

Experimental Analysis to Optimize the Process Parameter of Friction Stir Welding of Aluminium Alloy

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Abstract - In many industrial applications steel is replaced by non-ferrous alloys like aluminium alloys. Aluminium alloys having good mechanical properties as compared to structural steel and low weight that allows a significant reduction in weight. But the welding of aluminium alloy by conventional processes can cause serious problems. The difficulties are like loss of alloying elements and presence of the segregation and porosities in the weld joint. Friction stir welding (FSW) is a solid state welding process, which eliminates all these problems of solidification associated with the conventional fusion welding processes.

In this research work the attempt has been made to develop an empirical relationship between FSW variables (tool rotation, tilt angle and welding speed) and tensile strength and yield strength of single pass and multi pass friction stir welded aluminium alloy 6082 butt joints. Taguchi method and particle swarm optimization technique was adopted for the analysing the problem in which several independent variables influence the response. A three -factors three level central composite design was used to determine the optimal factors of friction stir welding process for aluminium alloy.

Key Words: Design of experiment, Friction stir welding, Taguchi method.

1. INTRODUCTION

In today's modern world there are various welding techniques to join metals. They range from the conventional oxyacetylene torch welding to the laser welding. The two types of welding can be separated as fusion welding and pressure welding. The fusion welding is the process involves bonding of the metal in the molten stage and may need a filler material if required such as a unpreserved electrode or a spool of wire. Some processes may also need an inert ambience in order to avoid corrosion of the molten metal. A flux material or an inert gas shield in the weld zone protects weld pool to avoid defects. example of fusion welding are metal inert gas welding (MIG), tungsten inert gas welding (TIG) and laser welding. There are a lot of disadvantages in the welding techniques where the metal is heated to its melting temperatures and let it the harden to form the joint. The disadvantages also include porosity, oxidation, micro

segregation, hot cracking and other microstructure defects in the joint. A process also limits the combination of the metals that can be joined because of various thermal coefficients of expansion.

From the literature survey the various material of aluminum serious is tested but the aluminum alloy of 6082 is remain so I selected this material.

1.1 NEED OF FRICTION STIR WELDING

More than 100, 00,000 workers in the world are currently employed full time as welders, while higher number of workers performs welding intermittently as part of their job. A number of epidemiologic studies have reported a higher incidence of respiratory ill health in welders. Respiratory effects observed in welders have included bronchitis, airway irritation, metal fume, etc. pneumonitis, lung infection changes, and a possible increase in the incidence of lung cancer. It is necessary to reduce welding fume toxicity and exposure whenever possible. Jayaraman^[2] states the effect of friction stir welding process parameters on tensile strength of cast LM6 aluminum alloy also the quality of weld zone was investigated using macrostructure and microstructure analysis. They proposed that about the 12 joints fabricated, that the joint made-up using the process parameters of 900 r/min (tool rotation speed), 74 mm/min (welding speed) and 3 KN and (axial force) yielded higher tensile strength compared to other joints.

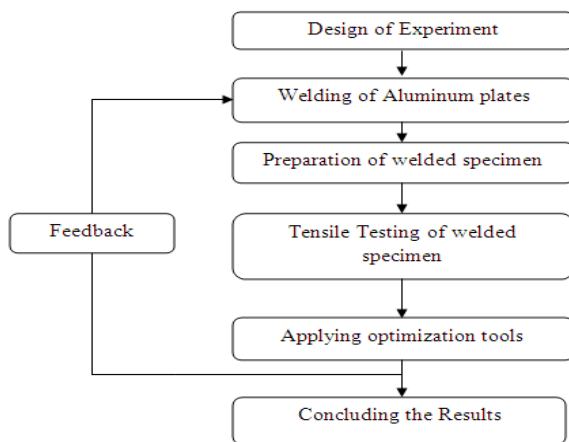
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2. METHODOLOGY

For the welding purpose the plates of aluminum AA6082 were prepared then these plates were welded by using a square profile tool with single pass and double pass. The specimens were prepared and tested on universal testing machine. The obtained results of the tensile strength were optimized by using the optimization techniques like ANNOVA and PSO. Thus optimum values were found.

