"QUALITATIVE AND QUANTITATIVE ANALYSIS OF FRICTION STIR WELDING JOINTS"

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Abstract: Friction Stir Welding (FSW), a solid state welding process, look like a most promising techniques for joining an aluminium alloys avoiding a large number of difficulties arising from the use of traditional fusion welding processes. In experimentation, the effect of friction stir welding process parameters like Tool Travel speed, Rotational speed ,and shoulder diameter on mechanical properties and microstructural properties of Friction stir welding joint of 6111-T4 studied by using Factorial and Taguchi design and analysis. The Quantitative results gives the maximum responses such as Tensile strength at rotational speed 1000 rpm, tool travel 18 mm/min, shoulder diameter 24 mm and Hardness at 1100rpm, 18 mm/min and 24mm. An ANOVA analysis indicates an influence of individual parameters on Ultimate Tensile strength a of welding joint. a mathematical relations are proposed for Tensile strength and Hardness of weld joint. Whereas a qualitative observations gives are the best for optimal conditions suggested in by prediction model.

Index Terms: Factorial; Taguchi design; Microstructural ;ANOVA.

I. INTRODUCTION

Friction Stir Welding (FSW), as a solid state welding process is one of the promising process for joining Aluminum alloys to overcome the limitations of conventional processes. FSW is a solid state welding process, patented in 1991 by The Welding Institute (TWI), in which rotating tool is introduce into the adjacent edges of the work piece metal are welded and moved along length of the joint. The composition of the tool rotation and advancing velocity vectors induces a characteristic metal flow all around the tool adjacent surface. The tool travel determines heat creation due to friction forces and material deformation work. The process has been demonstrated to be effective and is currently industrially utilized for materials difficult to be welded, especially aluminum and magnesium alloys. As a matter of fact, the use of a solid state welding process limits the insurgence of defects, due to the presence of gas in the melting bath, and avoids the negative effects of material metallurgical transformations strictly connected to the change of phase. Finally, the reduced thermal flux – with respect to traditional fusion welding operations – results in smaller residual stress values in the joints and, consequently, in limited distortions in the final products [1,2]. due to safety and legal constrictions and to maintenance procedures, the analyses and the control of welding parameters in order to obtain high resistance, uniform microstructure and fatigue performances become fundamental in the case of such technology. Many papers are presented in the literature on microstructural, physical and mechanical behavior of friction stir welded Al-alloys, only few papers focus on the effect of processing parameters to obtain joints good efficiency in terms of tensile and fatigue properties. In the authors show the results of an optimization study of tool geometry in order to improve the tensile properties of FSW joints. In [4,5] the authors focus the attention on the effect of tool rotation speed, advancing speed and tool geometry on fatigue strength of aluminium alloy.

II. EXPERIMENTAL DESIGN

Friction stir welding process parameters tool travel speed, rotational speed and shoulder diameter of FSW Tool were selected on the basis of research papers and previous studies of FSW. The design of experiment has been done by using factorial design with 3 factor and 3 level of process parameter method to get a wide range in sample space as mentioned in table no.1. With the basic parameter like rotational speed and transverse feed or tool travel was consider an effective and significant factor for making a quality joint in friction stir welding. For non-ferrous aluminium alloy metals are mainly joining by using FSW in several joint configurations. During FSW metals are joined in the solid state due to the heat generated by the friction and flow of metal by the stirring action of a pinned tool. In this investigation, the effect of friction stir welding process parameters like Tool Travel speed, Rotational speed and shoulder diameter on ultimate tensile strength, joint hardness and micro structural properties of Friction sir welding joint of AA 6111-T4.

Table 1 Mechanical properties and chemical composition of AA 6111-T4

Tensile strength		Melting point (T4)	Elongation at break		
210-280 MPa		505-650°C	26%		
Al	Cr	Mg	Mn	Si	Ti
95.6 %	0.10 %	1.0 %	0.45 %	0.10 %	0.10 %

2.1 Process Parameter Selection

As motioned in various research papers about a quality joint, the response parameter ie ultimate tensile strength was consider for this research. A set of process parameters and the response parameters are framed in typical ranges base on a literature data and hypothetical analysis. The sample random numbers was been used to run a best trial for a P value and R^2 values in Statistical Software

Tool. The orthogonal array L27 selection for an experimental run has been selected from standard reference chart as mentioned in Taguchi method for 3 factor and 3 level.

