}$ = -log $\left(\frac{1}{n}\right)$ Σ $1/y^2$. In the present study, Tensile Strength (TS) data is analyzed to determine the effect of FSW process parameters. Experimental results are transformed into means and S/N ratio.

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Table 1: Process Parameter with their range and values at three levels

FACTOR	LEVELS	VALUES
SPINDLE SPEED (rpm)	3	700,1400,2000
WELDING SPEED (mm/s)	3	0.8,2.4,4.0
PLUNGE DEPTH (mm)	3	0.0,0.1,0.2

III. RESULTS AND DISCUSSION

Aluminium 6063 Alloy has been cut to dimensions of 100 mm x 100 mm x 6 mm. Square butt joint configuration was prepared to fabricate FSW joints with the non-consumable HSS tool. The friction stir welding was performed in vertical milling machine as per the L9 orthogonal array shown in Table 2. Taguchi's orthogonal array method was used for design of experiments with three factors and three levels.

The material was welded according to specification of welding parameters. The Welded specimens were fabricated as per the American Society for Testing of Materials (ASTM E8) standards using a wire cut EDM machine to evaluate the tensile strength of the joints. Tensile strength of the FSW joints was evaluated by conducting test in Micro tensile testing machine. The tensile strength in terms of means and S/N ratios were shown in the Table 2.

The results from the tensile tests were given as input to the Minitab software for getting optimized parameter levels to achieve maximum tensile strength of the friction stir welded joints

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Table 2: Design table and Experimental value of Tensile Strength (Mean and S/N Ratio)

SPINDLE SPEED (rpm)	WELDING SPEED (mm/s)	PLUNGE DEPTH (mm)	TENSILE STRENGTH (N/mm^2)	S/N Ratio (No Unit)
700	0.8	0.0	65.077	36.2686
700	2.4	0.1	112.958	41.0583
700	4.0	0.2	76.575	37.6817
1400	0.8	0.1	114.184	41.1521
1400	2.4	0.2	93.992	39.4618
1400	4.0	0.0	81.604	38.2342
2000	0.8	0.2	113.278	41.0829
2000	2.4	0.0	66.246	36.4232
2000	4.0	0.	150.956	43.5770

During tensile testing, the specimen was broken at retreating side of the heat affected zone as This shows that the bond formed between the two plates is good. The results of the tensile tests were tabulated and were used as input for optimization of the welding parameters. Fig 2a & 2b shows the specimens before and after tensile testing. Analysis of variance (ANOVA) for means has been performed to identify statistically significant process parameters, which affect TS of FSW joints as shown in Table 6. Results of ANOVA indicate that the selected process parameters were highly significant factors affecting TS of FSW joints.

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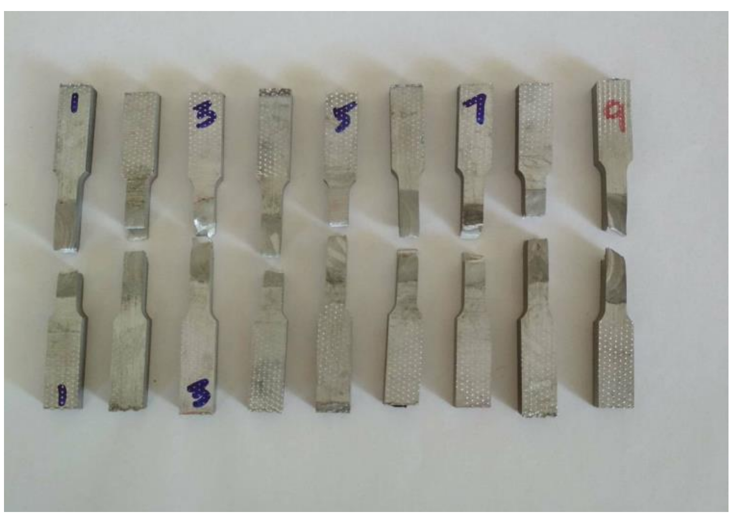
Fig 2a Before Tensile Testing

