INVESTIGATION OF FSW PROCESS PARAMETERS BY TAGUCHI METHOD OF 6061- 6082 ALUMINIUM ALLOYS

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ABSTRACT

The friction stir welding is recently developed solid state welding process used in many engineering industry to overcome the problem of fusion welding. The objective of present work is to find the effect of parameters like tool rotation speed, welding speed and tool tilt angle on tensile strength and also to get the optimal parameters combination for maximum tensile strength. In these work two diverse base materials has been chosen as AA6061 and AA6082 for butt joint. Taguchi L9 orthogonal array with three factors and three levels is utilized for design of experiment. Besides the tensile strength was obtained using tensile testing machine. Signal to Noise(S/N) ratio and Analysis of variance (ANOVA) was carried out to find the most significant factor and percentage contribution of individual factor for Tensile strength. The experimental results were analyzed by a statistical software MINITAB.

Keyword: - *Friction stir welding, Aluminium alloy, Taguchi, L9 Orthogonal array, S/N ratio, ANOVA, MINITAB*

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1. INTRODUCTION

Friction Stir Welding (FSW) is a revolutionary solid state welding technique invented at The Welding Institute (TWI) in 1991 [1]. The FSW process operates below the solidus temperature of the metals being joined and hence no melting takes place during the process. This process is a derivative of the conventional friction welding and is being used to produce continuous welded seams for plate fabrication [2]. Since its invention in 1991, continuous attempts have been made by researchers to understand, use and improve this process. Friction Stir Welding is a hot-shear joining process in which a non-consumable, rotating tool plunges into a rigidly clamped work piece and moves along the joint to be welded [3]. The cylindrical rotating tool used in FSW has a profiled threaded or unthreaded probe of length less than the weld depth, extruding from the tool shoulder. Localized heating softens the material around the tool pin and the combination of both rotational and translational movement of tool movement of material takes place from front of the tool to the back of the tool that is called as advancing and retreating side[4] .The working principle of FSW process is presented in figure 1.

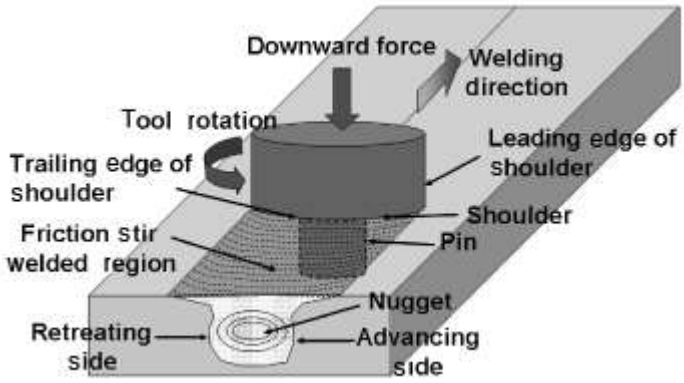

Fig-1 Friction stir welding Schematic diagram [4]

2. LITERATURE REVIEW

Lots of researchers have been studied about the effect of friction stir welding parameters and metallurgical properties of similar and dissimilar aluminium alloys joint. Elatharasan et al. [5] Ultimate tensile strength of the FSW joints increased with increase of rotational speed, welding speed and tool axial force up to a maximum value, and then decreased. Tensile elongation increases with increase of rotational speed and axial force, but decreased by increasing of welding speed, continuously. Kwon et al. [6] Investigated the influence of the tool rotation speed on the Tensile strength of the friction stir welding aluminium 1050 and concluded that Tensile strength of the weld increased significantly with decreased tool rotation speed. Boz et al. [7] the tensile strength of the defect-free joint increases with the welding speed, and the maximum tensile strength is equivalent to 69% of that of the BM. The tensile fracture location is in the HAZ adjacent to the TMAZ on the AS. Anil Kumar K. S. et al [8] Reported that tensile strength of welded joints increased with increasing in rotational speed from 355rpm to 560 rpm, traverse speed from 12.5mm/min to 20 mm/min but further increase in the rotational speed from 560rpm to 900rpm decreased the tensile strength of the joints. S. M. Bayazid et al.[9] studied that 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 aluminium alloys joints. Hirano et al. [10] performed dissimilar FSW of Al 1050 and AZ31 Mg with reasonable mechanical properties. Likewise, Kostka et al. [11] found that during friction stir welding of Al 6040 to AZ31 alloys, relatively high travel speeds (225 mm/min) and tool rotation speeds (1400 r/min) were necessary to obtain successful joints. Galvao et al. [12] investigated the influence of the FSW process parameters on the formation and distribution of inter-metallic phases at the interface of the joint between copper. It has been pointed out that under lower heat input, only a thin iner-metallic layer distribution along Al/Cu interface was formed inside the nugget, reported that increasing the heat input promoted material mixing and the formation of increasing amount of a rich inter-metallic structure. Eramah et al.[13] have been performed on formulization and optimization of effects of FSW parameters on mechanical and metallurgical properties. Taguchi is a useful method which, specify effectiveness of involved parameters on the main purpose of process. Taguchi method, have been used for optimization of metallurgical processes in past. Jayaraman et al.[14] studied the friction stir welding on A319 cast alloy and showed that vertical force has maximum influence on tensile strength of welded joint as compared to tool rotational speed and welding speed. In other words it can be stated that the total effect of rotational speed and tool travel speed on tensile strength of welded joint, is less than the effect of vertical force. Kumbhar et al.[15] selected the various process parameter that control the quality of the weld are tool rotation speed, axial force, traverse speed and tool tilt angle and optimize these parameter to obtain the defect free welded joints. It is also observed that during welding operation an extensive deformation at the nugget zone that evolve microstructure that affects the mechanical properties of friction stir welded joints. Nourani et al.[16] showed in their experiment that by optimization and formulization of welding parameters of two distinct alloys along with time saving there will reduction of cost also.

