ISSN 2395-1621

Influence of process parameters on friction stir welded AA 6082 aluminium alloy butt joint.

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ABSTRACT

In many industrial applications steel is readily replaced by non-ferrous alloys like aluminium alloys. Aluminium alloys having good mechanical properties as compared structural steel and low weight that allows a significant reduction in weight. But the welding of aluminium alloys by conventional processes can causes serious problems. The difficulties are like loss of alloying elements and presence of 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 an attempt has been made to develop an empirical relationship between FSW variables (tool rotation and tilt angle) and tensile strength and yield strength of multi pass friction stir welded aluminium alloy AA 6082 buttjoints. Taguchi method was adopted for analyzing 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.

***Keywords*— Friction stir welding, Design of experiment, Taguchi method.**

ARTICLE INFO

Article History

Received :18th November 2015

Received in revised form :

19th November 2015

Accepted : 21st November , 2015

Published online :

22nd November 2015

I.INTRODUCTION

Aluminium, the second most plentiful metallic element on earth, became an economic competitor in engineering applications as recently as the end of the 19th century. The emergence of three important industrial developments would, by demanding material characteristics consistent with the unique qualities of aluminium and its alloys, greatly benefit growth in the production and use of the new metal. Electrification would require immense quantities of light-weight conductive metal for long-distance transmission and for construction of the towers needed to support the overhead network of cables which deliver electrical energy from sites of power generation. Aluminium industry works for the structurally reliable, strong, and fracture-resistant parts for airframes, engines, and ultimately, for missile bodies, fuel cells, and satellite components.

Friction stir welding (FSW) is a relatively new solid state welding process which is used for butt joints. This process has made possible to weld a number of aluminium alloys that were previously not recommended (2000 series & copper containing 7000 series aluminium alloys) for welding. Because the material subjected to FSW does not melt and re-solidify, the resultant weld metal is free of porosity with lower distortion. An added the advantage that it is an environmentally friendly process. FSW is a solid state, localized thermo mechanical, joining process.

In FSW, a non-consumable rotating shouldered-pin-tool is plunged into the interface between two plates being welded, until the shoulder touches the surface of the base material, and then tool is transverse along the weld line. In FSW, frictional heat is generated by rubbing of tool shoulder and base material surface. During traversing, softened material from the leading edge moves to the trailing edge due to the tool rotation and the transverse movement of the tool, and this transferred material is consolidated in the trailing edge of the tool by the application of an axial force. FSW parameters are tool geometry, axial force, rotational speed, transverse speed and tool tilt angle [2].

II. WORKING OF FRICTION STIR WELDING

Friction Stir Welding (FSW) is a simple process in which a rotating cylindrical tool with a shoulder and a profiled pin is plunged into the abutting plates to be joined and traversed along the line of the joint. The plates are tightly clamped on to the bed of the FSW equipment to prevent them from coming apart during welding. A cylindrical tool rotating at high speed is slowly plunged into the plate material, until the shoulder of the tool touches the upper surface of the material. A downward force is applied to maintain the contact. Frictional heat, generated between the tool and the material, causes the plasticized material to get heated and softened, without reaching the melting point. The tool is then traversed along the joint line, until it reaches the end of the weld.

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

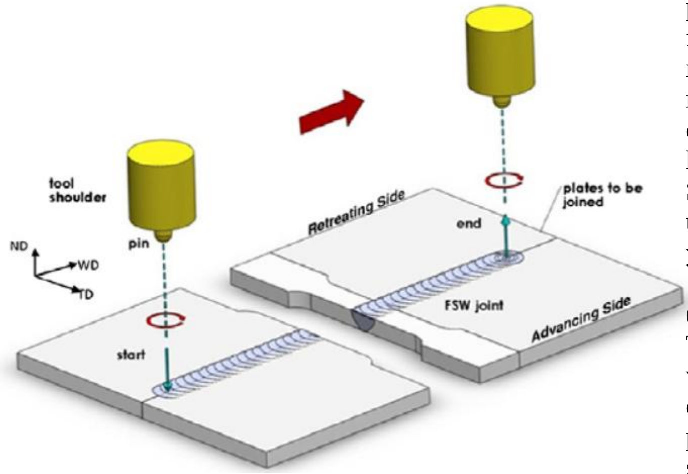


Figure.1.Schematic representation of (a) FSW process and (b)tool profile with dimension

III.TAGUCHI METHOD

The Taguchi method is very effective, because it is simple to carry on the experimental design and its approach is very systematic to provide good quality and low cost in manufacturing (Demirciet al., 2011). The main aim of the Taguchi method is to analyze the statistical data, which has been given as an input function to produce an optimum result. The effect of the combination of the input functions as a result is produced by the S/N ratio and mean response (Wu et al., 2002). The strength of the weld is Varied by the parameters such as the tool rotating speed, tool tilt angle, depth of tool penetration, dwell time and travel speed. Among these input parameters, rotating speed, tool tilt angle and travel speed are taken and the other parameters are maintained constant. The input parameters are entered in the array table with the output characteristics as the average tensile strength. The shorter conical pin with a concave shoulder should be optimized to have a better weld, with a suitable process parameter, and hence, the Taguchi technique is applied to a self analysis of the high strength material based on the tensile strength.

