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Parametric Optimization of Friction Stir Welding Parameters Using Taguchi Technique for Dissimilar Aluminum Alloys (AA5083 and AA6061)

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Abstract: *The advancement of the Friction Stir Welding has given another improved method to creating aluminum joints, in a speedier and solid way. In present investigation the impacts of welding process parameters on the Vickers micro hardness of dissimilar aluminum alloy (AA5083 - AA6061) joints created by Friction Stir Welding is analyzed. Tool rotational speed, welding speed and tool tilt angle have been taken as process parameters. Taguchi Design of Experiment (DOE), Analysis of variance (ANOVA) and main effect plot were utilized to calculate the significant parameters and set the optimal level for every parameter. Confirmation trials were performed on the optimum level. As indicated by the ANOVA results, the most critical contributing factors for Vickers micro hardness was determined as Tool rotational speed (1120rpm) and welding speed (70 mm/min) and tool tilt angle (2^0 degrees). Vickers micro hardness tests were performed keeping in mind the end goal to describe the hardness in the region of the weld affected area. The predicted optimal value of hardness of friction stir welded dissimilar AA5083 and AA6061 alloys is 94.8 VHN. The outcomes were confirmed by further trials.*

Keywords: *Dissimilar aluminum alloy, Friction Stir Welding, process parameters, Taguchi design, Vickers micro hardness.*

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I. INTRODUCTION

Friction stir welding(FSW) has risen as an innovation of far reaching enthusiasm because of its various points of interest, most essential of which is its ability to weld generally unweldable alloys[1]. Compared with a number of fusion welding processes that are commonly utilized for joining structural alloys, FSW is a solid state joining method in which the material that is being welded less than its melting point[2]. Defect free welds with good mechanical properties have been made in different aluminum alloys, even those previously thought to be not weldable. Porosity and hot cracking defects won't get in the friction stir welding process. FSW generates great surface finish and need not required post weld cleaning [3]. There have been various attempts to understand the impact of process parameters on microstructure development and material flow behavior, henceforth mechanical properties of friction stir welded joints. The effect of a few parameters such as rotational speed, traverse speed and tool tilt angle on weld properties is major points for investigators[4].Taguchi design of experiment (DOE) is a powerful tool to calculate significant factor from many by conducting relatively few number of tests, regardless, this design basically does not represent the interaction among processing parameters. In context of time and cost sparing, every so often these interactions are ignored. In the event that mandatory, the missing interactions can be found by further conducting the required trials. In this research work ,applying Taguchi systems on fusion welding procedures and casting methods have been accounted for in literatures[5], it indicates that the optimization of FSW process parameters of AA5083 and AA6061 aluminum alloy utilizing Taguchi technique has not been reported effectively yet. Considering the above truths, the Taguchi L9 Orthogonal array is used to calculate the influence of each processing parameters (i.e. rotational speed, traverse speed and tool tilt angle) for optimum Vickers micro hardness of friction stir welded joints of AA5083 and AA6061 aluminum alloy. Shige Matsu et. al. (2003) [6] managed Joining of 5083 and 6061 aluminum alloys by friction stir welding. He found that in this process, a rotating tool goes down the length of contacting metal plates, and produces an exceptionally plastically deformed zone through the related stirring action. The localized heating zone is produced by friction between the plate top surface and the tool shoulder and also plastic deformation of the material in contact with the tool. N. T. Kumbhar et. al. 2008[7] oversaw

Friction Stir Welding of Al 6061 Alloy. States that when the friction stir welding, more deformation is seen at the nugget zone and the produced microstructure strongly impacts the mechanical properties of the joint. FSW trials were conducted on the vertical milling machine for Al 6061 alloy. Morteza Ghaffarpour, et. al. 2013[8] In his Review on Dissimilar Welds of 5083-H12 and 6061-T6 performed by Friction Stir Welding, reports that as the conventional fusion welding is unwanted for welding aluminum alloys, there are many works performed on the aluminum alloys by FSW. These works are thinking about to the impacts of FSW parameters on sheet formability, weld quality after FSW, and optimization of the FSW process.