The flow chart given below represents the methodology for the project. Friction Stir Welding is a simple method in which the rotating cylindrical tool with a shoulder and a

profiled pin is plunged into the adjoining plates to be joined and traversed along the line of the joint.



A cylindrical tool rotating at high speed is gradually plunged into the plate material, until the shoulder of the tool touch the upper surface of the material. The tool is then traverse along with the joint line, until it reaches the end of the weld.

As the tool is then moved in the direction of welding, the leading edge of the tool that forces the plasticized material, on either side of the line, to the back of the tool. In effect, the transferred material is forged by that the close contact of the shoulder and the pin profile. In order to achieve the complete through thickness welding, the length of the pin should be slightly less than a plate thickness, since only limited amount of deformation occurs below the pin. The tool is generally tilted by 2 to 4°, to facilitate better consolidation of the material in the weld.

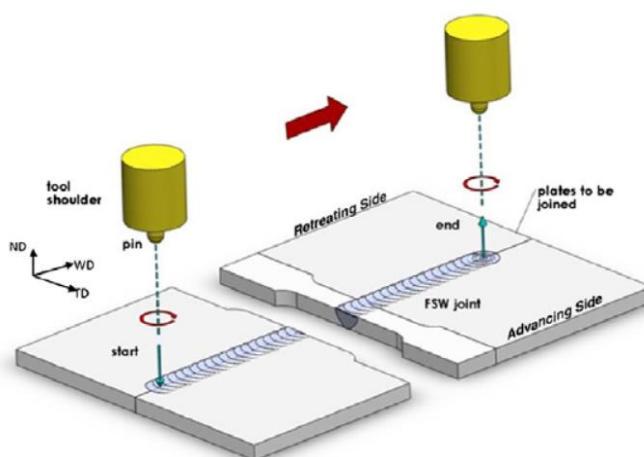


Fig.1.Schematic representation of (a) FSW process and (b) tool profile with dimension

3. EXPERIMENTAL METHOD

A. Design of Experiments

Design of experiments is a method of designing experiments, in which only selected number of experiments are to be performed. For example if there are three parameters with three levels of each parameter, then the total number of experiments to be performed is $3^3= 27$ experiments. But using design of experiments method, only 9 experiments are required to be performed. On the basis of these 9 experiments, the significance and optimal levels of each parameter is obtained. According to the L9 orthogonal array, 3 experiments in each set of process parameters have been performed on IS 3039 plates. The 3 factors used in this experiment are the rotating speed, tool tilt angle and travel speed. The factors and the level of the process parameters are presented in Table. and these parameters are taken based on that the trials to weld the FSW of steels. The experiment notation is also included in the L9 orthogonal array which results in an on additional column, in order to represent the parameters, as presented in Table.2. The experiments are performed on the vertical milling machine which serves to perform the FSW operation. It is a well known factor that at higher rotating speed, FSW produces high heat input and these three levels were selected as low, medium and high speed among the highest speeds available in the machine. Only at low travel speeds, the weld could be achieved with a shorter pin and hence the three least travel speeds were taken. Beyond the tool tilt angle of 2° the pin pierces out the plasticized material for the thickness of 3mm plate, and hence 0°, 1° and 2° tool tilt angles were taken. The various process parameters are as follows.

A. Fixed parameters

1. Force
2. Shoulder plunger
3. Penetration ligament
4. Tool pin profile

B. Variable parameters

1. Tilt angle
2. Rotational speed
3. Welding speed

Table 1: Process Parameters and their Levels

Process parameters	Levels		
	1	2	3
Tool rotational speed(rpm)	710	900	1035
Weld speed(inch/min)	1	1.5	2
Tilt angle(degrees)	1	2	3

Table 2 : L9 (33) Orthogonal Array for Final Experimentations

Sr. No.	Tool rotational speed(rpm)	Weld speed (inch/min)	Tilt angle
1)	700	1	1
2)	700	1.5	2
3)	700	2	3
4)	910	1	2
5)	910	1.5	3
6)	910	2	1
7)	1035	1	3
8)	1035	1.5	1
9)	1035	2	2