MINITAB Release 13 is the software that gives the statistical analysis of how to form a combination of input parameters and to find out the most significant combination (MINITAB TM 2008). Process parameters are control factors, and the factors which initiate variability in the process are the noise factors. In a Taguchi designed experiment, the noise factors are manipulated for the variability to occur, and from the results optimal control factors that make the process robust, can be identified. The Signal to Noise ratio (S/N) indicates the control factors settings that minimize the effects of the noise factors.

The Taguchi experiments are carried out in a two step optimization process.

Step 1: use the S/N ratio to identify those control factors that reduce variability.

Step 2: identify the controlfactors that bring the meanto target and havelittle ornoeffect on theS/Nratio.

Usually, the calculation of the main effect of the S/N ratio and mean response is done by three categories of quality characteristics, as listed below.

(1)The Smaller the better criterion is applied to the problems, when a minimization of the response is required for the output characteristics data; (i.e.) if the output result needs to be the minimum in value and the data are non-negative with a target value of zero. Here, in this optimization, maximum tensile strength is required and hence the smaller the better criterion is not applied.

S/N ratio (η) = -10 log10 ((1/n) Σ (yij) 2) Where n is the number of replications

yij is the observed response value. i = 1, 2, 3….n; j = 1, 2, 3…k

(2) TheLarger the better:

The Larger the better criterion is applied to the problems, when the maximization of the response is required for the output characteristics data .The data of the target value is positive. Here the optimized result needed is higher tensile strength, and hence this criterion is selected to find out the optimum process parameter, which can give better strength. The following formula is used to find the optimum result,

S/N ratio (η) = -10 log10 ((1/n) Σ (1/ (yij) 2))

(The value of the response table for the mean and S/N ratio given by the MINITAB software is verified, using this equation manually. See appendix)

(3) The Nominal thebest:

The Nominal the best criterion is applied to target the response, and base the S/N ratio on the mean and standard deviations. The data are non negative with an absolute zero, in which the standard deviation is zero when the mean is zero.

The Taguchi method has been implemented using

MINITAB software, which includes the S/N ratio and ANOVA. Through ANOVA the contribution of the individual parameter in making better FSW welds can be identified. The response for the signal to noise ratio gives the most influencing parameter. Through the mean plots of the S/N ratio and mean response, the optimum parameter has been identified.

S/N ratio (η) = $-10 \log10 (\mu2/\sigma2)$,

Where $\mu = (y1+y2+y3+\ldots\ldots.+yn) / n$,

$\sigma = ((yi-y) 2 / (n-1))$

2.2 Experimental method

According to the L9 orthogonal array, three experiments in each set of process parameters have been performed on IS: 3039 plates. The three factors used in this experiment are the rotating speed, tool tilt angle and travel speed. The factors and the levels of the process parameters are presented in Table.2 and these parameters are taken based on the trials to weld the FSW of steels. The experiment's notation is also included in the L9 orthogonal array which results in an additional column, in order to represent the parameters, as presented in Table.3. The experiments are performed on a 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.

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

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 (conical, triangular, square, pentagon, and hexagon cross sections) maintaining 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-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. 4.3 shows these tools.

Table 4.5 FSW tool parameter

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

Fig.4.3 Hexagonal tool profile

Two dimensional geometries of tools are as follows,

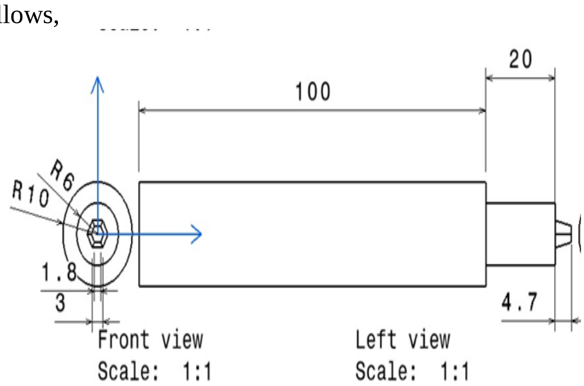
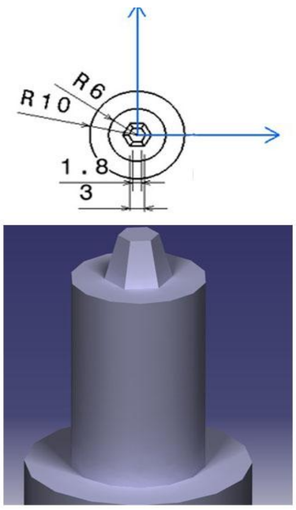


Fig. 4.4 2D drawing of hexagonal pin tool



Welding of aluminium alloy

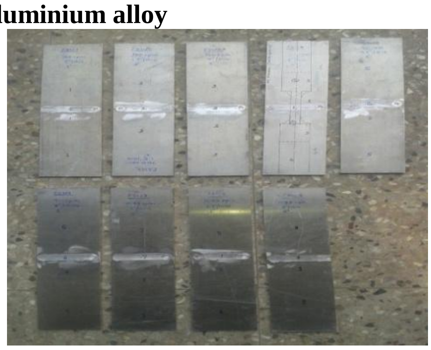


Fig. 5.2 Welded Parts by hexagonal tool (According to Experiments No.)