II. MATERIALS AND METHODS

*II.**A.** Taguchi method*

Taguchi method is an intense critical thinking device, which can enhance the execution of the procedure, product, plan and framework with a significant slash in experimental cost and time[9]. Taguchi technique finds the most effective parameters in the whole execution. The optimum weld parameters found from the Taguchi idea is not sensitive to the change in environmental condition and other noise factors[10]. In DOE number of trials increments when the quantity of process parameters increment. To solve this trouble, the Taguchi method uses a specific design of orthogonal array to find the overall process parameters with a few number of experiments only. Taguchi has described/ created three critical signals to noise ratios (S/N) (i.e. the nominal-the-better, smaller-the-better and the higher-the-better) depending on the of the quality characteristics.The S/N ratio for every process parameter is calculated based on S/N examination. . Notwithstanding the order of the quality characteristics, a higher S/N ratio relates to better quality characteristics. Therefore, the biggest S/N ratio shows to the optimal level of process parameter. Statistical analysis of variance (ANOVA) can be performed to calculate the significant process parameter. A confirmation test is led to approve the predicted optimal levels determined from the analysis.

***II.B**.FSW process parameters*

An Ishikawa figure (cause and effect diagram) was developed as shown in Fig.1 to recognize the FSW process parameters that may impact the quality of FSW joints. Fig 2 shows the changes in friction stir welding process.

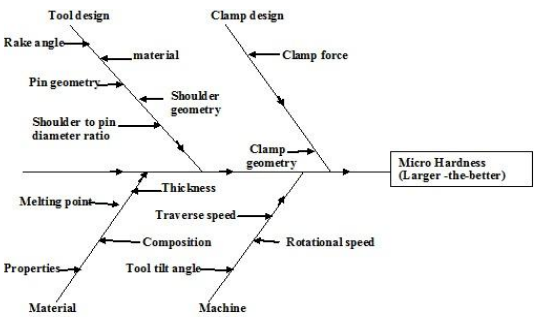

Figure 1. Cause and effect diagram

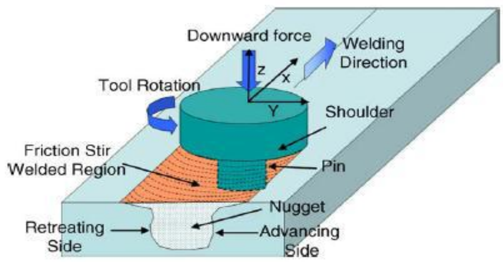

Figure 2. Frictions stir welding set up

From Fig.1, the welding process parameters for example tool rotational speed, traverse speed, tool tilt angle, assume a major part in choosing the weld quality. In the present research, 3 level process parameters, i.e. rotational speed(RPM), weld travel speed(WS) and tool tilt angle (TTA) were considered. Trail experiments were conducted using 5 mm thick plates of AA5083 and AA6061 Aluminium alloys to set the working scope of FSW process parameters. The chemical composition and mechanical properties of the parent metals (AA5083 and AA6061) used as a piece of this investigation are given in Table 1 and 2 individually.

Table1: Chemical composition of base materials (mass fraction, %)

Alloy	Mg	Mn	Cu	Cr	Si	Fe	Al
AA6061-T6	1.046	0.101	0.259	0.195	0.533	0.262	Bal
AA5083-H321	4.0	0.548	0.065	0.10	0.145	0.238	Bal

Table2: Mechanical properties of base materials

Alloy	Yield strength Mpa	Ultimate tensile strength Mpa	% of Elongation mm	Average hardness at 0.5kg load (HV)	Impact strength (J)
AA6061-T6	283	353	18	120	8
AA5083-H321	238	311	20	96	16

The range of process parameters was selected as 560-1800 rpm for rotational speed, 40-100 mm/min for weld travel speed and 0-2^{o} for tool tilt angle. The FSW process parameters along with their ranges are given in Table 3.

