OPTIMIZATION OF PROCESS PARAMETERS OF FRICTION STIR WELDED AA6082 ALUMINIUM ALLOYS

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ABSTRACT

Friction stir welding (FSW)) is a new innovative solid state joining technique for joining Similar and dissimilar metals which has been used in aerospace, rail, automotive and marine industries. This paper optimized the effect of the welding parameters on 5 mm thick AA 6082 aluminum plates. The process parameters are optimized by using ANOVA technique based as L8 orthogonal Array. Experiments have been conducted based on three process parameters, namely, the tool rotation speed, welding speed and plunge speed at two different levels. Ultimate tensile strength, yield strength, percentage elongation and Impact strength has been predicted for the optimum welding parameters and their percentage of contribution in producing a better joint is calculated by applying analysis of variance. The results indicate that the tool rotational speed, welding speed and plunge speed are the significant parameters in deciding the strengths and percentage elongation.

Keywords: ***Aluminum alloy, friction stir welding, tensile strength, Impact strength, Analysis of Variance***.

I. INTRODUCTION

In the recent years, the technologies of Friction stir welding (FSW) is gaining enormous potential in manufacturing applications. Although it has been widely used in defence and aerospace applications in the recent years. The friction stir welding (FSW) is a solid state joining technique invented in 1991 by the welding Institute (TWI), is extensively used in the joining of Aluminum, Magnesium, Titanium and their alloys [1] – [2]. In this process a cylindrical-shouldered tool with taper probe is rotated at a constant speed and fed at a constant traverse rate in to the joint line between two pieces of sheet or plate material, which are butted together. The parts have to be clamped rigidly on to a backing plate in a manner that prevents the abutting joint faces from being forced apart. The length of the pin is slightly less than the weld depth required and the tool shoulder is in intimate contact with the work surface. The pin is then moved against the work, or vice versa. Frictional heat is generated between the wear-resistant welding tool shoulder and pin, and the material of the work pieces. This heat causes the stirred materials to soften without reaching the melting point [3]. FSW is a solid state welding process, means the welding is done at temperatures well below the melting point of the base metal. Results of [4] show that the welds between the aluminum alloys formed by FSW are much better that high temp welding method like Gas metal Are welding. The quality of the weld in FSW is determined by the process parameters tool rotation speed, tool traverse speed and plunge speed, depth of tool penetration and axial force on the shoulder [4] –[5]. Quality weld can be obtained by precise control of these above parameters. Mechanical properties in weld zone are affected by friction stir processing due to the rotation of the tool [6].

The most common approach of testing affect of several parameters on the response is to vary one parameter at a time and keep other constant. This conventional parametric design of experimental approach is time consuming and calls for enormous resources. This is called simple test strategy. One improvement over this process is better test strategy in which two factors are varied at a time. Although this provides response in few number of steps then previous method, it becomes obsolete an inefficient when the number of factors increase. One solution for this is to use efficient test strategies [7]. Owing to limited resources, a modified Taguchi L8 is used for the present study.

1.1 Design of Experiments

The three factors chosen are varied at two different levels low and high as shown in the table 1.

Table 1: Factors and their levels

	Levels	
Factors	Low	High
N(Tool rotation speed) Rpm	1800	2400
V (Welding speed) mm/min	30	50
P (Plunge speed) mm/min	10	20

The three factors at two different levels are arranged according to modified Taguchi L8 Orthogonal array as shown in table2.

Table 2: Factors arranged according to L8 orthogonal Array

Trial No	Column Number		
	1	2	3
L1	1800	30	10
L2	1800	30	20
L3	1800	50	10
L4	1800	50	20
L5	2400	30	10
L6	2400	30	20
L7	2400	50	10
L8	2400	50	20

II. SELECTION OF PROCESS PARAMETERS

The Important parameters affecting tensile strength are tool rotation speed, tool traverse speed, tool till angle, tool penetration depth and tool plunge speed. The factors which primarily affect the tensile strength yet can be varied easily on any vertical machining centre are tool rotation speed (N), welding speed (V) and tool plunge speed (P). Therefore these factors are chosen in the present study.

