PARAMETRIC OPTIMIZATION OF FRICTION STIR WELDING OF ALUMINUM ALLOYS[1]

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ABSTRACT

Friction Stir Welding (FSW) has demonstrated a significant potential for joining low melting point non-ferrous metals 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 and micro structural properties of Friction sir welding joint of 6111-T4 by using Taguchi method. By Factorial and Taguchi design and analysis for process parameters and experimental results gives the maximum responses such as Tensile strength at rotational speed 1100 rpm, tool travel21mm/min, shoulder diameter 26mm. 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.

Keywords: *FSW; Factorial design; Taguchi method; ANOVA*

1. INTRODUCTION

The quality of joint in friction stir welding have been majorly influence by Tool rotational speed, Tool geometry ,shoulder diameter and distribution and many other parameters. An plenty of experimentation has done on the effect of friction stir welding parameters on the Mechanical and Metallurgical properties of various grades of Aluminum Alloys. Taguchi is very beneficial method for designing and analysis of process parameters .it also used to control and optimize the mechanical and metallurgical properties. Vertical force or pressure acting on a welding plates plays a major role while estimating the Tensile strength as response characteristics as compares to the process parameters like. Rotational speed , tool travel while joining of cast alloys. On other hand Some studies demonstrated that a rotational sped plays a vital role than other parameters like tool geometry ,welding speed and vertical force for increasing the tensile strength and percentage elongation of friction stir welded joint Mehta M., Arora A., A. De, and T. Debroy.(2011)[1].The previous investigation on this aluminum alloy shows that the surface condition of welds was not satisfactory specially in the back of the welded joint. as we know heat generated by contact of tool and work piece is the weld cause thus the preheating process should improve the mechanical properties like Tensile and hardness properties Sundaram N S, and Murugan N, (2010) [2].As an alternative for a lots of experimentation and trials, one should optimize and formulate a standard set of process parameters and experimental conditions. Therefore, this investigation tried to investigate the consequences of process parameters like rotational speed, Tool geometry, welding speed and shoulder diameter on tensile strength of welding joint of 6111-T4.

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2. EXPERIMENTAL DESIGN AND PROCEDURE

The process parameters selected for friction stir welding were Tool travel speed , rotational speed and shoulder diameter of FSW Tool. The design of experiment has been done by using factorial design with 3 factor factors of process parameter as input and 3 level method to get a wide range in sample space. 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.

2.1 Material selection

Friction Stir Welding (FSW) has demonstrated a significant potential for joining low melting point non-ferrous metals 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 and micro structural properties of Friction sir welding joint of 6111-T4.

2.2 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 L9selection for an experimental run has been selected from standard reference chart as mentioned in Taguchi method for 3 factor and 3 level.

Table no.I FSW Process parameter levels

Process Parameter	**Cod**	**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

2.3 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 and 4.8 mm respectively. And it was made from H30 Steel.

2.4 Machine tool selection:

An 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

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2.5 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 5 thickness of 6111-T4 Alloys plat was used as base materials.

Table no III. L9 Orthogonal Array design of process parameter

N	1	1	1	2	2	3	3	3
F	1	2	3	2	3	1	2	3
SD	1	2	3	3	1	3	1	2

3. RESULT AND DISCUSSION

The three factor and three levels was selected and run by using factorial design over various and An orthogonal array L9 selected for ANOVA analysis. The same process parameters was then defines and analyze in Taguchi method. A robust design was selected to make a wide margin of process parameter selection and parametric optimization. Following are speed ,tool travel speed and shoulder diameter parameter are set by L9Array and corresponding S/N ratios table IV.

Table no IV. Taguchi Analysis design of process parameter

N	F	SD	TS1	TS2	SNRA1	SNRA2
900	18	18	137	132	42.73441	42.41148
900	21	22	132	140	42.41148	42.92256
900	24	26	138	140	42.79758	42.92256
1000	18	22	136	130	42.67078	42.27887
1000	21	26	137	140	42.73441	42.92256
1000	24	18	135	137	42.60668	42.73441
1100	18	26	133	136	42.47703	42.67078
1100	21	18	150	137	43.52183	42.73441
1100	24	22	133	139	42.47703	42.8603

The residual plot for tensile strength with set 1 trial indicates with concentrated trend at lower side of range of ultimate tensile strength . In histogram the residual spread is towards the center. It would not clearly demonstrate a individual signal of FSW parameters.

