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EXPERIMENTAL ANALYSIS ON MECHANICAL PROPERTIES OF FRICTION STIR WELDING IN DISSIMILAR ALUMINIUM ALLOYS

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Abstract* — Friction stir welding (FSW) is an innovative solid state joining technique and has been employed in industries for joining aluminum, magnesium, zinc and copper alloys. The FSW process parameters such as tool, rotational speed, welding speed, axial force, etc play major role in deciding the weld quality. A mathematical modeling was developed based on experiments to predict the tensile strength of dissimilar FSW aluminum alloys. The maximum tensile strength of 210 MPa can be obtained at the tool rotational speed of 1100 rpm, welding speed of 35mm/min and an axial load of 7 kN is the Optimum welding parameters.

***Keywords* — Friction stir welding, Dissimilar Aluminum Alloys, Mechanical Properties, Response Surface Methodology**

I. INTRODUCTION

FSW was a solid state welding technique. It was invented by Wayne Thomas in December 1991 in The Welding Institute, United Kingdom [1]. In this welding technique the materials which are not able to weld by using the conventional methods are possible to weld [2], [3]. The FSW process was shown in Figure-1[4]. The energy required in this method is lower than the conventional method[5],[6] and also it has various advantages like improved weld ability, safety, eco friendly welding technique[7],[8] reduced distortion, improved appearance, improved mechanical properties could be easily automated, high welding efficiency etc. with less disadvantages like exit hole left when the tool is taken off. This technique was successfully applied in ship building, marine industries, aerospace industries, railway, automotive and many other industrial sectors. The friction stir welding can applied for the materials such as aluminum alloys, copper alloys, magnesium alloys, mild steel, plastics, lead, zinc, titanium, metal matrix composites, magnesium to aluminum, aluminum to steel, aluminum to copper , aluminum to aluminum etc. In this welding technique, a rotating tool was inserted in between the work pieces; due to the action of the axial load it produces a highly plastically deformed zone through the given stirring action.

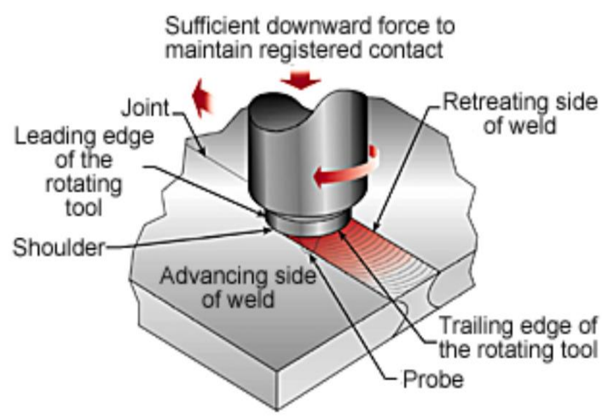

Fig 1 : FSW process

The materials were joined by 80% of the melting temperature [9] of those materials. The tensile strength of the friction stir welded cast aluminum alloy using RSM. Lakshminarayanan et al. [10] studied the effect of FSW welding parameters on the tensile strength of square butt joints made out of AA 7039 aluminum and A384 alloys using Taguchi parametric design approach. K.Anganan et al. [11] investigated the mechanical property in AA7075-T6 and A384.0-T6 aluminum alloys of 6.35mm thickness plate in 600 to 1000rpm, feed rate of 30 to 50mm/min and 6 to 10KN of axial load. In this study the conclusions was at the maximum tensile strength of 277.37MPa can be obtained at the tool rotational speed of 920rpm,welding speed of 46mm/min and the axial load of 9.2KN is the optimum welding parameters. This paper describes the method to employ RSM to develop empirical relationship relating to the FSW input parameters of tool rotational speed, welding speed, axial load and the 4 output

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responses of the ultimate tensile strength, yield strength, percentage of elongation and hardness to find the optimum operating parameters.

II. EXPERIMENTAL PROCEDURE

The base metals used for FSW in the present study were 6.35 mm thick plates of wrought aluminum alloy AA 7075-T6 and cast aluminum alloy of A 384.0-T6. Their chemical composition and the mechanical properties are shown in Table1 and Table 2 respectively[11][12].