Table 3 Process parameters with their range and values at three levels

Level	Rotational speed RPM (r min^{-1})	Weld travel speed WS (mm min^{-1})	Tool tilt angle TTA (degrees)
Range	560 - 1800	40-100	0 - 2
Level 1	560	40	0
Level 2	1120	70	1
Level 3	1800	100	2

***II.C**. Selection of orthogonal array(OA)*

The optimal process parameters were determined by analyzing the characteristics obtained by using orthogonal arrays (OA). The number of degrees of freedom requires to be calculated to choose a reasonable orthogonal array for the trials. Taguchi creates number of standard orthogonal arrays and relating linear graphs were produced by Taguchi for this reason. In this research three variables were selected, i.e., Friction stir welding process parameters for the 3 variables and 3 levels Taguchi proposed some standard array. Hence an L9 OA (3^3) was selected for this research. This array requires nine trial runs and has three columns.

III. EXPERIMENTAL WORK

In this research for base material used for the friction stir welding experiments were cut into 5 X 75 X 200 mm size from AA5083 and AA6061 aluminum alloys plates. Two plates of parent metal (AA5083 and AA6061) were friction stir welded (FSW) with butt configuration on the vertical milling machine. The two plates located side by side and clamped rigidly to stop abutting joint faces from being forced apart. The length of the tool pin is a little shorter then work piece thickness. In this research single pass welding method was used to produce the joints. The frictional heat created between the tool shoulder surface and the parent material of workpiece surfaces due to rotating of weld tool. The heat created by mechanical mixing technique due to the mixed materials to soften below the melting point. As tool pin is travelled in the direction of welding the front face of the tool pin, with the assistance of special tool pin profile, forces plasticized material to the back of the pin while applying an adequate forging force to solidify the weld metal. The weld metal was facilitated by intense plastic deformation in solid state involving dynamic recrystallization of base material. The welded joints sliced by using with an EDM wire cutting machine to required dimensions, Vickers microhardness conducted at weld nugget and load applied 0.5kgs, dwell time 10 seconds . In this work the tool made of H13 tool steel, concave shoulder with scrolling on shoulder surface and cylindrical taper treaded probe was used. Tool shoulder diameter = 18mm, Root diameter = 6mm, Probe diameter = 4mm, Probe length= 4.7mm. The tool shown in figure 3.

(a) (b) (c)

Figure 3: (a) &b weld tool, (c) Probe Dimensions

IV. EXPERIMENTAL RESULTS AND DISCUSSION

IV.A. Signal to noise ratio

Vickers microhardness (at weld nugget) is the main characteristic considered in this research describing the quality of FSW joints. So as to evaluate the impact of factors on the response, the Signal-to-Noise ratios (S/N) and means for every control factor can be calculated. The signals are indicators of the impact on average responses and the noises are measures of the impact on the deviations from the affectability of the experiment output to the noise factors. The suitable S/N ratio must be selected using past learning, skill, and understanding of the process. At the point when the objective is settled and there is trivial or absent signal factor (static design), it is possible to select the signal-to-noise (S/N) ratio depending on the target of the design [11]. In this study, the S/N ratio was chosen corresponding to the criterion of the larger- the-better, in order to maximize the response. In the Taguchi technique, the signal to noise ratio is utilized to determine the deviation of the quality characteristics from the desired value. The S/N ratio η_j (larger-the-better) in the j_{th} experiment can be communicated as

$$\eta_j = -10 \log_{10}((1/n)\sum(Y_{ijk})^2) \quad (1)$$

where *n* is the number of tests and Y_{ijk} is the experimental value of the *i*th quality characteristics in the *j*th experiment at the *k*th test.