B. Tool Design

Tool introduction

According to K.Ramanjaneyulu, G. Madhusudhan Reddy, A. Venugopal Rao, and R. Markandeya, Experiments were conducted with different tool pin profiles are (conical, triangular, square, pentagon, and hexagon cross sections) maintain that the same swept volume during the tool rotation. The shoulder diameter was also kept constant for all tools at 12 mm; thereby ensuring that the pin profile is the only variation from tool to the tool. In other words, the pin-to-swept volume ratio varies due to changes in the physical volume of the pin only. In other words, the pin-to-swept volume ratio varies due to changes in the physical volume of the pin only.

In our project work we had studied various papers and finally we have selected hexagonal and. Fig. 1 shows these tools.

Table 3. FSW tool parameter

Tool	Dimensions
Pin length	4.7 mm
Shoulder	12 mm
Taper angle	14°

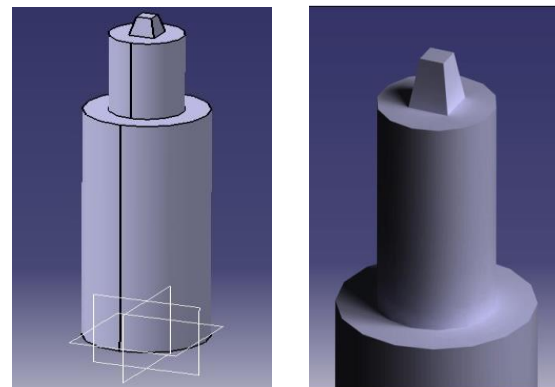


Fig.2 Square tool profile

Two dimensional geometries of tools are as follows,

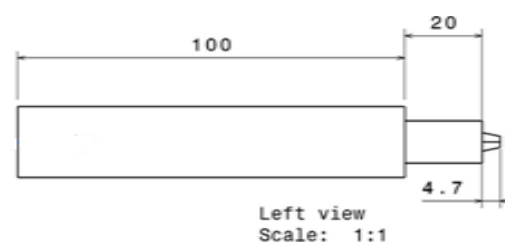


Fig. 3 2D drawing of square pin tool

C. Welding Of Aluminum Alloy



Fig. 4 Welded Parts by square tool for single pass



Fig. 5 Welded Parts by square tool for multipass

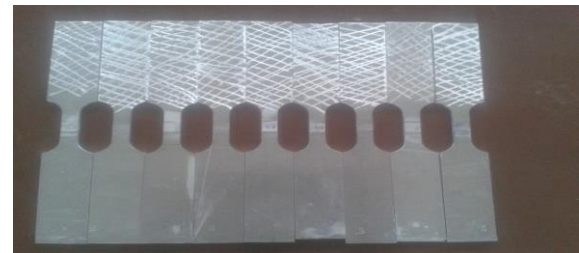


Fig 7 Tensile Strength Specimen

4. PREPARATION OF TENSILE TEST SPECIMEN

Transverse tensile test samples are prepared from welds joints according to the ASTM specifications, E-8M-08 [ASTM-2008] by VCM at Bhansali Tractors at Kopergaon using specimen of two inch gauge length as shown in Fig 6. Eighteen tensile test pieces are prepared from the each weld joints to ensure accuracy (nine for each tool). Data from each weld specimens is giving single values of tensile strength. The specimens are marked for identification, the centre of the weld is identified and two inch mark was made to facilitate the measurement of elongation after the test sample breaks under tension.

The tensile strength of parent material of Al 6082-T6 is 250 N/mm². The highest tensile strength achieved of the weld zone is 183.73 N/mm². The ultimate tensile strength of butt weld reaches to 68 to 70 % of the base metal ultimate tensile strength.

