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Experimental Investigation and Analysis of the Effect of Tool Pin Contour on Friction Stir Welding Aluminium Alloy AA 5083 and AA7075

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ABSTRACT: Friction Stir Welding is a type of welding in which the relative motion of the specimen and the tool creates heat, which connects the edges. Aluminium alloy is utilised in aircraft applications because of its outstanding characteristics, which include high corrosion resistance, weld ability, and fatigue strength. In a Vertical CNC Machine, experiments were conducted out on the aluminium alloys AA5083 and AA7075. The performance characteristics were calculated, and the results indicated that tension strength and process parameters are inextricably linked. As a result, a database of friction stir welding process variables must be created in order to identify optimal process parameters. An ANOVA test was used to identify the most relevant process parameter that influences tension strength.

Keywords: friction stir welding, ANOVA, S/N Ratio, Array of Orthogonal.

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I. INTRODUCTION

The welding dissimilar aluminium alloys using fusion welding is extremely challenging owing to weld solidification flaws such as hot fracture, lack of penetration, and porosity. The welded metal composition has a significant impact on the cracking solidification of aluminium alloys. The quantity of dilution, the base metal, and the filler metal all have a role in the composition. As a result, the filler type and welding parameters must be carefully adjusted so that the resultant weld composition is not vulnerable to solidification cracking. In such circumstances, fusion welding of comparable aluminium alloys may be accomplished without difficulty. FSW techniques are useful for a variety of applications, including the joining of different aluminium alloys. This approach does not need the melting of anything. There is no chance of the weld splitting during the solidification process. Similarly, with aluminium alloys, FSW methods tackle a variety of fusion welding issues such as porosity, segregation, and liquid cracking in the heat-affected zone [1]. FSW is the finest choice for welding dissimilar aluminium alloys. It may be used to weld a variety of joints, including butt joints. Friction stir processing [2,3], Friction stir channelling, friction stir riveting, and friction stir forming [4] are becoming increasingly prevalent, as are certain newer techniques based on FSW principles, such as additive friction stir [5].

The optimum technique for eliminating the property of the AM/MAM method has been discovered to be AFS. It's one of a kind since it's a core AM system with lateral strength that's equivalent to, if not higher than, longitudinal strength [6]. AM goals included all aspects of information dynamics design, software, historical development, tolling, and so on [7]. The tensile strength and microstructure of AA2219-T87 and AA5083-H321 were studied by FSW. The Taguchi technique was used to optimise the process parameters. The rotating speed, transverse speed, tool form, and the proportion between the tool shoulder diameter and pin diameter are all factors to consider. The parameters of the optimal condition are determined in terms of tensile strength [8].

The FSW process parameters are being adjusted in terms of tensile strength, and the appropriate level settings have been found, such as 15 mm/min transverse speed, 700 rpm rotating speed, and D/d ratio 3 [9]. The fatigue strength of the AA2024-7075 have been studied. They discovered that the positive Kr (Stress Intensity Factor) value measured at the cross-section of the different welds had a significant influence on the development of fatigue cracks [10].

The process parameters in FSW of different aluminium alloys were studied. They used a variety of tool rotating rates, including 600, 800, 1000, and 1200 rpm. Tool rotation speeds of 600–1200 rpm have been used to achieve high-quality welds. In the weld nugget area, no fault develops regardless of tool rotation speed. The experimental examination of the aluminium alloy AA6603, using the axial force, traverse speed, and tool rotating speed as process parameters, is presented in this research.

II. RELATED WORK

The Figures 1 and 2 depict coated and uncoated tools, respectively. For the experiments, thin AA5083 and 7075 plates were utilised. The plate is 100 mm in length, 6 mm in thickness, and 50 mm in width. Shearing was used to cut the plate to the right size, and then a milling machine was used to grind the end. To remove burrs and scratch marks, the edges were polished using emery sheets [11]



Fig.1.Coatedtool.



Fig.2.Uncoatedtool.

Figures 3 and 4 depict coated and non-coated weldments, respectively. As a result, it smoothes down the edges of the plates, reducing the distance between them. The plate has a length of 100 mm, a thickness of 6 mm, and a width of 50 mm.



Fig. 3.Weldmentsby coatedtool.



Fig.4.Weldmentsbynon-coatedtool.



III. TOOL DESIGN

The test specimen is shown in Figure 5. The tool is made of M2 grade high carbon-chromium steel. M2 is a tungsten and molybdenum series high-speed steel. One tool was coated, while the other was left untreated. Tools were machined, heat-treated, and hardened using a lathe turning machine. The tool has a 4 mm pin diameter, 5.7 mm pin length, and a 19.5 mm shoulder diameter [12].



Fig. 5. Tensile test specimen

To enhance the tool's hardness (2600–3300 HV), which is about equal to 190 HRC [13], a Titanium Aluminium Nitride coating is applied using the Physical Vapour Deposition technique for tools up to 30 mm in length. The force and extension graph for the weld section is shown in Figure 6. The coating has a thickness of 4 mm. The aluminium plates were welded in the CNC vertical milling machine with the coated tool by adjusting the tool's rotational speed and feeds according to the process parameters. The Vickers hardness test is used to determine the hardness of tools.

