Friction stir welding of dissimilar aluminium alloys: AA6061-T651/ AA7075-T651

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Abstract: In this work joining of dissimilar AA6061 T651 and AA7075 T651 plate was carried out using friction stir welding (FSW) technique and the process parameters were optimized using Taguchi L_9 orthogonal design of experiments. The parameters taken into consideration were tool rotational speed, tool translational speed and plunge depth. The optimum process parameters were determined with reference to tensile strength of the joint. The predicted optimal value of tensile strength was confirmed by conducting the confirmation run using optimum parameters. This study shows that defect free, high efficiency welded joints can be produced using a wide range of process parameters and recommends parameters for producing best joint tensile properties. Based on the experimental data, empirical relations among the parameters correspond to each output feature has been developed using simple regression method.

***Index terms* - Friction stir welding, Tensile strength, Taguchi analysis.**

I.INTRODUCTION

Friction stir welding (FSW) is a solid state joining process, the joints are created by the combined action of frictional heating and mechanical deformation using a special rotating tool. A non-consumable rotating tool is pushed into the materials to be welded and the central pin or probe, followed by the shoulder, is brought into contact with the two parts to be joined. The rotation of the tool heats up and plasticizes the material it is in contact with and, as tool travels along the joint line, the material from the front of the tool is swept around the plasticized annulus to the rear, so eliminating the interface.

AA6061 T651- Aluminium alloy contains nominally 1.2% magnesium & 0.80% silicon with iron as the primary alloying element. It is used in applications requiring high strength to weight ratio, as well as good fatigue resistance. It is weldable only through friction welding, and has average machinability. It has good workability, medium static strength, high fatigue strength, good weldability, and very good corrosion resistance, especially in marine atmospheres. It also has the low density and excellent thermal conductivity common to all aluminium alloys.

AA7075 T651 aluminium alloy is a precipitation hardening aluminium alloy, containing magnesium and copper as its major alloying elements. It has good mechanical properties and exhibits good weldability. It is one of the most common alloys of aluminium for general purpose use. It is a versatile heat treatable extruded alloy with medium to high strength capabilities.

Robust design is an engineering methodology for obtaining product and process conditions, which are minimally sensitive to the various causes of variation to produce high quality products with low development and manufacturing costs. Taguchi parameter design is an important tool for robust design for performance, quality and cost. Taguchi method which combine the experiment design theory and the quality loss function concept have been applied to the robust design of products and process and have solved some confusing problems in manufacturing.

In full factorial design are considered, taguchi defines the quality of a product, in terms of the loss imparted by the product to the society from the time the product shipped to the customer. Some of these losses are due to deviation of the products functional characteristic from its desired value, and these are called losses due to functional variation. The uncontrollable factors which cause the functional characteristics of a product to deviate from their target values are called noise factors, manufacturing imperfections are due to variation of product parameter from unit to unit and product deterioration. The overall aim of quality engineering is to make products that are robust with respect to all noise factors.

Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. The experimental results are then transformed into a signal to noise (S/N) ratio. Taguchi recommends the use of S/N ratio to measure the quality characteristics deviating from the desired values. The S/N ratio for each level of process parameters is computed based on the S/N analysis. Regardless of the category of the quality characteristic, a greater S/N ratio corresponds to better quality characteristics. Therefore the optimal level of the process parameter is the level with the greatest S/N ratio.

- The parameter design of the taguchi method includes the following steps:
- Identification of the quality characteristics and selection of design parameters to be evaluated;
- Determination of the number of levels for design
- Parameters and possible interactions between the design parameters
- Selection of the appropriate orthogonal array and assignment of design parameters to the orthogonal array

- Conducting the experiments based on the arrangement of the orthogonal array
- Analysis of the experimental results using the S/N
- Selection of the optimal levels of design parameters

II. EXPERIMENTAL PROCEDURE

The experiments were conducted on a vertical milling machine where a tool is mounted in an arbor with a suitable collate. The vertical tool head can be moved along the vertical guide way (Z-axis), the horizontal bed can be moved along X and Y axis. The aluminium alloys (AA6061 T651 and AA7075 T651) has chosen for the study were 6mm thick plate of commercially available aluminium alloy. The weld faces of the test plates are machined and clamped in horizontal bed with zero root gaps aligned with the centre line of the FSW tool with the help of a specially designed fixture and back plate needs to be tightly clamped to one another. Figure 1 shows the experimental setup for clamping of FSW plate.

Figure 1. Experimental Setup describing clamping of FSW plate

The Aluminium alloy plates (AA6061 T651 and AA7075 T651) have been cut into the required size (100×75×6mm) by power hacksaw cutting, butt joint was configured. Before welding the plates, side and edge preparation done to fabricate FSW joints.

Taguchi analysis has been carried out in this project. Tool rotational speed, welding traverse speed, plunge depth are considered as process parameters. The levels and values are indicated in table 1.

Table 1: Process parameters and levels

Parameters	Level 1	Level 2	Level 3
Spindle speed (RPM)	900	1400	1800
Welding Traverse speed (mm/min)	65	100	135
Plunge depth (mm)	0.10	0.15	0.20

III. RESULTS AND DISCUSSION

Table 2. Tensile test Results

S.NO	Spindle Speed (Rpm)	Welding Traverse Speed (mm/min)	Plunge Depth (mm)	Ultimate Tensile Strength (N/mm^2)
1	900	65	0.10	91.227
2	900	100	0.15	85.613
3	900	135	0.20	75.560
4	1400	65	0.15	97.640
5	1400	100	0.20	136.653
6	1400	135	0.10	40.920
7	1800	65	0.20	115.310
8	1800	100	0.10	92.720
9	1800	135	0.15	98.560

The table 2, shows the tensile test results. In the present study, the ultimate tensile strength data were analyzed to find the impact of FSW weld parameters. Figure 2 shows the tensile test samples after testing.