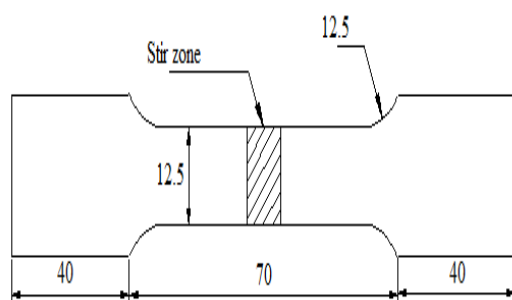


Fig 6: Dimensions of the Tensile Test Specimens [ASTM E8M-08]

A. Tensile Strength of Weld Specimens

Tensile strength of weld specimen is measured by Universal Testing Machine at VSP testing and calibration lab, MIDC Ambad, Nashik. Table below shows tensile strength. After performing all experiments, the values of response variables are fed to software for analysis. The value of response variable is shown in Table 4. Tensile strength is measured by universal testing machine.

Table 4. Tensile strengths of weld specimen For Square pin tool profile for single pass and multi pass

Sr. No	Tool rotational speed (rpm)	Tilt angle (degrees)	Weld speed (inch/m in)	Welding strength	
				Single pass	Multi pass
1)	700	1	1	163.49	125.25
2)	700	2	1.5	180.26	154.93
3)	700	3	2	183.73	114.80
4)	910	1	1.5	169.18	137.55
5)	910	2	2	180.33	169.17
6)	910	3	1	177.66	151.91
7)	1035	1	2	127.53	125.75
8)	1035	2	1	128.26	163.98
9)	1035	3	1.5	145.44	161.04

After welding the tensile strength of welded specimen comparing with standard material shown by graph.

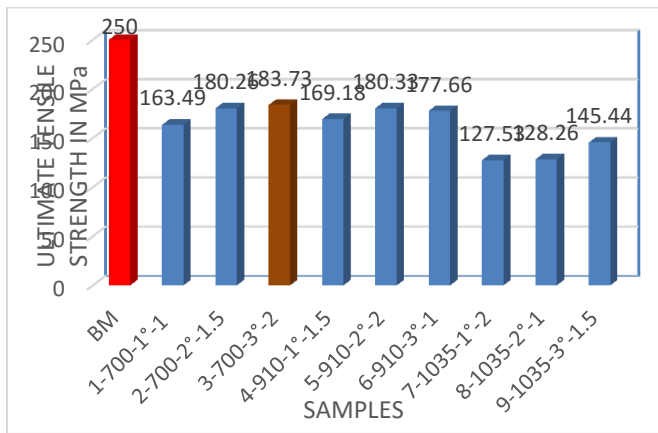


Fig 8 Ultimate Tensile Strength Single Pass

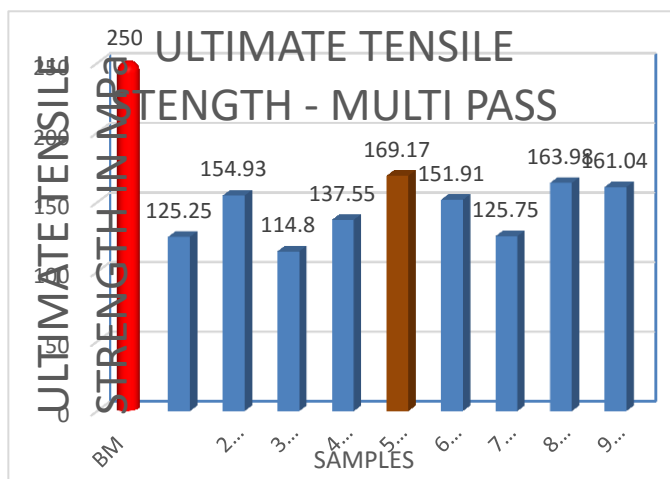


Fig 9 Ultimate Tensile Strength Multi Pass

B. Analysis of Tensile Strength

ANOVA

The main aim for selection of ANOVA is to estimate the percentage of the individual contribution of the welding parameter on the tensile test of weld, after performing final experiments analysis of experimental data is done by using MINITAB-17 software. The effect of various input parameters that on output responses will be analyzed using analysis of variance (ANOVA). Analysis of variance (ANOVA) test is performed to identify the process parameters that are statistically significant and which affect the tensile strength of FSW joints.