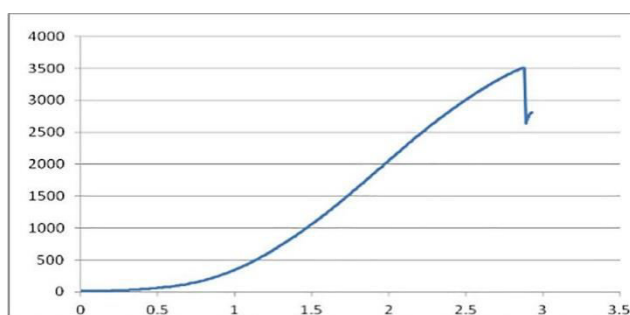


Fig.6. Force and extension graph for welded part.

First, the sample is raised until it makes contact with the indenter. The indenter then applies the test power to the test sample, progressively increasing it until it reaches the predetermined esteem. The surface region of the square created space is then calculated by holding this power for the appropriate amount of time. Figure 7 depicts the S/N Ratio for various input values. The AES technique measures the material that falls off the surface when a beam electron is engaged onto the surface to determine coating thickness [21]. The levels of the parameters in the process are shown in Table 1.

1.1. Taguchi method

This approach is a problem-solving strategy that can improve product design efficiency while decreasing trial time and cost. This technique combines the design of experiments with the quality loss function. These concepts are used to tackle a variety of difficult problems in product design. The most important metric for overall performance is calculated using this approach [14].

The process's optimum parameters, as determined by this approach, are indifferent to a variety of environmental and other variables. As the number of process parameters grows, so does the number of tests. To solve the challenge, the Taguchi technique employs a unique orthogonal array architecture that allows just a minimal number of tests to be run throughout the entire process parameter space. In the study of the (Signal / Noise) ratio, Taguchi distinguishes between three categories of quality characteristics: smaller-the-better, higher-the-best, and nominal-the-better. For each of the process parameters, the S / N ratio was calculated using S / N analysis [15].

Regardless of the quality attributes, a greater S/N ratio results in higher quality characteristics. As a result, the highest S / N ratio is the optimal level of process parameters. In addition, ANOVA was used to check if the process parameter became statistically significant for each quality feature. For the experiment, the traverse and rotational speeds are considered process parameters. With each process

parameter, three levels are chosen [16]. To carry out the experiment presented in Table 2, the L9 orthogonal array was chosen using design of experiments. Using CNC vertical machining centre, FSW was performed as per the L9 Array of Orthogonal.

Table 1 Parameters in the process and their levels.

Parameters	Level 1	Level 2	Level 3
Traverse speed (mm/min)	20	40	60
The rotational speed of tool (rpm)	1200	1500	1800

Table 2 L9 Array of Orthogonal.

EXPERIMENT NUMBER	TRAVERSE SPEED mm/ min	ROTATIONAL SPEED RPM
1	20	1200
2	40	1200
3	60	1200
4	20	1500
5	40	1500
6	60	1500
7	20	1800
8	40	1800
9	60	1800

With the aid of a CNC vertical milling machine, the aluminium plates were welded utilising coated and uncoated tools at varied speeds and feeds. The welded plates were then trimmed to the normal size when they were completed.

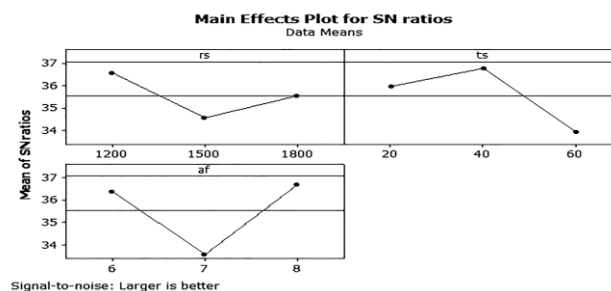


Fig.7.S/N Ratioplots for the different input parameter.

IV. EXPERIMENTAL RESULTS

The Wire EDM technique is used to cut welded parts of the size 100 50 6 into samples of the dimensions required by ASTM E8 standards. The samples were put through their paces in UTM by being fitted onto a specific plate structure. The yield point and tension strength were determined by testing.

We cut 27 samples of the aforementioned dimensions from the welded plates from the 9 workpieces, except the 19.5 mm at the front and rear ends of the retracting side. The samples were put through their paces in UTM by being fitted onto a specific plate structure. As a consequence, the tension strength and yield point were determined. The tensile strength of the composite plate sample was first determined to be 148.8 MPa.

According to the findings, the majority of the welded joints had 60–65 percent of the original composite's tensile strength. Other than welded connections, several components were discovered to have damaged [17]. Certain were discovered to contain casting flaws and voids in those locations. The fracture started at the site of the tunnel flaw in the samples having tunnel defects. The acquired tensile strength values were then calculated to establish the mean S/N ratio as well as the optimum combination [18]. The ASTM E8 specifications and tabulated S/N ratio for ultimate tension strength are shown in Tables 3 and 4.