III. TOOL MANUFACTURING

The FSW Tool is designed for this Research is tool pin profile of cylinder of D/d ratio 3. Out of various Tool materials like tool steel, High speed steel (HSS), high carbon chromium steel, carbon and carbon boron nitride, among which HSS steel is chosen as Tool material because of its high strength, high hot hardness, easy to process, easily available and low cost. The FSW tool is manufactured using CNC Turning centre and wire cut EDM (WEDM) machine. The tools are oil hardened to obtain a hardness of 52 HRC. The tool material properties as given in table (3). The hardening temperature of HSS-M_2 is 1240-1290^{0}C, the quenching medium is oil/air, the tempering temperature is 550-580^{0}C and Brinnel Rockwell hardness is 64-66

Table 3: Tool Material Properties

C	Si	MN	Cr	Ni	W	Co	V	Mo
0.75-0.9	0.10-0.35	0.20-0.40	3.57-4.50	-	5.50-6.50	-	1.75-2.00	5.50-6.50

IV. CONDUCTING THE EXPERIMENTS

Sheets of AA6082 of 5 mm thick are cut to the dimensions 150x75 mm$^{2.}$ The chemical composition of base materials is given table4.

Table 4: Chemical composition of AA6082 (%weight)

Si	Fe	Cu	Mn	Mg	Ti	Zn	Cr	Others	Aluminum
1.240	0.415	0.041	0.567	1.124	0.006	0.047	0.042	0.054	Balance

A three axis CNC vertical milling machine was used to fabricate the joints. Test specimens were prepared and tested for tensile strength on a Universal Testing Machine (UTM) and Impact strength on Impact testing machine. Performance tests were performed on the base metal and the results are tabulated in table 5.

Table 5: Performance test results on AA 6082.

Base material	AA 6082
Density (X 1000 kg/m^3)	2.7
Elastic Modulus (Gpa)	70
Ultimate Tensile Strength (Mpa)	267.453
Yield Strength (MPa)	250
Hardness (VHN)10kgs	82.3
Percentage Elongation	17.56

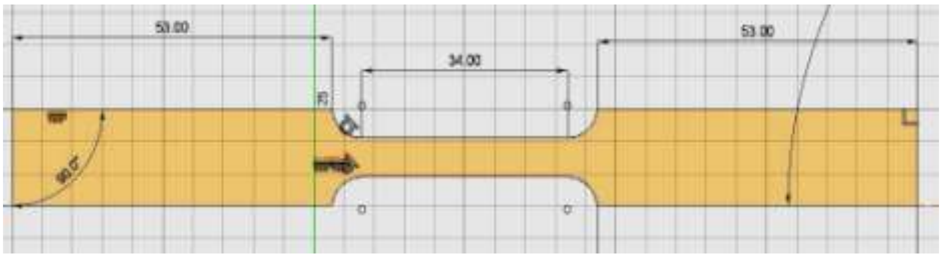

Fig1. Dimensions of Tensile Test specimen

Fig 2. FSW experimental setup

V. ANALYSIS AND DEVELOPMENT OF REGRESSION EQUATION

A general model of the response is expressed as

$$Y=b_0+b_1x1+b_2x_2+b_3x3+b_{12}x_1x_2+b_{13}x_1x_3+b_{23}x_2x_{3+}\ b_{123}\ x_1x_2x_3 \quad (1)$$

Where y is the response property while x_1x_2 and x_3 are selected variables namely tool rotational speed, welding speed and plunge speed. The analysis of variance (ANOVA) is conducted using Yates algorithm.

VI. MECHANICAL TESTS

Friction stir welded samples were tested for tensile & impact properties. The testing procedures, geometry of the samples including dimensions are as per ASTM standards.

