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OPTIMIZATION OF PROCESS PARAMETERS OF FRICTION STIR WELDING OF ALUMINIUM ALLOYS

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ABSTRACT:

The evolution of friction stir welding has proposed various approach for fabrication of high quality weld. Optimization of process parameters of friction stir welding to obtain the characteristics using Response surface methodology is the one toughest challenge in industries. To derive the experimental trails 27L orthogonal array have been utilized and the joints were fabricated with various tool rotational speed, axial force and welding speed by v-thread tool pin. The mechanical properties, like yield strength (YS), ultimate tensile strength (UTS) impact strength (IS) and percentage elongation (%El), are considered as responses. Based on the experimental results optimum levels of process control variables were obtained .Driven by the experimental results, optimum process parameters were obtained in Minitab software.

Keywords: Friction stir welding, mechanical properties, dissimilar aluminum alloy, Response Surface Methodology.

1.Introduction

Scientists and technicians are tackling incredible difficulties in the field of metal joining engineering as technology advances. The issue with traditional fusion methods is primarily due to new metals with reduced welding strength. Various process factors of the casting process influence the composites' mechanical and wear qualities. A tool for math and statistics for planning experiments is response surface methodology. The goal is to maximize a response that is influenced by a number of different independent variables. Response surface approach is an useful tool for optimizing process parameters in many manufacturing processes[1].Under limited runs, the Taguchi approach is a particularly effective toll for process optimization. The results demonstrate that adopting the grey based taguchi approach improves the tensile strength and elongation of welded aluminium alloy[2].The investigation reveals that the taguchi optimization solution is efficient when the objective function includes weld temperature field data, such as the HAZ distance from the weld line and/or the workpiece's peak temperature, according to Mohammad Reza Nourani et al [3].According to M.V.R.Durga Prasad, et al., The most critical aspect in assessing the influence of hardness at the weld zone was welding speed., accounting for 67.5 percent of the total, while tool rotation speed had the least effect, accounting for 4.39 percent[6].To forecast the corrosion resistance and hardness of friction stirrers, a mathematical model was devised with a 95% confidence level, weld AA 2219 aluminium alloy joints.By optimizing friction stir welding conditions, the RSM was used to improve corrosive resistance along with hardness in welded items [9]. The tensile strengths of friction stir welded AA 7075-AA 6061 were gradually raised using Taguchi grey relational analysis, and after the solidification and recrystallization operations, a homogeneous particle distribution on the surface of the weld nugget was also achieved..[11]. ANOVA research demonstrated that rotational speed, travel speed, and plate position tensile strength of joint were all effective to a degree of 59 percent, 30%, and 7%, respectively, according to S. M. Bayazida, et.al.[12]. M.Shiva chander,et.al concluded the use of the Taguchi-grey relation analysis methodology raised TS and HS by 12 percent and 8%, respectively. As a result, the proposed methodology may be considered to have been applied to solve the multi-objective issue with quality prediction features.[14].Of the four process characteristics evaluated, the tool pin form had the greatest impact on tensile strength followed by W.S, T.R.S, and tilt angle..The findings showed that the established models may be used as a stand-in for optimizing hardness and weight loss for certain process parameters[16].The variables in the technique were speed, welding speed, and tool diameter, and the outcomes were easily predicted by GRA and response surface methods for hardness and tensile strength.[19].Many optimization strategies of process parameters of welded aluminium fabricates were done based on the research, including the Taguchi method, grey relational analysis, and anova.The following are the limitations derived from the literature survey :The fundamental drawback of the Taguchi approach is that the results are just relative and do not explicitly state which parameter has the greatest impact on the performance characteristic value. Only a single dependent variable and a single factor can be investigated using ANOVA. It can tell us if at least one pair of means is significantly different when comparing the means of three or more groups, but it can't tell us which pair. The trend link between an alternative and the ideal alternative is reflected by grey relational analysis, but it cannot capture the situational relationship between the alternative and the ideal alternative. The current research discusses various critical welding factors and their impact on weld quality, as well as the weld joint's mechanical characteristics and the use of response surface methods to discover the optimal process parameters.

2. Materials and Methods

The aluminium amalgams AA7075-AA6101 and AA7075-AA6063 were used in this investigation. The aluminium alloy plates of 6mm thickness were cut off into the required size (100mm x 50mm x 6mm) using a power hacksaw machine, and the butting faces were squared using the milling process.Welding edges were aligned with goals that are perfectly parallel to one another. As a result, there are no uneven holes between the plates, which could lead to the failure of welded seam. In addition, to make the surfaces of both plates identical surface layout was carried out.