Table 2 FSW Process parameter levels

Process Parameter	Code	Units	L 1	L 2	L3
Rotational Speed	N	Rpm	900	1000	1100
Transverse Travel	F	mm/min	18	21	24
Shoulder Dia.	SD	Mm	18	22	24

2.2 Tool selection A welding tool including a shoulder diameter and Tool pin with half cone and half cylinder pin diameter of 18 mm to 26 mm and4.8 mm respectively. And it was made from H30 Steel. Experimentation was carried out on VF-5 TR a VMC machine at our FSW laboratory in advance manufacturing Tool Room. The tensile test samples were prepared in a perpendicular direction to the welding direction according ASTM –E8-04 Standard and Tensile tests were performed using UTM -400D Machine.

2.3 Orthogonal Array Selection

The material for friction stir welding joint by considering higher is the S/N ratio better will be the quality characteristic of FSW joint. An optimum conditions were identified for each level corresponding to each parameter. A best suited combination was been selected for higher S/N ratio from the table.01. The means and S/N ratio were been closely observe and selected the levels for ANOVA analysis. A detailed ANOVA design for assessing the significance of the process parameters is also provided .The optimal combinations of the process parameters can be then predicted. The 5mm thickness of 6111-T4 Alloys plat was used as base materials.

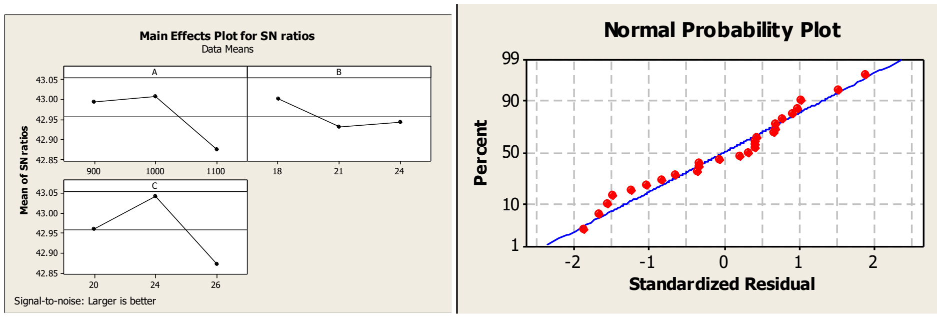
III. RESULT AND DISCUSSION

The quality of friction stir welding are mainly defend on the response values after experimentation. the design for an experimentation as mentioned in table no. The process parameters like speed ,tool travel feed()and shoulder diameter for conduction of friction welding process on the material 6111-T4 Alloys. Following table show the L27 tensile strength and Rockwell hardness of an aluminium alloy. On the basis of mean signal to noise ratio the effective parameters can be selected for best possible results.

Table 3 Effect of process parameter and signal to noise ratio for Tensile strength and Hardness

Speed	Tool travel F	Shoulder Dia SD	TS1,Mpa	S/N1	HRC1	S/N
900	18	20	150	43.1	74	37.96
900	18	20	140		81	
900	18	20	141		81	
900	21	24	136	42.9	85	37.87
900	21	24	147		79	
900	21	24	137		80	
900	24	26	130	42.9	80	37.66
900	24	26	150		82	
900	24	26	143		72	
1000	18	24	149	43.1	81	37.82
1000	18	24	158		79	
1000	18	24	130		82	
1000	21	26	136	42.9	73	37.82
1000	21	26	148		76	
1000	21	26	140		84	
1000	24	20	155	42.8	71	38.09
1000	24	20	130		82	
1000	24	20	135		75	
1100	18	26	137	42.6	73	37.68
1100	18	26	139		72	
1100	18	26	133		84	
1100	21	20	155	42.8	71	37.77
1100	21	20	136		78	
1100	21	20	131		77	
1100	24	24	135	43.0	78	37.72
1100	**24**	**24**	138		76	

Following figure no of main effects on TS of speed 1000 rpm ,Feed (tool travel) 18 mm/min and shoulder diameter 24 mm shows the significant effect on tensile strength.