VII. RESULTS AND DISCUSSIONS

7.1 Visual Inspection

Visual inspection of the welds shown in fig.3 revealed that the welds are of high quality and defect free. However pin holes are formed at being and termination of the tool along the centre line of weld. Surface roughness is found in weld made at low welding speeds and welds are smooth at high welding speed.

Fig 3. Visual inspection of welds.

7.2 Tensile Strength

It was observed that all the samples failed in Heat affected zone of advisable close to base metal indicating joint weaker than parent metal. Maximum tensile strength is found for the sample 4 and it is minimum for the sample 7. Maximum percentage of elongation is found for the sample 2 and it is minimum for sample 1.

Table 6: Regression equation and coefficient of correlation for responses

S. No.	Property	Regression Equation	Co efficient of correlation
1	Ultimate tensile strength	Y= 87.184+8.01(N)+2.06(V)—3.42(P)+6.35(VP)+3.33(NVP)	98.7%
2	% of elongation	Y= 10.88+0.505(N)+0.15(V)+0.14(P)—0.175(NV)+0.205(NVP)	92.6%
3	Yield strength	Y= 69.23+8.639(N)—1.556(P)+2.637(NP)—6.648(VP)+2.886(NVP)	103%
4	Impact strength	Y=0.181+0.0073(N)—0.0092(V)+0.0061(P)—0.0081(NV)—0.0055(NVP)	99.67%

Table 7: Optimum conditions of quality characteristics

Observed quality Characteristic	Optimum condition
Ultimate Tensile Strength (N/mm^2)	X_1(+1)x2(+1)x3(-1)
Yield strength (N/mm^2)	X_1(+1)x2(-1)x3(+1)
Percentage elongation	X_1(+1)x2(-1)x3(-1)
Impact Strength (J/mm^2)	X_1(+1)x2(-1)x3(+1)

Table 8: ANOVA for Ultimate tensile strength (Design of Experiments method-L8 Orthogonal Array)

EXP NO	Factors			Coefficient	Ultimate strength	1	2	3	SS	Coefficient
	N	V	P							
L1	-1	-1	-1	1	72.352	164.366	362.435	697.475	60808.92	87.18
L2	-1	-1	+1	$\beta 1$	92.014	198.069	335.04	64.157	514.51	8.01
L3	-1	+1	-1	$\beta 2$	94.648	176.098	28.435	16.547	34.22	2.06
L4	-1	+1	+1	$\beta 12$	103.421	158.942	35.722	4.941	3.05	0.617
L5	+1	-1	-1	$\beta 3$	83.076	19.662	33.703	-27.395	93.81	-3.42
L6	+1	-1	+1	$\beta 13$	93.022	8.773	-17.15	-1.207	6.63	0.910
L7	+1	+1	-1	$\beta 23$	66.583	9.946	-10.889	-50.859	323.32	-6.35
L8	+1	+1	+1	$\beta 123$	92.359	25.776	15.83	26.719	89.23	3.33

Y=87.184+8.01(N)+2.06(V)-3.42(P)+6.35(VP)+3.33(NVP)..(2)

Co efficient of correlation =98.7%

Table 9: ANOVA table for UTS (Taguchi method)

Source	SS	DOF	MS=S.S/DOF	Percentage of contribution(P)	F - test
N	514.51	1	514.51	47.41	53.15
V	34.22	1	34.22	2.3	3.53
P	93.81	1	93.81	7.9	9.69
VP	323.32	1	323.32	29.45	33.40
NVP	89.23	1	89.23	7.47	9.21
Error	9.68	2	4.84	0.9	-
Total	1064.77	7	-	-	-

Table 10: ANOVA for % elongation (Design of Experiments method –L8 Orthogonal Array)