3. Design of Experiments

The strategy for determining the link between process variable and performance is called as design of experiments(DOE). To control tool rotation speed, welding speed and axial force three friction stir welding process parameters are considered. According to response surface approach, three process parameters and three pitches should be used for each L27 orthogonal array parameter. The amounts of friction stir welding operating factors are considered.

4. Experimentation

The Friction Stir Welding (FSW) Machine is shown in Figure 1. In this investigation, at various process settings butt welding of dissimilar alloy materials AA7075-AA6101 and

AA7075-AA6063 with size of 100*50*6 mm is done. The tool pin was thrown to a predetermined depth near the butting surface's borders, and the tool was installed in a tool holder with a tilt angle of 1.5 degrees. After a period of waiting, the tool was transversed forward, and the joint was produced in a single pass.

Figure 1. . Machine for friction stir welding

4.1. Process Response Measurement

To determine the tensile behavior of FS welded connections UTM was used (Make: FIE & Model: UTN 40) and trails were dimensioned as shown in Figure 2. To determine the average tensile strength, three identical specimens were evaluated as shown in Figure 3 . To determine impact toughness a pendulum-type impact test machine was used (Make: FIE & Model: IT 30 ASTM) and machined to the ASTM E23 standard size shown in Figure 4. Figure 5 shows actual photos of FS welded joint specimens shattered during charpy testing. Table 4 and 5 illustrates the L27 orthogonal array, as well as testing findings for AA7075-6063 and AA7075-6063.

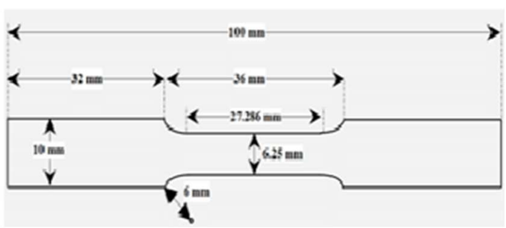


Figure 2. Test specimen of ASTM E8 Standard Tensile

Figure 3. Test specimen of tensile after fracture

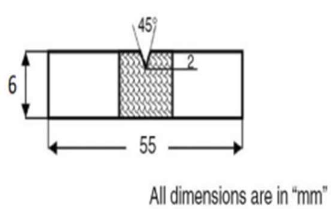


Figure 4. Test specimen ASTM E23 Impact

Figure 5. Test specimen of impact after fracture

Table 4 Experimental Results of L27 Orthogonal Array for AA7075-6063

Trail	Rotational Speed (rpm)	Axial Force (KN)	Welding Speed (mm/min)	Tensile Strength (Mpa)	Yield Strength (Mpa)	% of Elongation	Impact Strength (joules)
1	1000	4	30	120.69	75.69	12.65	2
2	1000	4	45	123.69	78.23	14.69	3
3	1000	4	60	126.25	82.02	17.23	5
4	1000	5	30	123.58	77.23	15.95	4
5	1000	5	45	126.85	80.36	17.26	5
6	1000	5	60	129.26	83.26	20.36	7
7	1000	6	30	126.85	80.23	17.65	6
8	1000	6	45	130.48	82.96	19.25	7
9	1000	6	60	133.25	85.23	22.02	9
10	1100	4	30	129.73	82.25	19.65	7
11	1100	4	45	133.45	85.23	21.06	11
12	1100	4	60	136.21	88.02	24.05	13
13	1100	5	30	132.48	84.98	22.03	11
14	1100	5	45	135.24	86.23	24.05	13
15	1100	5	60	138.25	89.65	26.32	15
16	1100	6	30	135.41	86.32	24.08	13
17	1100	6	45	139.65	88.69	26.98	15
18	1100	6	60	143.65	91.02	29.26	17
19	1200	4	30	139.54	89.65	26.29	16
20	1200	4	45	142.32	92.36	28.06	18
21	1200	4	60	146.23	95.15	31.09	20
22	1200	5	30	142.03	92.02	29.32	18
23	1200	5	45	145.98	94.32	32.06	22
24	1200	5	60	149.02	97.54	34.09	24
25	1200	6	30	145.65	94.98	31.09	21
26	1200	6	45	149.38	96.95	33.33	23
27	1200	6	60	153.98	99.98	36.29	25