(a) Main effects N,F and SD (b) Regression Analysis TS for N, F, SD
Fig1(a,b) main effect and normality graph for tensile test

By using statistical tool with general random factorial design the Taguchi design of experiment predicts the value of signal to noise ratio for optimize value of 43.13. the model was selected that the S/N ratio larger is the best with the mean value of 144.48 Mpa is predicted value. The predicted value from the standardize model in Taguchi are Speed 1000 RPM ,Tool travel 18 mm/min and 24 mm shoulder diameter. The linear regression model was selected for FSW welding process. The regression equation was estimated for best possible value of response factor tensile strength. For an optimize values of signal factors like Speed feed and shoulder diameter 1000,18 and 24 mm was estimated equal to 147.88 in equation no 01. The following normal probability plot indicates the standard normality of the observations of welding process. The spread is evenly aligned to the inclined straight line. A regression equation estimated from the analysis of regression and found that the contribution of all factors of process of friction stir welding.

$$TS = 123 - 0.0250 N + 0.278 F + 1.87 SD \quad (1)$$

The predictor test was been carried out on the observations taken with the help of L27 design of experiment. The following table indicates the contribution level of individual parameters are significantly highlight the Rotational speed of tool and tool geometry.

Table no.4 Regression analysis for tensile strength

Predictor	Coef	SE coff	T	P
Constant	122.56	34.11	3.59	0.002
N	-0.02500	0.02365	-1.06	0.0302
F	0.2778	0.7884	0.35	0.728
SD	1.8690	0.7742	2.41	0.024

S = 6.0350 R-Sq = 73.5% R-Sq(adj) = 15.5%

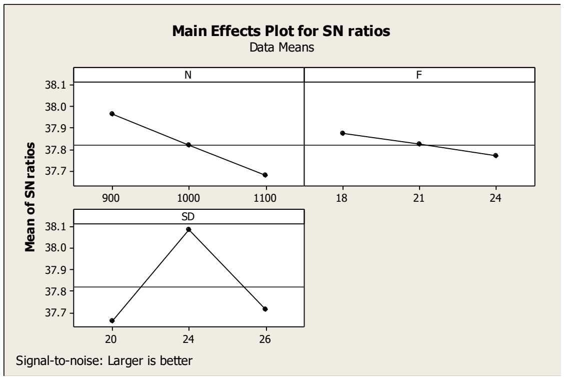
The analysis of variance table shows contribution of p values 9% as indicated in table no. with considering Durbin-Watson statistic 1.66052.

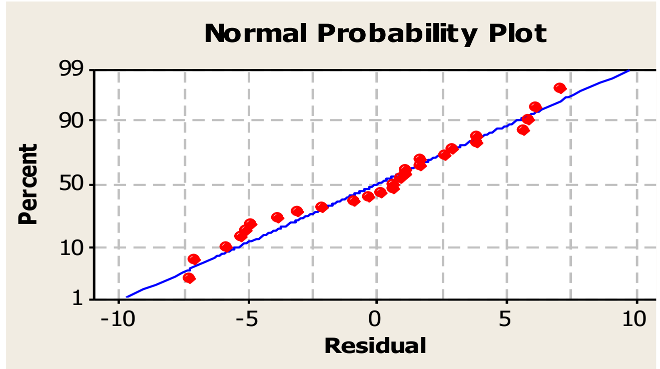
Table no.5 The Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	71.9	237.3	2.36	0.098
Residual Error	10	236.1	100.7		
Total	13	308.0			

The predicted values of tensile strength with the help of equation 1 were estimated equal 147.88 before actual performance over work piece plate and after experimental trial over a same set up the Tensile strength values were found 152.63 Mpa ,155.35 Mpa and 149.67 Mpa. The average value of tensile strength after the 152.34 Mpa and it found to be closer to estimated values.

The main effects of process parameters with hardness values of friction stir welding joint. As tensile strength increases the hardness values are comparative lower.





(a) Main effects of S/N for Hardness **(b) Normality plot for Residual**

Fig.2 (a,b)Main effect and normality test graphs for Hardness of weld joint

The predicted values of signal to noise ratio 37.46 and mean value of Hrc values of 75. The predicted values of process parameters ie speed 1100 rpm, feed 24 mm/min and shoulder diameter 20 mm for best response values for tensile strength and hardness.After the regression analysis with linear method was run for tensile strength and hardness observations. The predicted equation by regression model was found to be as below i.e equation (2) where the tool speed and shoulder diameter are more influencing parameters. An estimated values for hardness of weld joint.