In the present study, the Vickers microhardness (at weld nugget) data were analyzed to find the impact of FSW weld parameters. 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 Vickers microhardness, means and signal-to-noise (S/N) ratio are given in Table 4. Every experiment will give the analysis of mean for better combination of parameters levels that guarantees a high level of Vickers microhardness 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 mean response of crude information and S/N ratio of Vickers microhardness for every parameter at level 1, 2 and 3 were computed and are shown in Table 5. The means and S/N ratio of the different process parameters when they converted from the lower to higher levels are also shown in Table 5. It is clear that a larger S/N ratio with respect to better quality characteristics. Therefore, the optimal level of weld parameter is the level of highest S/N ratio. The mean effect and S/N ratio for Vickers microhardness were computed by statistical software [12], showing that the Vickers microhardness was at highest when rotational speed, welding speed and tool tilt angle are at level 2, 2 and 3i.e. rotational speed at 1120 r/min, welding speed at 70 mm/min and tool tilt angle at 2^0 degrees . The comparison of mean effect and S/N ratio are given in Fig.5.

IV.**B**. Analysis of variance (ANOVA)

Analysis of variance (ANOVA) test was conducted to find the weld parameters that are statistically significant. The purpose of the ANOVA test is to research the importance of the process parameters which influence the Vickers micro hardness of FSW joints. The ANOVA results for Vickers microhardness of means and S/N ratio are given in Tables 6 and 7 separately. Also, the F-test named after Fisher can also be utilized to find which process has a significantly affects on Vickers micro hardness. Generally, the change of the process parameter significantly affects the quality characteristics, when *F* is high. The results of ANOVA show that the considered weld parameters are highly significant factors affecting Vickers microhardness of FSW joints in the order of rotational speed, tool tilt angle weld travel speed.

IV.C. Interpretation of experimental results

IV.C.1. Percentage of contribution

The percentage of contribution is the part of the total variation observed in the experiment attributed to every significant factor and interaction which is shown. The percentage of contribution is a function of the sum of squares for every significant item; it shows the relative power of a factor to minimize the variation. If the factor levels are controlled precisely, then the total variation could be minimized by the amount represented by the percentage of contribution.

Table 4 Orthogonal array for L9 with response (raw data and S/N ratio) replace the value

No	Input parameters			Response		Mean value	S/N ratio
	RPM	WS	TTA	H1	H2		
1	560	40	0	62.5	51.5	57.00	34.99
2	560	70	1	79.0	85.4	82.20	38.28
3	560	100	2	76.1	77.5	76.80	37.71
4	1120	40	1	77.3	78.6	77.95	37.84
5	1120	70	2	94.5	95.1	94.80	39.54
6	1120	100	0	75.8	76.1	75.95	37.61
7	1800	40	2	73.5	77.2	75.35	37.54
8	1800	70	0	78.0	72.9	75.45	37.54
9	1800	100	1	72.1	74.8	73.45	37.32

Table 5 Main effects of Vickers Microhardness at weld nugget (means and S/N ratio)

	for Means			for S/N Ratios		
Level	RPM	WS	TTA	RPM	WS	TTA
1	72.00	70.10	69.47	37.04	36.83	36.76
2	82.90	84.15	77.87	38.33	38.46	37.82
3	74.75	75.40	82.32	37.47	37.55	38.26
Delta	10.90	14.05	12.85	1.29	1.63	1.50
Rank	3	1	2	3	1	2

(RPM,WS,TTA are process parameters)

Table 6 ANOVA for Vickers microhardness at weld nugget (for mean)

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% of distribution
RPM	2	192.79	96.397	16.77	0.056	25.3
WS	2	302.06	151.028	26.28	0.037	39.7
TTA	2	255.48	127.742	22.23	0.043	33.5
Error	2	11.49	5.747			1.5
Total	8	761.83				100.00

Table 7 ANOVA for Vickers microhardness at weld nugget (S/N ratio)

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% of contribution
RPM	2	2.5748	1.2874	6.50	0.133	24.4
WS	2	4.0079	2.0040	10.12	0.090	38.0
TTA	2	3.5690	1.7845	9.01	0.100	33.8
Error	2	0.3961	0.1981			3.8
Total	8	10.5479				100.0

DF- Degrees of freedom, Adj SS-Adjusted of square, Adj MS-Adjusted mean square, F- Feisher ratio, P- Probability that exceeds the 95% confidence level.