Table 5 Experimental Results of L27 Orthogonal Array for AA7075-6101

Trial Tool	Rotational Speed (rpm)	Axial Force (KN)	Welding Speed (mm/min)	Tensile Strength (Mpa)	Yield Strength (Mpa)	% of Elongation	Impact Strength (joules)
1	1000	4	30	130.65	80.45	20.35	4
2	1000	4	45	134.98	83.65	23.98	5
3	1000	4	60	139.36	86.02	26.32	7
4	1000	5	30	132.55	82.98	23.65	6
5	1000	5	45	137.56	85.65	25.65	7
6	1000	5	60	142.36	88.03	28.45	9
7	1000	6	30	135.65	85.65	25.69	9
8	1000	6	45	140.2	87.45	28.32	10
9	1000	6	60	145.23	90.32	30.84	11
10	1100	4	30	138.25	87.32	28.1	11
11	1100	4	45	142.96	89.98	30.54	12
12	1100	4	60	147.78	92.65	33.12	14
13	1100	5	30	140.65	89.02	30.98	13
14	1100	5	45	145.35	91.91	33.12	15
15	1100	5	60	150.45	95.21	35.92	16
16	1100	6	30	142.36	91.45	32.78	16
17	1100	6	45	148.36	94.02	35.21	19
18	1100	6	60	153.26	98.23	37.35	23
19	1200	4	30	145.54	93.03	35.45	18
20	1200	4	45	151.21	96.98	37.12	20
21	1200	4	60	155.87	100.02	39.54	25
22	1200	5	30	148.36	96.65	37.89	21
23	1200	5	45	153.26	99.03	39.87	22
24	1200	5	60	158.67	102.65	41.64	26
25	1200	6	30	150.24	98.32	39.54	23
26	1200	6	45	156.23	101.32	41.65	25
27	1200	6	60	161.52	104.95	43.02	27

5 Results and Discussions

5.1 Response surface methodology Technique

Combination of mathematical and statistical approaches is R.S.M so that may be used to generate empirical models, improve and optimize process parameters, and find the interplay of several influencing elements. It reduces the number of experiments required for a given number of components and their levels. The key benefits of R.S.M are detecting the interaction between the independent variables, mathematically modelling the system, and saving time and money by lowering the number of trials. To identify the process characteristics that have a substantial impact on the response Analysis of variance is used. Regression equations are used to forecast the response for the given process characteristics and levels. Response surface plots show the effect of process parameters on response.

5.2 Mathematical modeling

Using RSM approach models for predicting reaction parameters like tensile strength, yield stress, elongation, and impact were developed. Listed below are the mathematical models for the parameters, equations 1-4 for aluminium 7075-6063 and 5-8 for aluminium 7075-6101.

Tensile stress= 85.5 -0.0029 TRA - 4.73 AF-0.117 WS+ 0.000038 TRA*TRA + 0.613 AF*AF -0.000499 WS*WS + 0.00081 TRA*AF + 0.000243 TRA*WS+ 0.02356 AF*WS — (1)

Yield stress = 90.6 - 0.0987 TRA - 1.36 AF+ 0.241 WS + 0.000074 TRA*TRA+ 0.210 AF AF +0.001126 WS*WS + 0.00189 TRA AF- 0.000074 TRA*WS - 0.01611 AF*WS — (2)

Elongation = -45.5 + 0.0164 TRA + 5.96 AF -0.090 WS+ 0.000021 TRA*TRA - 0.453 AF AF +0.001467 WS*WS + 0.00077 TRA*AF + 0.000078 TRA*WS + 0.00539 AF*WS — (3)

Impact = -41.0-0.0089 TRA+ 3.92 AF- 0.091 WS + 0.000028 TRA*TRA - 0.389 AF*AF -0.00025 WS*WS + 0.00250 TRA AF + 0.000278 TRA WS-0.0111 AF*WS — (4)

Tensile = 46.8 +0.0652 TRA+ 1.76 AF+ 0.0449 WS+ 0.000003 TRA*TRA+ 0.0683 AF AF -0.000363 WS*WS - 0.000600 TRA*AF+ 0.000212 TRA*WS + 0.01772 AF*WS —- (5)

Yield = 39.4 +0.0085 TRA+ 1.36 AF-0.139 WS 0.000020 TRA*TRA - 0.025 AF*AF +0.000733 WS*WS+0.00105 TRA AF+ 0.000241 TRA"WS + 0.00106 AF*WS —- (6)

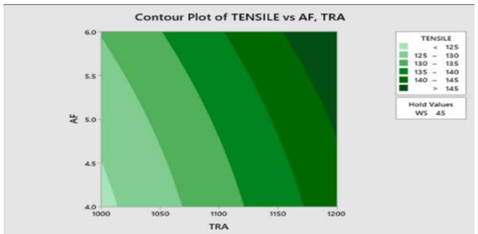
Elongation = -127.4 +0.1527 TRA + 7.62 AF+0.4945 WS - 0.000029 TRA*TRA - 0.301 AF AF
-0.000072 WS*WS - 0.001750 TRA*AF -0.000256 TRA WS-0.01044 AF*WS —- (7)