$$HRC = 45.9 + 0.0244\ N + 0.019\ F + 0.278\ SD \qquad (2)$$

Table No.6 Anova analysis for Tensile strength

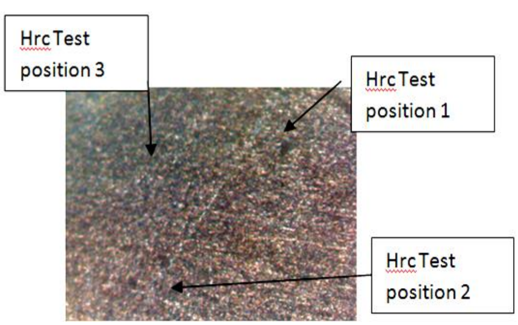
Predictor	Coef	SE Coef	T	P
Constant	45.94	15.67	2.93	0.007
N	0.02444	0.01086	2.25	0.034
F	0.0185	0.3621	0.05	0.960
SD	0.2778	0.3556	0.78	0.043
S = 4.60912	R-Sq = 69.8%	R-Sq(adj) = 9.3%		

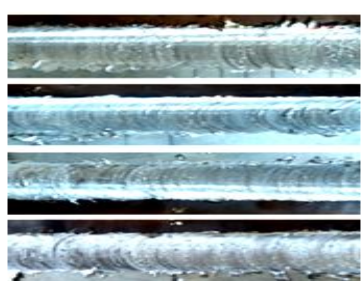
A following table indicates the one way ANOVA analysis for three level ,three factor design indicates better contribution values for the harness of the friction stir welding joint. Durbin-Watson statistic 2.05944 factor was used to analyze the parameters of process.

Table No.7 Regression for Residuals

Source	DF	SS	MS	F	P
Regression	3	120.57	40.19	1.89	0.0189
Residual Error	10	188.61	160.7		
Total	13	310.2			

From regression equation 2 ,the predicted value before without doing an experimentation can be found to be 78.75 and after actual performance on experimental set up was equal to 73.98 ie very closer to estimated value of hardness. The microstructural texture of a joint is shown as below in figure no.





(a)Microstructural texture for Harndness (b) weld joints of samples (c) Microstructural texture for TS

Fig 3(a,b,c) microstructure of weld joint for better Hardness and strength response and weld joint samples of AA6111-T4

VI. Qualitative Analysis

A qualitative test was been carried out on the basis of visual observations and non destructive testing. An emery paper and dye solutions were used to realize the observations of weld joints. Following are the observations for getting the most prominent combinations of process parameters to enhance weld quality as shown in table 8.

Table. 8 Qualitative characteristic chart of L27 OA trials

Trial by L27 Array	No of defects	Abnormality type	Surface texture	Microstructural characteristic	TS , Hardness	Rank
4	2	Rupture ,cut holes	Poor	Rough	136,85	-
5	1	Fine holes ,smooth texture	Excellent	Fine	155,83	2
11	2	Brittle deposits AS	Poor	Fine	147 ,79	3
12	3	Solid deposit	Poor	Rough	130,82	-
14	2	Fracture Marks RS	Poor	Rough	136,73	-
15	1	Smooth surfaces	Excellent	Fine	140,84	-
19	1	Polish surfaces at interface	Excellent	Fine	155,71	1
20	4	Unfused material	Poor	Rough	133,72	-
22	-	Even polish texture	Good	Fine	138 ,84	-
25	1	Even polish texture	Excellent	Fine	138 ,76	-

V. CONCLUSION:

In this investigation, AA 6111-T4 alloy was welded by using FSW process. A stir half cylindrical and half tapered threaded pin profiles with variable shoulder diameter were designed to study the influence of the pin geometry on the weld quality by using quantitative and qualitative method. Also, the influence of various process parameters are investigated and the following conclusions a can be summarize:

- The effect of Rational speed and tool geometry i.e. shoulder diameter was significantly contributed in weld surface texture and vey less defect was observed.
- The results shows an individual factor like speed and shoulder diameter has a majorly affecting the mechanical properties i.e. ultimate tensile strength and weld interface hardness.
- An optimized process parameter after ANOVA and regression Analysis are 1000 rpm,18 mm/min,24mmfor ultimate tensile strength and 1100 rpm,18 mm/min,26 mm for hardness with the half cylindrical and half taper screw threaded tool.
- The quantitative results estimated and actual TS and Hardness values are reaches to the 70.41% and 72.54 % and 74.93 % and 82.89 respectively that of the base metal. The qualitative observation point towards the superior physical condition of weld joint of by using selected optimized process parameters.

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