Table 1. Chemical Compositions of the Base Metals

Metal s/elem ents	M g	Mn	Pb	Zn	Fe	Cu	Si	Cr	Ni	Al
AA 7075-T6	2. 29	0.0 47	0. 00 4	5.4 4	0. 20	1.4 5	0.0 71	0.2 4	0.00 6	Bal
A 384.0-T6	0. 11	0.2 4	0. 54	1.8 3	0. 96	1.5 4	10. 15	0.0 31	0.09 9	Bal

Table 2. Mechanical Properties of the Base Metals

Base metals	UTS(MPa)	YS(MPa)	Elongation(%)	Hardness(H v)
AA 7075-T6	581.1	379.8	11.7	205.3
A 384-T6	102.0	-	1.0	105.6

The material cast aluminium A384.0-T6 was cast and it is formed into 100 X 50 X 6.35 mm by using sawing machine and lathe. The material wrought aluminium AA 7075-T6 was purchased and it is formed into 100 X 50 X 6.35 mm by using sawing and milling machines [13][14]. The material A384.0-T6 was placed in the advancing side and the material AA7075-T6 was placed in the retreating side. Both the materials were clamped very tightly in order to reduce or to avoid the vibration and the displacement during the welding process.

2.1. Welding Tool Size And Welding Parameters

A non-consuming HRC material tool was used to fabricate the welded joints [15][16][17]. A double sided cylindrical pin was used as the welding tool. The tool has shoulder diameter, pin diameter and pin length of 18 mm, 6 mm and 5.7 mm respectively. This was shown in Figure-2.

Fig 2 : Double Sided Cylindrical Pin

The welding tool was fitted in the chuck and the chuck was fitted to the spindle of the FSW machine. The welding tool was rotating in the clockwise direction but stationary during the FSW process. The specimens to be welded are tightly placed in the FSW fixture. The fixture was held firmly in the FSW machine which travels forward during the FSW process. In this study, the direction of welding was normal to the rolling direction.

The tool rotation was in clockwise direction and single pass welding was used to fabricate the welded joints. The welding parameters investigated were the tool rotational speed, the welding speed and the axial load. The parameter values and the levels are shown in Table-3

Table-3. The parameter values and the levels.

Process Parame ters	Unit	Symbol	Levels				
			-1.682	-1	0	1	1.682
Tool Rotatin g Speed	rpm	N	800	900	10 00	1100	1200
Weldin g Speed	mm/ min	S	30	35	40	45	50
Axial Load	kN	F	6	7	8	9	10

In this investigation, the experimentations are designed on the basis of RSM method. Three factors, 5 levels Central composite circumscribed design consists of 20 sets of coded conditions. The CCC design composed of a complete factorial of $2^3 = 8$, plus 6 central points and 6 star points. For this MINITAB 17 software was used. The lowest and the highest values are coded as -1.682 and +1.682 respectively. The intermediate values are calculated from the relationship X =1.682 [2X - (X X)] / (X X). Where X is the i max + min max + min I required coded value of variable X, and X is any value of the variable from X to X X is the highest value of the max min. max variable and the X is the lowest value of the variable.

In the CCC design the identified experimental parameters are the tool rotational speed, welding speed and the axial load. In this experimental study work, the effect of these parameters on the ultimate tensile strength, yield strength, percentage of elongation and hardness are carried out. The tests are conducted in the longitudinal direction of the welding. On the basis of the trial runs, the working ranges of the selected parameters are fixed. While conducting the experiments one factor is varied and the other factors are kept constant. The experimental results were analyzed by using the MINITAB – 17 software system.

III. RESULTS AND DISCUSSION

3.1. Response Surface Analysis

To predict the effect of individual input parameters and their interaction effect on the responses (like tensile strength, hardness etc.) the mathematical models of response surface analysis were developed. By using MINITAB – 17 software the various response surfaces are created which shows a reasonable acceptance of the actual and the predicted responses. The ultimate tensile strength, yield strength, percentage of elongation and the hardness of the FSW joints are the functions of the tool rotational speed, the welding speed and axial load. This can be expressed as Y= f (N,S,F). For the two factors, the selected polynomial can be expressed as

$$Y = b_0+b_1N+b_2F+b_3S+b_{11}N^2+b_{22}S^2+b_{33}F^2+b_{12}NS+b_{13}NF+b_{23}SF$$

In the above equation b_1 b_2 and b_3 are the linear terms. b_{12}, b_{13} and b_{23} are the interactive terms. b_{11},b_{22} and b_{33} are the quadratic terms of the polynomial. The coefficients b_0 ,b_1 ,b_2 ,b_3 , b_{11} ,b_{22} ,b_{33} ,b_{12} ,b_{13} ,b_{23} are the least square estimates of true polynomial, representing the response surface. The strength of the respective process parameters and their interactions are represented by these coefficients. The p value of the regression analysis indicates the linear, square and the interaction of the FSW parameters with the response functions and these p values are used to identify the significant parameters on the response functions. Design Matrix and Estimated Mechanical Parameters are shown in Table-4.