5.5 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 Kopargaon using specimen of two inch gauge length as shown in Fig 5.4. Eighteen tensile test pieces are prepared from the each weld joints to ensure accuracy (nine for each tool)y. 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.

Tensile strength is one of the main characteristic considered in this investigation which describes the quality of FSW joints. The experiments are carried out on universal testing machine.

The tensile strength of parent material of Al 6082-T6 is 240 N/mm^2. The highest tensile strength achieved of the weld zone is 165.33 N/mm^2. The ultimate tensile strength of butt weld reaches to 68 to 70 % of the base metal ultimate tensile strength.

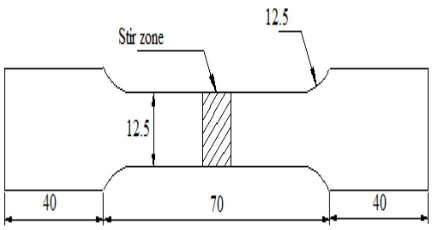


Fig 5.4: Dimensions of the Tensile Test Specimens[ASTM E8M-08]

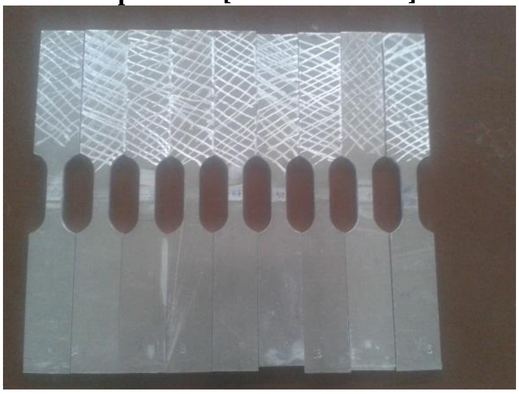


Fig 5.5 Tensile Strength Specimen

Tensile Strength of Weld Specimens

Tensile strength of weld specimen is measured by Universal Testing Machine at Testing of Materials Laboratory, SRES COE Kopargaon. Table below shows tensile strength.

Table 5.3 Tensile strengths of weld specimen For Hexagon pin tool

Weld No.	Tensile Strength (MPa)
FSW 1	144.132
FSW 2	157.272
FSW 3	154.44
FSW 4	145.92
FSW 5	146.904
FSW 6	156.324
FSW 7	175.164
FSW 8	140.316
FSW 9	164.808

Analysis of tensile strength

5.7.1 ANOVA

After performing final experiments analysis of experimental data is done by using MINITAB-17 software. The effect of various input parameters 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 FSW joints in the order of rotational speed, tilt angle and traverse speed.

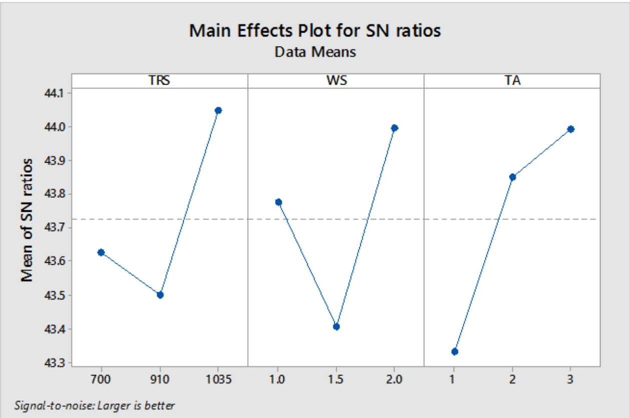
ANOVA for Tensile Strength

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Tool Rotational speed(rpm)	2	179.1	179.1	89.56	0.44	0.0492
WS(inch/min)	2	167.0	167.0	83.48	0.41	0.0207
Tilt angle(degrees)	2	232.3	232.3	116.16	0.58	0.0304
Error	2	402.8	402.8	201.42		
Total	8	981.2				
S =34.67 R-Sq =82.56 % R-Sq(adj) =83.23%						

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 5.5 Response Table for Means

Level	Tool rotational speed	Weld Speed	Tilt Angle
1	151.9	155.1	146.9
2	149.7	148.2	156.0
3	160.1	158.5	158.8
Delta	10.4	10.4	11.9
Rank	2	3	1



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.

IV.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:

1) 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.

2) Tensile strength of FSW is found to increase with increase in rotational speed. Maximum tensile strength of 175.16 MPa is observed at 1035 rpm (tool rotation speed), 1 inch/min (welding speed), 3° (tilt angle)

3) The ultimate tensile strength of butt weld reaches to 70% to 80 %of the base metal ultimate tensile strength.

4) The developed models by using ANN were capable of predicting values with less than 5% error.

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