Fig 2b After Tensile Testing



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Mean response of raw data and S/N ratio of TS for each parameter at level 1, 2 and 3 were calculated and presented in Fig 3. It was observed that the larger S/N ratio corresponds to better quality characteristics. Therefore, optimal level of process parameter is the level of highest S/N ratio. Mean effect and S/N ratio calculated by statistical software indicate that the TS was maximum while using the parameter level of 900 rpm Spindle Speed, 2.4 mm/sec weld speed, 0.20 mm shoulder penetration. Also the response table ranking given in Table 3, interprets the degree of parameter which influences on response. The first dominant parameter was a welding speed which is followed by spindle speed, and plunge depth.

Fig 3 Main Effects Plot for SN ratios of three levels

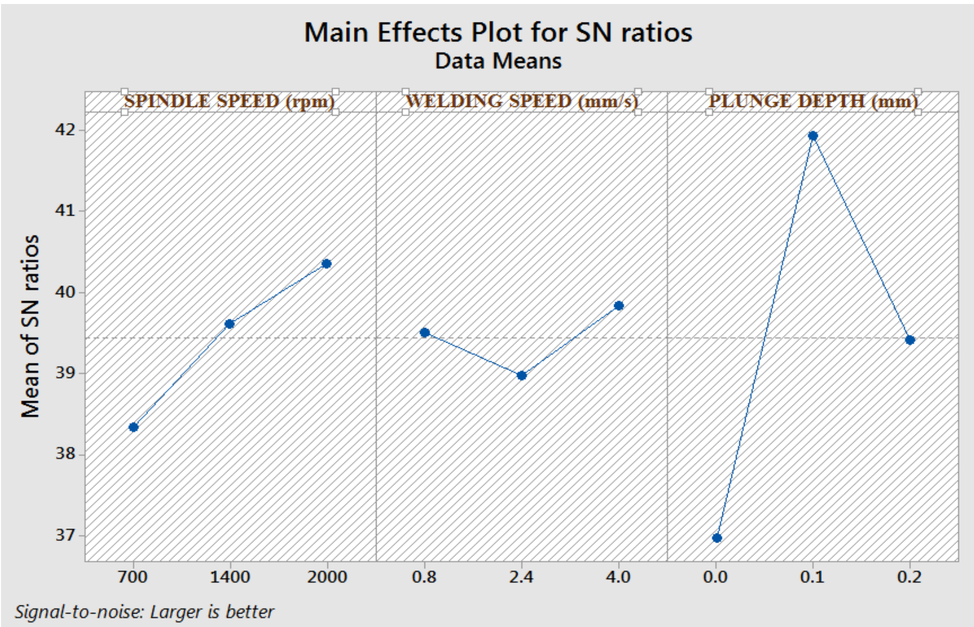

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Table 3 Response Table for S/N Ratio and Means

LEVELS	**CONTROL FACTORS**		
	SPINDLE SPEED (rpm)	WELDING SPEED (mm/s)	PLUNGE DEPTH (mm)
1	38.34	39.50	36.98
2	39.62	38.98	**41.93**
3	**40.36**	**39.83**	39.41
DELTA	2.02	0.85	4.95
RANK	2	3	1

Table 6:ANOVA for Tensile Strength (Means)

SOURCE	**DF**	**Adj SS**	**F-Value**	**P-Value**
SPINDLE SPEED (rpm)	2	961.1	480.5	0.384
WELDING SPEED (mm/s)	2	215.7	0.36	0.736
PLUNGE DEPTH (mm)	2	4577.2	7.63	0.116
ERROR	2	600	300	
TOTAL	8	6353.9		

IV. CONCLUSION

Taguchi's Orthogonal Array has successfully used to find the optimum level setting of process parameters and response table ranking interprets the degree of parameter influencing on response. As a result the most influencing parameter is welding speed and the least influencing parameter is plunge depth. Optimum process parameter levels which are found to achieve greater tensile strength are such as 2000 rpm spindle speed; 4.0 mm/sec weld speed.

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