Therefore by all these above study it has been tried to study the effect of various process parameter like tool rotational speed, travel speed and tool tilt angle on properties of dissimilar alloys joint, so that effectiveness of each parameter on tensile strength of friction stir welding process for AA6061 and AA6082 joints could be determined.

3. EXPERIMENTAL PROCEDURE

The basic concept behind the friction stir welding is very simple that a non-consumable rotating with specially designed pin and shoulder is inserted into abutting edge of the two parts two be joined and travel along the line of joint. The experiments were performed on vertical milling machine to weld AA6061 and AA6082 alloys. The FSW operation has several steps, it starts with facing the work pieces and clamping then the allow the pin plunge and penetrates into plates until the shoulder has inserted into the material at prescribed depth that enables sufficient pressure and produce enough heat by friction.

Taguchi is most powerful statistical technique for process design and for solving production problem. In this number of experiment depends upon number parameters and their levels. In current work three parameters and three levels were selected based on several trial experiments within the range. FSW parameters and their level is presented in table 1. Taguchi L9 orthogonal array has been opted for experimentation which composed nine different runs presented in table 2. The selected parameters for this study were tool rotational speed, tool travel speed and tilt angle. Taguchi method was used for experimental data and the signal to noise ratio (S/N) for each level of process parameters is measured based on the S/N analysis. S/N ratio has been calculated for higher the better according to formula which is mentioned in equation1. ANOVA analysis has been done to access the significance of each process parameter on the tensile strength of welded joints. Now a day's aluminium alloys are used in many applications because it shows a very unique characteristic combination of high strength and low weight so it is very attractive in air frame work and in any aerospace industry. 6 mm thickness 6061-T6 Al and 6082-T6 alloys plates was used as base material. Commercially available two different aluminium alloys were used for welding which chemical compositions are listed in Table 3. AA6061 of size 100 × 50 × 6 mm on advancing side (which supports the weld in the direction of tool travel) and aluminium 6082 of size 100 × 50 × 6 mm on retrieving side (which opposes the weld in opposite direction of tool travel. Usually material with high hardness used on advancing side among aluminium 6061 and aluminium 6082, aluminium 6061 is harder so it is used on advancing side. After welding operation the tensile test samples were prepared in perpendicular direction to the welding direction and tests were performed on tensile testing machine at room temperature which is tabulated in table 4.

Table 1: Factors and their level

Factor	Unit	Level 1	Level 2	Level 3
Tool rotation speed	rpm	900	1120	1400
Welding speed	mm/sec	40	60	80
Tool tilt angle	degree	0	1	2

Table 2: Standard L9 orthogonal array in coded form

Run	Tool rotation speed	Traverse speed	Tilt angle
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

Table 3: Chemical Composition

Material	Mg	Mn	Cu	Cr	Si	Fe	Al
AA6061-T6	1.20	0.15	0.20	0.04	0.60	0.75	Balance
AA6082-T6	1.20	1.00	0.10	0.25	1.3	0.50	Balance