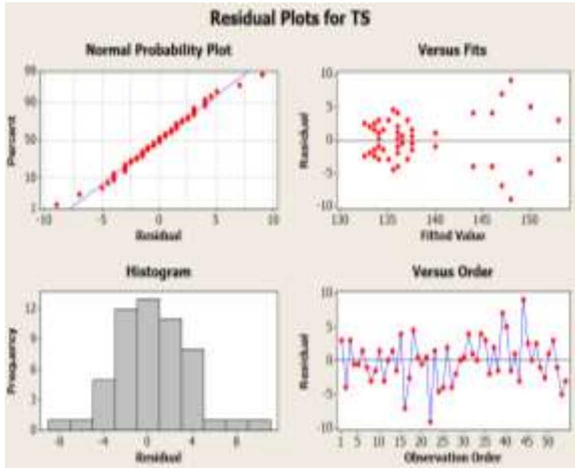

Figure.01 Residual effect on Tensile strength

An inteaction of three process parameters ,F 24 mm/rev and N 1000 rpm ,SD 20mm and N 1000 rpm,F21 mm/rev and SD 22mm repecively shown in figure. Following graphical observation it perspect that SD 20mm and N 1000 rpm are the best combination for better mechanical properties ie tensile strength.

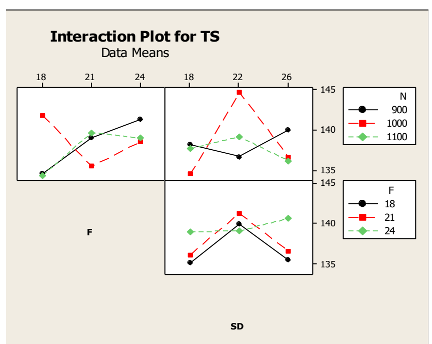

Figure. 02 Interaction effect over tensile strength

The following main plot for tensile strength at N 1000 rpm,F 24 mm/rev and SD 22 mm are the indudual effect shows an significant effect over TS but for variation occurs in mean plaot of SD.

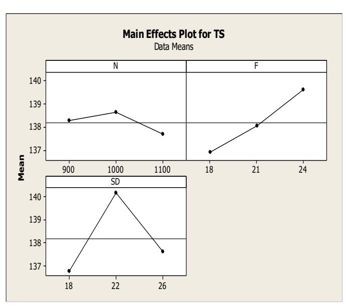

Figure.03 mean effect of TS

3.1 Signal to noise ratio analysis for Ultimate Tensile Strength

In this study , the responses like tensile strength and percentage elongation had investigated as the leading quality characteristics of welding joint. The S/N ratio analysis was mainly employed to keep optimum variations in tensile strength value. An achievement of an investigation was an occurrence of maximum value of Tensile strength of a joints. Therefore , the optimal level of process parameters is the level with largest S/N ratio and for higher is the better quality characteristics. By Taguchi design a set of experiments were performed in framed conditions as motioned in table no.01. The tensile strength values were been found with respect to process parameter and various level conditions as per L9 orthogonal array. The main values of S/N ratio are arranged corresponding to their process parameters in table no. 02.

3.2 ANOVA analysis of Tensile strength Set -01

An ANOVA analysis was been carried out after the robust factorial and Taguchi trials for best possible output range of tensile strength. The various set for trial was selected to get best ultimate tensile strength values. Set and Set 2 was selected from experimental design and designated by TS1 AND TS2 for discussion in this chapter. Following table no.04 denotes a comparative ANOVA analysis of S/N and Mean values. The rank identified in table are 3,2,1 denotes the best maximum values of controllable factors over a noise. In following table the mean value and S/N ratios for N 42.83 and 138.7,F 42.83 and 139.7,SD 42.95 and 140.7 are the observations validate from table no. it is found that the speed ,feed and Shoulder diameter responded 150,136 and 137 Mpa tensile strength. So better it is to keep speed and moderate feed and Shoulder diameter at moderate for getting higher value of tensile strength. From this ANOVA table it can predicted that optimum levels from table no. are speed, feed and Shoulder diameter 1100 rpm,21mm/rev and 26 mm.

Table no V. ANOVA analysis TS Vs N,F,SD

Level	N		F		SD	
	S/N	Mean	S/N	Mean	S/N	Mean
1	42.65	135.7	42.63	135.3	42.95	140.7
2	42.67	136.0	42.89	139.7	42.52	133.7
3	42.83	138.7	42.63	135.3	42.67	136.0
Delta	0.18	3.0	0.26	4.3	0.43	7.0
Rank	3		2		1	

ANOVA Table V TS1 Analysis of Variance for SN ratios An experimentation are by considering the design parameter in FSW are analyze by following table no.03. The contribution of an individual parameters are not clearly distinguished by using set one experimental results. The values of P and Residual error are not up to the mark.

Table no VI. ANOVA analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
N	2	0.055	0.055	0.027	0.14	0.875
F	2	0.137	0.137	0.068	0.35	0.741
SD	2	0.292	0.292	0.146	0.75	0.573
Re Error	2	0.392	0.392	0.196		
Total	8	0.87				

3.2 Analysis of Variance for SN ratios for Tensile strength 02

An ANOVA analysis for Taguchi design had carried out by using statistical software by consider a P and R^2 after experimentation. The signal to noise ratio after an ANOVA analysis was found to be maximum is best following table.04 equal to level 1,1,1 for speed Tool travel and shoulder design**.**In following table the mean value and S/N ratios for N 42.7 and 138.6,F 42.8 and 135.33,SD 42.85 and 133.66 are the observations validate from table no. it is found that the speed ,feed and Shoulder diameter responded 140,140 and 139 Mpa tensile strength. So better it is to keep speed and moderate feed and Shoulder diameter at moderate for getting higher value of tensile strength. From this ANOVA table it can predicted that optimum levels from table no. are speed, feed and Shoulder diameter 1100 rpm,21mm/rev and 26 mm.