Figure 2. Tensile tested samples

Main Effect Plot

The trial results were then converted into means and signal-to-noise (S/N) ratio. In this work, 9 means and 9 S/N ratios were computed and the estimated tensile strength, means and signal-to-noise (S/N) ratio are given in Table 3.

Table 3 Main effect on tensile strength(S/N ratio)

Parameter	Level 1	Level 2	Level3	Delta	Rank
Spindle speed	38.47	40.08	36.93	1.90	3
Welding Traverse speed	38.25	40.24	39.44	3.68	1
Plunge Depth	40.15	36.56	40.51	3.58	2

Every experiment will give the analysis of mean for better combination of parameters levels that guarantees a high level of ultimate tensile strength according to the experimental set of data. The mean response indicates to the average value of execution characteristics for every parameter at various levels. The mean for one level was computed as the average of all responses that were fund with that level.

The main effect plot is the graph of the average or means of response at each level of the factor or input parameter. The main effect plot helps one to determine the influence of individual input parameters on the responses measured, by disregarding the effect of any other input parameter present. Figure 3 shows the Main effects plot of S/N ratios for tensile test.

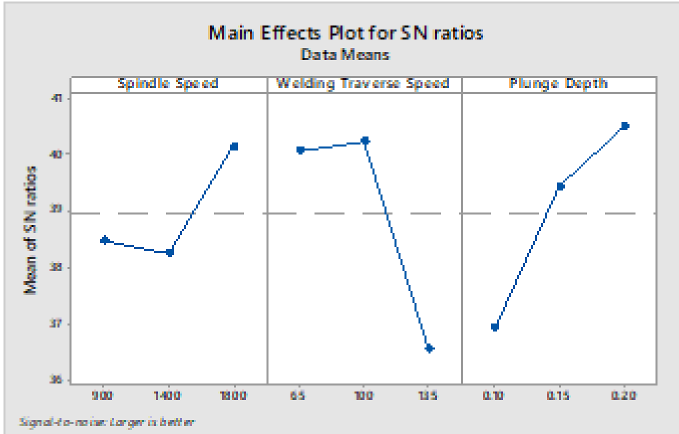

Figure 3 Main effects plot of S/N ratios for tensile test

RESPONSE TABLE FOR OUTPUTS

Table 4 Main effect on tensile strength (means)

Parameter	Level 1	Level 2	Level3	Delta	Rank
Spindle speed	84.13	101.39	74.96	18.06	3
Welding speed	91.74	105.00	93.94	33.32	2
Plunge Depth	102.20	71.68	109.17	34.22	1

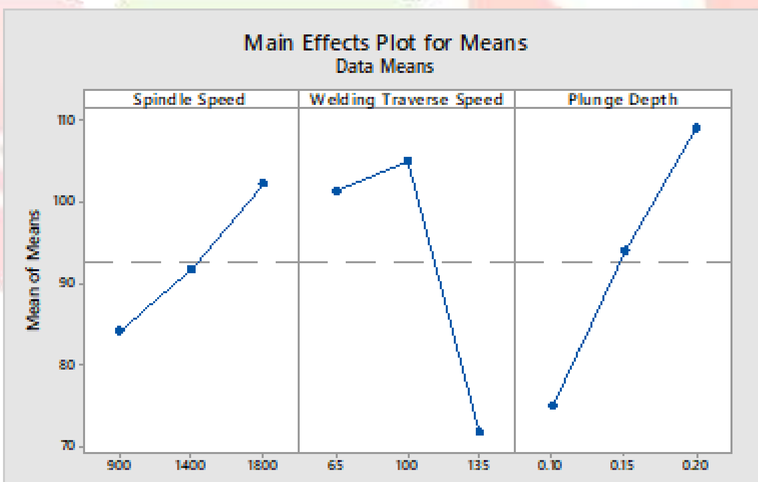

Figure 4 Main effect plot of means for tensile strength

Response table can also indicate which process parameters has greater influence on the responses measured by giving the process parameter a rank. Also one can infer the optimal condition from the response table. Table 4 and figure 4 shows the Main effect on tensile strength (means).

OPTIMIZING THE PROCESS PARAMETERS

Analysis of mean for experiments gives better combination of parameter levels. Means response refers to average value of performance characteristics for each parameter at different levels. Analyzing means and S/N ratio of various process parameters it is observed that a larger S/N ratio corresponds to better quality characteristics. Therefore, Effect of process parameter is level highest S/N ratio. Mean effect and S/N ratio Plunge depth calculated by minitab software indicated that

Plunge depth was at maximum. The optimum process parameter is found to be a combination of Spindle speed of 1800 rpm, welding speed of 100mm/min, and plunge depth of 0.20mm.

IV.CONCLUSION

The analysis presents effect of spindle speed, welding traverse speed and plunge depth on weld quality. Tensile strength and hardness of friction stir welded dissimilar aluminium alloy have been evaluated under different conditions using Taguchi experimental design.

Plunge depth has found to be the most dominant parameter which affects tensile strength. The other parameters which influence the tensile strength in order of ranking are welding traverse speed, spindle speed.

From this analysis, it is revealed that plunge depth is prominent factors which affect the strength of welding for the selected aluminium alloys. The Plunge Depth (P = 36.76 %) is the most influencing factor in determining the tensile strength of the sample followed by Welding traverse speed (W = 23 94 %) and Spindle speed (S = 8.7 %). The tensile strength of the specimen has a direct relation with the strength of the joint.

Optimum condition for high tensile strength are found to be Spindle speed= 1800 rpm, Welding traverse speed =100 mm/min, Plunge Depth= 0.20mm by Taguchi analysis.

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