4. RESULTS AND DISCUSSION

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. Control factors are those design and process parameters that can be controlled. Noise factors can't be controlled during production or product use, but can be controlled during experimentation. In a Taguchi designed experiment higher values of the signal-to-noise (S/N) indicate control factor settings that minimize the effects of the noise factors. S/N ratio is calculated using the formula for larger the better.

$$S/N = -10*\log (\Sigma (1/Y^2)/n) \text{ ---------- (1)}$$

Where, Y- Responses for the given factor level combination

n- Number of response in factor level combination

After design of experiment and plate preparation as per dimension 9 experiments were conducted according to table 2 input parameters to obtain the tensile strength of joint. In current experimental study the tensile strength of welded joint had been investigated as main parameter in order to get with proper quality. Signal to noise ratio were calculated for each run to maximize the fluctuation in ultimate tensile strength by using MINITAB software and presented in table 4. Purpose of this study to achieve maximum tensile strength of joint for selected alloys. So the optimal level of parameters is the level which shows the highest S/N ratio and for higher the better quality characteristics the S/N ratio is calculated. As according to the results presented in the table 4 the optimal

combination of factors and levels were obtained by analyzing each calculated main values, in order to achieve the maximum tensile strength. As its clear that higher value of S/N ratio of an experiment corresponds to better quality of welded joint. Therefore the optimal condition is a combination with highest S/N ratio.

Table 4: L9 orthogonal array with actual value and their result

Exp.no.	Tool rotation(rpm)	Welding speed(mm/min)	Tilt angle(º)	UTS(MPa)	S/N ratio
1	900	40	0	88.342	38.9233
2	900	60	1	116.370	41.3168
3	900	80	2	106.907	40.5801
4	1120	40	1	91.071	39.1876
5	1120	60	2	128.505	42.1784
6	1120	80	0	111.268	40.9274
7	1400	40	2	102.818	40.2414
8	1400	60	0	145.912	43.2818
9	1400	80	1	133.333	42.4988

4.1 Analysis of Variance (ANOVA)

Analysis of variance is used to find the relative importance of welding process parameters on performance characteristic. The purpose of ANOVA test is to identify the significant parameters and effectiveness of each process parameter on Tensile strength. In this study Analysis of variance test was done to investigate the significance of various parameter like tool rotational speed, welding speed and tilt angle which are directly connected with the result Tensile strength of friction stir welding operation. ANOVA results display in table 5 and shows the contribution of the three parameters on Tensile strength. The percentage contribution by each of parameter is calculated using software by using formula that is summation of all the squared deviations and this can be used to show the importance of each process parameter involved as decision factor which show the change on the performance characteristic. A factor with higher percentage contribution shows that it has a great influence on the performance at a small variation and vice-versa. From the results obtained by ANOVA the parameter that mostly affects the Tensile strength in friction stir welding operation is the welding speed with 67.70%. The second parameter that is tool rotational speed contributed with 29.71% in the variation of tensile strength and last around 1% contribution of tool tilt angle. Analysis of variance is also almost similar to regression equation in that it is used to investigate and model the relationship between a response variable and one or more predictor variables.

Table 5: ANOVA table

Factor	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value	Contribution
Tool rotation	2	883.93	883.93	441.96	13.06	0.071	29.71%

speed							
Welding speed	2	2014.06	2014.06	1007.03	29.76	0.033	67.70%
Tilt angle	2	9.13	9.13	4.57	0.13	0.881	0.31%
Error	2	67.67	67.67	33.84			2.27%
Total	8	2974.79					100.00%

DF- Degrees of freedom, Seq SS - Sequential sum of squares, Adj SS - Adjusted sum of square, Adj MS - Adjusted mean square, F - Fisher ratio, P -probability that exceeds the 95 % confidence level

5. CONCLUSION

In this examination the impact of tool rotational speed, welding speed and tool tilt angle on strength of different aluminium compound AA6061-T6 and AA6081-T6 joint was researched by utilizing Taguchi strategy and ANOVA investigation. Two diverse aluminium combinations AA6061-T6 and AA6082-T6 are welded effectively through FSW under chose boundaries. From S/N proportion investigation the ideal condition for highest tensile strength is accomplished when the selected boundaries estimations of revolution speed, welding speed and tilt angle were 1400 rpm, 60 mm/min and zero degree individually. At this condition UTS was 145.912 MPa. At last ANOVA examination shows that the effectiveness of all chose boundaries like turn speed, welding speed and tool tilt angle on strength of joint are 30%, 70% and around 1% individually.

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