Table no VII. **Variance for SN ratios and mean**

Level	N		F		SD	
	S/N	Mean	S/N	Mean	S/N	Mean
1	42.7	138.66	42.4	139.66	42.6	140.66
2	42.6	136.00	42.8	135.33	42.6	136.00
3	42.7	135.66	42.8	135.33	42.8	133.66
Delta	0.11		0.41		0.21	
Rank	3		2		1	

From following fig.04 it is observed that the level 3,2,3 for speed ,feed and shoulder design are looking to be significant over rest of trials.

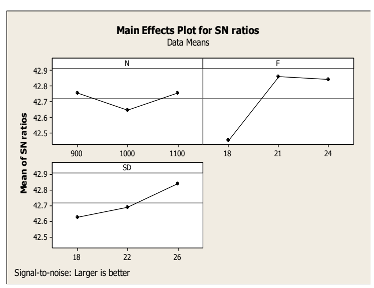

Figure.04 main effects for SN ratio

3.2.1 Analysis of Variance for means

An ANOVA analysis for Taguchi design had carried out by using statistical software tool after experimentation. The means after an ANOVA analysis was found to be maximum is best following table.04 equal to level 3,2, for speed Tool travel and shoulder design**.**

Table no VIII. Analysis of Variance for means

Source	DF	Seq SS	Adj SS	Adj MS	F	P
N	2	0.023	0.023	0.011	0.89	0.530
F	2	0.313	0.313	0.156	11.86	0.078

SD	2	0.071	0.071	0.035	2.70	0.270
Res Error	2	0.0264	0.026	0.196	0.013	
Total	8	0.435				

The following linear regression equation no for optimal values of speed feed and Shoulder diameter 1100 rpm and 21 mm/rev and 26 mm by prediction model would be equals to 136.34 Mpa.

The regression equation is

TS1 = 135 + 0.0150 N - 0.00 F - 0.583 SD (1)

3.3 Estimated Model Coeff for SN TS1

Table no.ix Coefficients for SN ratios TS1

Term	Coef	SE Coef	T	P
Constant	42.7146	0.1476	289.41	0.000
N 900	-0.0668	0.2087	-0.320	0.779
N 1000	-0.0440	0.2087	-0.21	0.853
F 18	-0.0872	-0.2087	0.418	0.717
F 21	0.1747	0.2087	0.837	0.491
SD 18	0.2397	0.2087	1.149	0.370
SD 22	-0.1948	0.2087	-0.933	0.449
S =1.84	R-Sq = 85.3%	R-Sq(adj) = 0.46%		

3.3.1 Linear Model Analysis SN TS2

The linear regression model was been selected to have trial run and results before actual experimentation. Following table X denotes the optimize levels at higher speed at 1000 rpm and medium feed 18 mm/min and shoulder diameter about 18 to 22 mm for better confidence range value.

Table no.x Estimated Model Coefficients for SN ratios

Term	**Coef**	**SE Coef**	**T**	**P**
Constant	42.7146	0.1476	289.41	0.000

N 900	0.0347	0.05423	0.639	0.588
N 1000	-0.0723	0.05423	-1.333	0.031
F 18	-0.2638	0.05423	-4.865	0.040
F 21	-0.0908	0.05423	-1.674	0.236
SD 18	-0.2638	0.0542	- 4.865	0.040
SD 22	-0.0303	0.0542	-0.559	0.632
S = 0.11	R-Sq = 93.9%	R-Sq(adj) = 75.7%		

From the prediction model of linear regression an estimated equation for the optimum values of Speed feed and shoulder at 1100 rpm and 21 mm/rev and 26 mm diameter was 149.86 Mpa.

The regression equation is

$$TS2 = 109 - 0.0000\,N + 1.43\,F + 0.417\,SD \quad (2)$$

CONCLUSION:

In this paper, 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 method. Also, the effect of different welding speed is investigated in this research. From this investigation, the following conclusions a can be outline:

- The effect of tool pin shoulder diameter and welding speed on the appearance of the weld is presented and no obvious defect was found.
- The results shows that tool pin shoulder diameter has a significant effect on mechanical properties.
- The ultimate tensile strength of the half cylindrical and half taper screw thread reaches to the 68. 17 % and 74.93 % of the base metal ultimate strength.
- An optimized joint was fabricated at the welding speed of 1100 rpm ,tool travel of 21 mm/min and shoulder diameter of 26 mm have demonstrated more ultimate strength 6111-T4.

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Conflict of interest: None

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