The results of ANOVA indicate that the considered process parameters are highly significant factors affecting the tensile strength of friction stir welding joints in the order of rotational speed, tilt angle and traverse speed.

1. ANOVA for Single Pass

Table V ANOVA for Tensile Strength for single pass

Here, DF= Degree of Freedom Seq SS= Sequential Sum of Squares Adj SS= Adjusted Sum of Squares

Adj MS= Adjusted Mean Square F= Test of hypothesis

P= Value of hypothesis

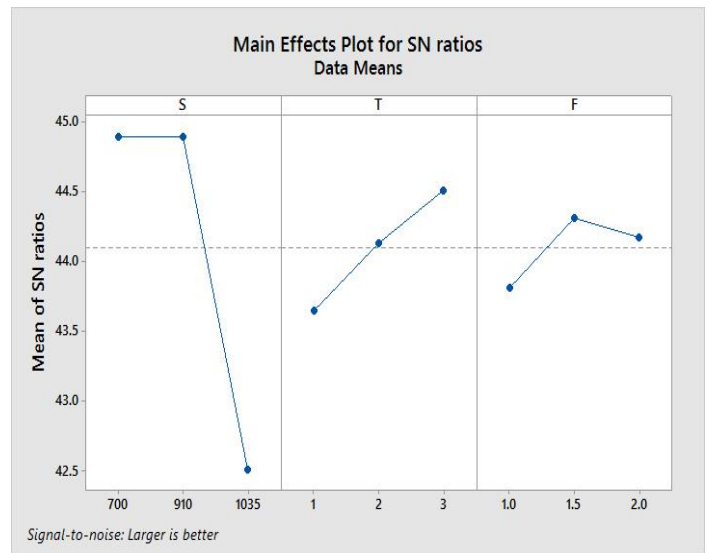


Fig.10. Main Effects Plot of Means of SN Ratios for Tensile Strength (Single pass)



Fig.11. Main Effects Plot of Means for single pass.

2. ANOVA for Multi Pass

Table 5. ANOVA for Tensile Strength for Multi pass

Source	DF	Adj SS	Adj MS	F	P
Tool	2	802.8	401.4	3.1	0.24
WS(inch/min)	2	339.9	169.9	1.3	0.43
Tilt	2	1675.	837.9	6.5	0.13
Error	2	503.0	215.4		
Total	8				

S=11.3495 R-sq=91.63% R-sq(adj)66.50% R-sq

Here, DF= Degree of Freedom Seq SS= Sequential Sum of Squares Adj SS= Adjusted Sum of Squares

Adj MS= Adjusted Mean Square F= Test of hypothesis P= Value of hypothesis

Table 6. Response Table for Means

Level	Tool rotational speed	Weld Speed	Tilt Angle
1	131.7	147.0	129.5
2	152.9	151.2	162.7
3	150.3	136.6	142.6
Delta	21.2	14.6	33.2
Rank	3	2	1

Tensile Strength (Multi pass)

From the ANOVA it is found that tilt angle is the most influencing parameter among all three parameter. Tool rotational speed is second most influencing parameter and weld speed is last influencing parameter.

C. Particle swarm optimization (PSO)

The basic variant of the particle swarm optimization algorithm works by having a population (called a swarm) of candidate solutions (called particles). When better positions are being discovered these will then come to guide the movements of the swarm. The process is frequent and by doing so it is hoped, but not guaranteed, that a satisfactory solution will eventually be discovered.

Optimization of Weld Strength and Nugget Formation

The objective function for T-S strength and nugget diameter which must be maximized was derived as equations below. The constraints of the welding parameters are given in Table 4 Here we restate these equations.