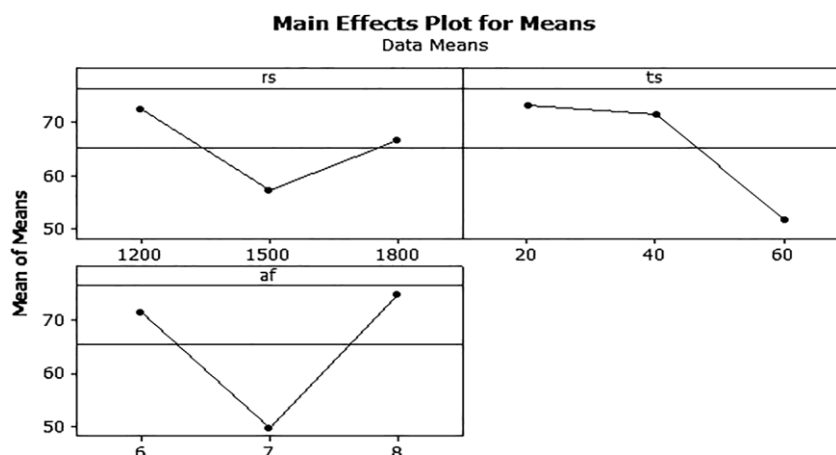
Table 3 ASTM E8 Standards.

Description	Dimension (mm)
Length of gauge	25
Width	6
Thick	5
Radius fillet	6
Overall length	100
Length of reduced portion	32
Grip section length	32
Grip section width	10

Table 4 Tabulated S/N ratios for Ultimate strength of tension.

ROTATIONAL SPEED (RPM)	TRAVERSE SPEED MM/MIN	AXIAL FORCE (KN)	MEAN ULTIMATE TENSILE STRENGTH (MPA)	MEAN S/N RATIO
1200	20	6	95.14	39.16
1200	40	7	63.85	36.1
1200	60	8	58.16	34.46
1500	20	7	39.27	31.41
1500	40	8	81.56	38.22
1500	60	6	50.53	34.06
1800	20	8	85.08	37.36
1800	40	6	68.73	35.95
1800	60	7	46.17	33.26

The difference between the maximum and minimum values of each parameter was used to rank the process parameters based on the mean value of the Tensile strength [19]. A predominating factor is axial force, which has led to the adoption of a coated tool with no visible wear throughout the welding operation. The optimum combination of parameters from the trials was 1200 rpm rotation, 40 mm per minute traverse speed, and 8 kN axial force, as shown in Fig. 8.



VI. ANOVACALCULATION

ANOVA is a set of statistical models used to assess differences in inter-group resources and associated procedures (such as “variation” between and across groups), in which the observed variance in a variable is split into components owing to various sources of variation [20].

Table 5 ANOVA of Means of tensile strength.

SOURCE OF VARIATION	DF	SUM OF SQUARES	MEAN SUM OF SQUARES	TEST F	VALUE OF P	CONTRIBUTION PERCENTAGE
RS	2	356.7	178.3	0.66	0.603	12.52
TS	2	857.9	429.0	1.59	0.387	29.47
AF	2	111.6	558.4	2.06	0.326	39.05
ERRORS	2	541.2	270.6			18.92
TOTAL	8	2872.5				

Based on the F test for the 95 percent confidence level on each parameter in Table 5, we determined that the process is under control. In addition, axial force is the most important parameter (39.05%), followed by traverse speed. Table 6 shows that the error contribution to the overall value is greater than the axial force parameter. This is due to a variety of factors, which are outlined below.

Table 6 ANOVA of S/N value of tensile strength.

SOURCE OF VARIATION	DF	SUM OF SQUARES	MEAN SUM OF SQUARES	TEST F	VALUE OF P	CONTRIBUTION PERCENTAGE
RS	2	6.07	3.03	0.45	0.687	12.2
TS	2	12.8	6.41	0.96	0.510	25.8
AF	2	17.48	8.74	1.31	0.433	35.2
ERRORS	2	13.33	6.67			26.9
TOTAL	8	49.69				



1. Casting flaw - Inadequate stirring of SiC reinforcement in aluminium metal causes ceramic build up in a few spots and brittleness in the localised area.
2. Dimensional differences in work piece Errors in the milling and wire-EDM processes cause improper flatness and perpendicular in the mated work pieces during welding.
3. Welding process flaws - This happens when the tool path and the butt joint line aren't aligned properly, the plunge depth isn't deep enough, and the holding force on the work piece isn't strong enough.
4. Tool - Alumina deposition in the tool's pin throughout the course of a welding run, resulting in an increase in the pin's size.

V. CONCLUSION

FSW is more promising than fusion welding methods for connecting Al alloys. The specimens were collected and tested in the UTM according to ASTM E8 standards, with a tensile strength of 95.14 MPa at 1200 rpm. We investigated 1200 rpm rotation, 40 mm per minute traverse speed, and 8kN axial force for optimal welding using a coated tool. According to the findings, the majority of the welded joints had a tensile strength of 60–65 percent that of the original composite. Precipitate loss or over-aging in the weld area are the causes.

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