Impact = -79.7+ 0.1022 TRA - 0.56 AF- 0.552 WS - 0.000017 TRA*TRA + 0.500 AF*AF +0.00222 WS*WS -0.00167 TRA AF+0.000444 TRA WS+ 0.0000 AF*WS — (8)

The R-Squared value for these models was greater than 98 percent, demonstrating their ability to reliably forecast tensile strength, yield stress, elongation, and impact strength.

5.3 Analysis of experimental

Experiments were conducted to investigate the effect of various process variables on based on the equation generated through experimental observations and response surface methods. A few contour diagrams with effects of tool rotating speed, welding speed, and axial force are given below:



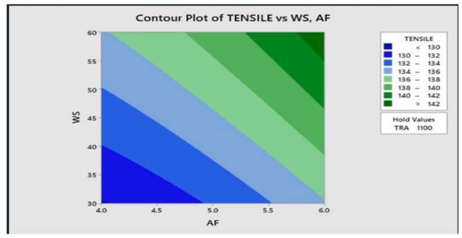
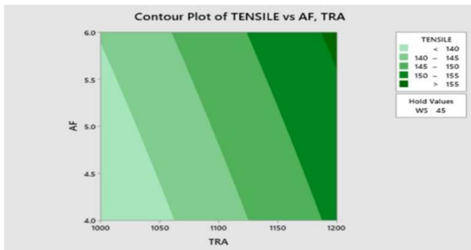


Fig. 6.a **Fig. 6.b**



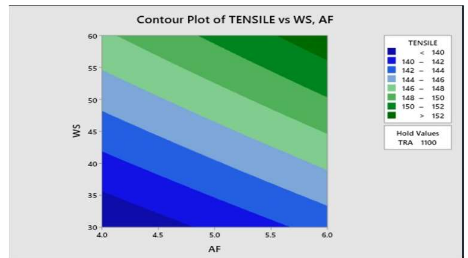


Fig. 7.a **Fig. 7.b**

Fig 6.a,b contour plots for AA7075-6063L
& Fig.7.a&b contour plots for AA7075-6101L

5.4 Optimization of process parameters

An optimal search model for the various process parameters is used to maximize the answers after designing experiments and determining the mathematical model with the best fits. After the numerical optimization, the response cubes are plotted. Using Response Surface Methodology,it is found that the turning operation parameters were the best . The optimal levels for turning AA7075-6063 aluminium alloy are tool rotating speed 1200 rpm, welding speed 45 mm/min, and axial force 5 KN to achieve maximum tensile strength, yield stress, elongation, and impact. Tool revolving speed of 1100 rpm, welding speed of 60 mm/min, and axial force of 6kN are the ideal settings for turning AA7075-6101 aluminium alloy for maximum tensile strength, yield stress, elongation, and impact.

6. Conclusion

Using a response surface technique, the optimal combination of friction stir welding process parameters for fusion of AA7075-AA6101 and AA7075-AA6063 alloy materials was established. The following are some of the most important conclusions from the study:

A. Tensile strength, yield stress, percentage elongation, and impact strength of friction stir welded joints of aluminium alloys AA 7075-AA6063 and AA7075-AA6101 were used to develop regression equations. At 95% confidence level, the developed models can predict reactions to within 10% of their experimental values.
B. The best combination of AA7075-6063 process parameters for simultaneously achieving optimum ultimate tensile strength of 142, maximum yield strength of 91, maximum percent of elongation of 28 percent, and impact strength of 16 kJ/m2 in the FSW process is tool revolving speed of 1200 rpm, welding speed of 45 mm/min, and axial force of 5 KN.

C. The best combination of AA7075-6101 process parameters for simultaneously achieving optimum ultimate tensile strength of 152, maximum yield strength of 99 MPA, maximum percent of elongation of 37.5 percent, and impact strength of 19 kJ/m2 in the FSW process is tool revolving speed of 1100 rpm, welding speed of 60 mm/min, and axial force of 6kN.

D. The response surface approach reveals that in the FSW process, the process control variable tool rotational speed has the greatest impact on the output reactions, while axial force has the least.

E. When compared to Taguchi, ANOVA, and grey relational analysis, R.S.M is a good method for analysing the impact of multiple factors and their interactions on one or more response variables.

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