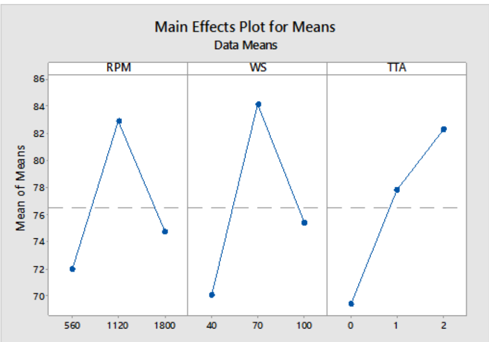

Fig:4 (a) Main Effects Plot for hardness (Means of MH)

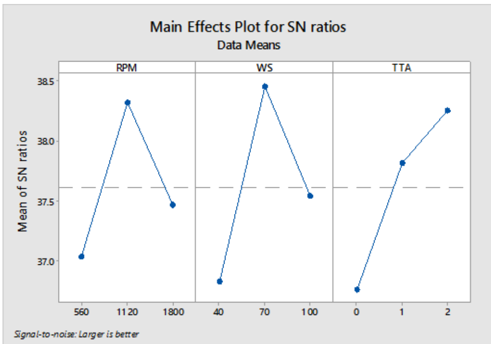

Fig:4 (b) Main Effects Plot for hardness (S/N ratio of MH)

IV.C.2.Estimation of optimum performance characteristics.

The methods explained in this procedure for Vickers microhardness prediction and optimization can end the requirement for conducting experiments on the basis of the conventional hit and trial system which is tedious and fiscally not reasonable. The present study is aimed at to recognize the highest influencing significant parameter and percentage contribution of every parameter on Vickers micro hardness of friction stir welded dissimilar AA5083 and AA6061 aluminum joints by conducting least number of experiments using Taguchi orthogonal array. Based on the greatest values of the S/N ratio and mean levels (Fig.4) for the significant factors RPM, WS and TTA the entire optimum condition thus obtained were RPM_2, WS_2 and TTA_3. Once an experiment is performed and the optimum process condition within the experiment is fund, one of two conceivable outcomes exists:

1) The suggested combination of factors level is identical to one of those in the experiment,
2) The suggested combination of factors level is excluded in the experiment.

The optimum value of Vickers microhardness is predicted at the chosen levels of significant parameters. The predicted Vickers microhardness is taken from the literature [13] The estimated mean of the response characteristics (Vickers microhardness) can be calculated as

Vickers micro hardness (predicted) = RPM2 +WS2+TTA3-2T (2)

where T is the overall mean of Vickers microhardness in HV .

RPM2 = The average Vickers microhardness second level of rotational speed,1120r/min;

WS2 = The average Vickers microhardness at second level of welding speed70 mm/min,

TTA3 = The average Vickers microhardness at third level of tool tilt angle 20derees. Substituting the values of various terms in Eqn (2), then

Vickers microhardness = 82.90+84.15+82.32-2*76.55 = 96.27 HV

IV.C. 3 .Confirmation test:

The confirmation test was conducted for Vickers microhardness(HV) and it was observed that predicted value (96.27 HV) for MH was very near to the values obtained after actual test conditions on optimum levels(94.8 HV).

V. CONCLUSION

1. AA5083 and AA6061 alloys were successfully friction stir welded under the following range ofprocess Parameters: tool rotational speed of 560 -1800 rpm, weld travel speed of 40-100 mm/min, and the tool tilt angle of 0-20.

2.The percentage contribution of FSW process parameters was evaluated. It is observed that the tool Rotational speed has 25.3% contribution, tool tilt angle 39.7% and traverse speed has 33.5 % contribution to Vickers microhardness of welded joints.

3.The optimum value of process parameters like rotational speed, weld speed and tool tilt angle are determined to be 1120 r/min, 70 mm/min and 20 degrees respectively.

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