For single pass

Maximize:

$$\text{STRENGTH} = -502.2 + 1.573 S + 11.64 T + 46.86 F - 0.001001 S^2 - 2.281 T^2 - 17.47 F^2 + 0.006795 S^2 T + 0.01610 S^2 F \dots\dots\dots(1)$$

Subject to constraint:

$$710 \leq S \text{ (SPINDLE SPEED)} \leq 1035$$

$$1^\circ \leq T \text{ (TILT ANGLE)} \leq 3^\circ$$

$$1 \leq F \text{ (FEED RATE)} \leq 2$$

The above equation shows that the most influencing variable parameter is FEED RATE because having highest multiplying factor

For Multi pass

Maximize:

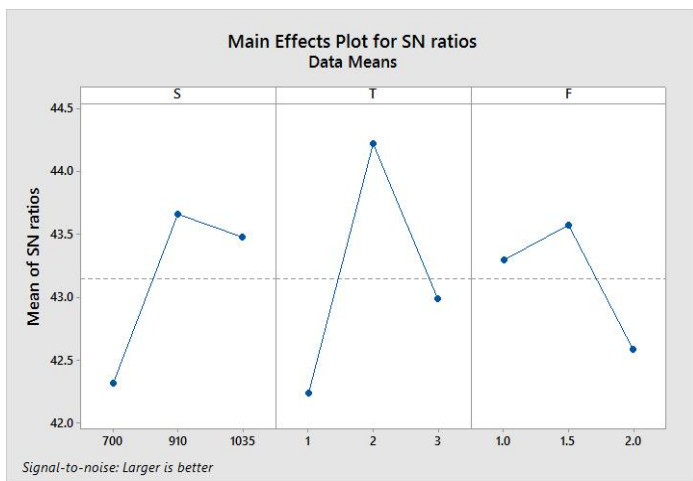


Fig.12. Main Effects Plot of Means of SN Ratios for

$$\text{STRENGTH} = -184.2 + 0.5166 S + 82.92 T + 28.71 F - 0.000364 S^2 - 28.34 T^2 - 26.28 F^2 + 0.04471 S^*T + 0.05417 S^*F \dots\dots\dots(2)$$

Subject to constraint:

$$710 \leq S \text{ (SPINDLE SPEED)} \leq 1035$$

$$1^\circ \leq T \text{ (TILT ANGLE)} \leq 3^\circ$$

$$1 \leq F \text{ (FEED RATE)} \leq 2$$

The above shows that the most infusing variable parameter is TILT ANGLE because it having highest multiplying factor

MATLAB Optimization toolbox and the function 'Particle swarm' were used for this optimization problem. The 'Particle swarm' function uses particle swarm optimization method for optimization. PSO methods represent state of the art tested method in terms of efficiency, accuracy, and percentage of successful solutions, over a large number of test problems. Two m-files were written viz. 'S_STRENGTH' and 'M_STRENGTH' for single pass and multi pass. The program to implement optimization using PSO. The input parameters to get maximum weld strength its corresponding values are shown in Table.

Table 7. Result of optimization

Response	Spindle Speed	Tilt Angle	Weld Speed	Optimized Output
Tensile Strength (Mpa)	(Rpm)	(Degree)	(Inch/Min)	
Single	809.685	3.000	1.7142	197.4239
Double	960.265	2.220	1.5359	177.9443

V. CONCLUSIONS AND FUTURE SCOPE

Based on the experiments performed for tensile strength of butt weld on AA6082-T6 material using FSW process the following conclusions are drawn:

A design of experiment and parametric study was performed to identify the effect of tilt angle tool rotation and feed rate on tensile strength of friction stir welded joint, and it found that tilt angle is most influencing parameter.

Tensile strength of FSW is found to increase with increase in rotational speed. Maximum tensile strength of 183.73 N/mm is observed at 700 rpm (tool rotation speed), 2 inch/min (welding speed), 3° (tilt angle) With the reference of table 5.5 and 5.6 the results obtained shows the optimum values which are as S=2.33670 R-sq=99.73% R-sq (adj) 98.92% R-sq (pre)=94.53%. PSO is used to optimize the combinations of input parameters to get maximum tensile strength. The optimum parameters are tool rotation speed is 809.68 second the tilt angle is 3 degrees, and third is the weld speed is 1.7142inch/min which will give maximum strength of 197.42 N/mm². The ultimate tensile strength of butt weld reaches to 80% to 90 %of the base metal ultimate tensile strength. The developed models by using ANOVA and PSO were capable of predicting values with less error.

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