Table 4. Design Matrix and Estimated Mechanical Parameters

Run No.	Coded Variables			Uncoded Variables		
	FSW Process Parameters			FSW Process Parameters		
	Tool Rotational speed (N)	Welding Speed (S)	Axial Load (F)	Tool Rotational speed (N)	Welding Speed (S)	Axial Load (F)
1	-1	1	-1	900	45	7
2	0	0	0	1000	40	8
3	1	-1	-1	1100	35	7
4	1	-1	1	1100	35	9
5	-1	-1	-1	900	35	7
6	1	1	-1	1100	45	7
7	1.682	0	0	800	40	8
8	-1.682	0	0	900	40	8
9	0	0	-1.682	1000	40	6
10	1	1	1	1100	45	9
11	0	1.682	0	1000	50	8
12	-1	-1	1	900	35	9
13	0	0	1.682	1000	40	10
14	-1	1	1	900	45	9
15	0	-1.682	0	1000	30	8
16	0	0	0	1000	40	8
17	0	0	0	1000	40	8
18	0	0	0	1000	40	8
19	0	0	0	1000	40	8
20	0	0	0	1000	40	8

Table 5. Estimated Mechanical Parameters

Run No	**Design matrix**			**Estimated Mechanical parameters**			
	FSW Process parameter			**UTS**	**YS**	**E**	**Hardness**
	N	**F**	**S**	**(MPa)**	**(MPa)**	**%**	**(HBR)**
1	-1	1	-1	181	150.23	1.1	91.1
2	0	0	0	186	154.38	1.3	90.4
3	1	-1	-1	210	170.28	1.5	91.1
4	1	-1	1	208	168.48	1.4	90.4
5	-1	-1	-1	163	135.29	1	84.4
6	1	1	-1	154	124.74	1	83.4
7	1.682	0	0	141	117.03	1	82.6
8	-1.682	0	0	115	106.21	1	83.4
9	0	0	-1.682	126	116.32	1	86.4
10	1	1	1	144	118.08	1	85.7

11	0	1.682	0	177	141.16	1	85.1
12	-1	-1	1	136	114.00	1	85.7
13	0	0	1.682	166	136.12	1	87.7
14	-1	1	1	167	135.27	1	86.2
15	0	-1.682	0	155	124.00	1	81.9
16	0	0	0	186	154.38	1.3	90.4
17	0	0	0	186	154.38	1.3	90.4
18	0	0	0	186	154.38	1.3	90.4
19	0	0	0	186	154.38	1.3	90.4
20	0	0	0	186	154.38	1.3	90.4

Estimated Mechanical Parameters are shown in Table-5. By u sing MINITAB-17 software the Regression equations are formed. The Regression equations of UTS, YS, %E and HBR are given below.

UTS = 158.2 - 3.53 N - 7.57 F + 0.49 S + 5.51 N*N - 2.09 F*F + 10.81 S*S - 3.50 N*F - 2.50 N*S + 18.25 F*S

YS = 132.34 - 2.65 N - 5.11 F + 0.79 S + 3.56 N*N - 0.86 F*F + 6.92 S*S - 2.88 N*F - 1.13 N*S + 16.13 F*S

%E = 1.0987 + 0.0023 N - 0.0516 F + 0.0346 S - 0.0093 N*N + 0.0260 F*F + 0.0437 S*S - 0.0250 N*F - 0.0250 N*S + 0.1750 F*S

HBR = 86.21 - 1.220 N - 1.492 F + 1.000 S + 0.676 N*N + 0.376 F*F + 0.871 S*S + 0.25 N*F - 0.50 N*S + 2.25 F*S

IV. CONCLUSION

Friction stir welding tool of cylindrical pin profile was developed successfully. It is identified and confirmed to be suitable for the dissimilar welding of aluminum alloys. The major process parameters that affect the quality of the joint are identified. The working range of the process parameters give defect free joints. It was developed for the dissimilar FS welding by trial experiments. Dissimilar FS joints were successfully developed as per Central Composite Circumscribed design matrix using cylindrical tool pin profile. Regression modeling equations of the dissimilar FS welded AA7075-T6 and A384.0-T6 aluminum alloys were developed on the basis of the experimental values of the ultimate tensile strength, yield strength, percentage of elongation and hardness. The developed models were confirmed for 95% confidence level. The maximum tensile strength of 210 MPa can be obtained at the tool rotational speed of 1100 rpm, welding speed of 35mm/min and an axial load of 7 kN is the Optimum welding parameters. At a certain level the responses of UTS, YS, % of E and Hv were increased when the tool rotational speed and axial load increases. All the values of the responses decrease after reaching a maximum value. But, the increase in welding speed has negative impact on the responses. The process parameters were optimized for maximum tensile strength characteristics and hardness.

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