EXP NO	Factors			Coeff icient	Percentage elongation	1	2	3	SS	Coefficient
	N	V	P							
L1	-1	-1	-1	1	0.52	2.86	6	10.88	14.79	1.36
L2	-1	-1	+1	$\beta 1$	2.34	3.14	4.88	4.04	2.04	0.505
L3	-1	+1	-1	$\beta 2$	1.42	1.98	2.12	1.2	0.18	0.15
L4	-1	+1	+1	$\beta 12$	1.72	2.9	1.92	-1.4	0.245	-0.175
L5	+1	-1	-1	$\beta 3$	0.54	1.82	0.28	-1.12	0.156	-0.4
L6	+1	-1	+1	$\beta 13$	-1.44	0.3	0.92	-0.2	0.005	-0.025
L7	+1	+1	-1	$\beta 23$	0.94	0.9	-1.52	0.64	0.051	0.08
L8	+1	+1	+1	$\beta 123$	1.96	1.02	0.12	1.64	0.336	0.205

Regression equation

Y= 10.88+0.505(N) +0.15(V) +0.14(P)—0.175(NV) +0.205(NVP)……………………(3)

Co efficient of correlation =92.6%

Table 11: ANOVA table for % elongation (Taguchi method)

Source	SS	DOF	MS=S.S/DOF	Percentage of contribution(P)	F - test
N	2.04	1	2.04	65.84	36.42
V	0.18	1	0.18	4.11	3.214
P	0.156	1	0.156	3.31	2.785
NV	0.245	1	0.245	6.27	4.375
NVP	0.336	1	0.336	9.29	6.00
Error	0.056	2	0.028	11.18	-
Total	3.013	7	-	-	-

7.3 Yield Strength

Maximum yield strength is found for the sample 6 and it is minimum for the Sample7

Table 12: ANOVA for Yield strength (Design of Experiments method –L8 Orthogonal Array)

EXP NO	Factors			Coefficient	Yield strength	1	2	3	SS	Coefficient
	N	V	P							
L1	-1	-1	-1	1	54.147	126.51	283.176	553.899	38350.512	69.23
L2	-1	-1	+1	$\beta 1$	72.365	156.664	270.723	69.115	597.11	8.639
L3	-1	+1	-1	$\beta 2$	75.438	146.878	24.006	7.119	6.33	0.889
L4	-1	+1	+1	$\beta 12$	81.226	123.845	45.109	-1.765	0.389	-0.221
L5	+1	-1	-1	$\beta 3$	64.828	18.218	30.152	-12.453	19.38	-1.556
L6	+1	-1	+1	$\beta 13$	82.05	5.788	-23.033	21.103	55.66	2.637
L7	+1	+1	-1	$\beta 23$	47.979	17.222	-12.43	-53.185	353.58	-6.648
L8	+1	+1	+1	$\beta 123$	75.866	27.887	10.665	23.095	66.67	2.886

Y= 69.23+8.639(N)—1.556(P)+2.637(NP)—6.648(VP)+2.886(NVP)………….................(4)

Co efficient of correlation =103%

Table 13: ANOVA table for Yield strength (Taguchi method)

Source	SS	DOF	MS=S.S/DOF	Percentage of contribution(P)	F - test
N	597.11	1	597.11	53.714	88.86
P	19.38	1	19.38	1.151	0.171
NP	55.66	1	55.66	4.452	0.662
VP	353.58	1	353.58	31.55	0.811
NVP	66.67	1	66.67	5.45	-
Error	6.719	2	3.35	3.683	
Total	1099.119	7			

7.4 Impact Strength

Maximum toughness is reported for the weld made at low welding speed using tapered pin. At low welding speeds, consolidation of the material is good. This may be attributed to the increased heat which refines the grains because of high friction coefficient with tapered pin. Minimum impact toughness is recorded for the weld mode with high welding speed. Regression analysis of impact toughness (Strength) was made and regression equation and coefficient of correlation are presented in table 6.8 while ANOVA results are included in table 6.9

Table 14: ANOVA for Impact strength (Design of Experiments method –L8 Orthogonal Array)

EXPNO	Factors			Coefficient	Impact strength	1	2	3	SS	Coefficient
	N	V	P							
L1	-1	-1	-1	1	0.175	0.3625	0.7005	1.45	0.262	0.181
L2	-1	-1	+1	$\beta 1$	0.1875	0.338	0.75	0.059	$4.35x10^{-4}$	$7.375x10^{-4}$
L3	-1	+1	-1	$\beta 2$	0.168	0.4	0.0145	-0.074	$6.845x10^{-4}$	$0.855x10^{-4}$
L4	-1	+1	+1	$\beta 12$	0.17	0.35	0.045	-0.065	$5.28x10^{-4}$	$0.66x10^{-4}$
L5	+1	-1	-1	$\beta 3$	0.175	0.012	-0.024	0.049	$3x10^{-4}$	$0.375x10^{-4}$
L6	+1	-1	+1	$\beta 13$	0.225	0.002	-0.05	0.0305	$1.16x10^{-4}$	$0.145x10^{-4}$
L7	+1	+1	-1	$\beta 23$	0.175	0.05	-0.0105	-0.026	$8.45x10^{-5}$	$0.105x10^{-4}$
L8	+1	+1	+1	$\beta 123$	0.175	-0.00.5	-0.055	-0.044	$2.42x10^{-4}$	$0.3x10^{-4}$

Y=0.181+0.0073(N)—0.0092(V)+0.0061(P)—0.0081(NV)—0.0055(NVP)……………..(5)

Co efficient of correlation =99.67%

Table 15: ANOVA table for Impact strength (Taguchi method)

Source	SS	DOF	MS=S.S/DOF	Percentage of contribution(P)	F - test
N	$4.35x10^{-4}$	1	$4.35x10^{-4}$	9.81	0.452
V	$6.845x10^{-4}$	1	$6.845x10^{-4}$	20.25	0.217
P	$3x10^{-4}$	1	$3x10^{-4}$	4.16	0.095
NV	$5.28x10^{-4}$	1	$5.28x10^{-4}$	13.7	0.549
NVP	$2.42x10^{-4}$	1	$2.42x10^{-4}$	1.73	0.251
Error	$2.005x10^{-4}$	2	$1.0025\ x10^{-4}$	50.35	-
Total	$23.9x10^{-4}$	7	-	-	-

VIII. CONCLUSION

The ANOVA technique has been used to optimize the welding parameters of friction stir welding to weld 5 mm thick AA 6082 Aluminum alloy plates, the conclusions drawn from the present study are listed below.

1. The ANOVA for the Ultimate Tensile strength result concludes that the tool rotation speed is the most significant parameter with 47.41% followed by the plunge speed of 7.9% and welding speed of 2.3%
2. The ANOVA for the Percentage elongation results concludes that the tool rotation speed of the spindle is the most significant parameter with 65.84% and followed by welding speed 4.11% and plunge speed 3.31%
3. The ANOVA for the yield strength result concludes that the tool rotation speed is the most significant parameter with 53.714% and followed by plunge speed of 1.151%
4. The ANOVA for the Impact strength results concludes that the welding speed is the most significant parameter with 20.25% and followed by the tool rotation speed 9.81%, plunge speed 4.16%.
5. The optimum combination of parameters for ultimate strength obtained from the ANOVA are tool rotation speed 2400 Rpm, welding speed 50mm/min and plunge speed 10 mm/min has been predicted to give the ultimate strength of 103.694 N/mm^2
6. The optimum combination of parameters for impact strength obtained from the ANOVA are tool rotation speed of 2400 Rpm, welding speed of 30 mm/min and plunge speed of 10 mm/20mm has been predicted to give the Impact strength of 0.217 J/mm^2
7. The optimum combination of parameters for yield strength obtained from the ANOVA are tool rotation speed 2400 RPM, welding speed 30 mm/min and plunge speed 20 mm/min has been predicted to give the yield strength of 82.712 N/mm^2
8. The optimum combination of parameters for percentage elongation from the ANOVA are tool rotation speed of 2400Rpm, welding speed 30mm/min and plunge speed 10 mm/min has been predicted to give the percentage elongation of 2.235%.
9. The tool rotation speed of 2400 Rpm is favorable to weld AA6082 aluminium alloy with good mechanical properties.

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