Influence of Shoulder geometry of tool on friction stir welded joint of aluminium alloy 6082 T6

[a]S.A.Thorat, *ME Mechanical SRES College of Engg.Kopargaon, SavitribaiPhule Pune University*
[b]Dr.A.G.Thakur, *Vice Principal and HOD, Mechanical Engg. Dept., SRES College of Engg. Kopargaon, SavitribaiPhule Pune University*

***Abstract*—In many applications steel is replaced by non-ferrous alloys. Low weight aluminium alloys are used now days. Welding of aluminium alloys by conventional way cause serious harm. Friction stir welding (FSW) is relatively a solid state welding process, ecofriendly and also eliminate the problems of solidification associated with the conventional fusion welding processes. In this project work we developthe relationship between FSW parameters (tool rotation, tilt angle and welding speed) with different tool shoulder diameters and tensile strength of friction stir welded aluminium alloy AA 6082 T6. Taguchi method with ANOVA was adopted for analyzing the problem wherenumber of variables influences the response. From the main effects plot for SN ratios it is cleared that tool shoulder geometry is the most influencing factor among all four factors.**

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

I. INTRODUCTION

The need for joining materials having higher hardness property and tensile strength has arisen with the present advancement inscience and technology. Friction stir welding (FSW) is a recent addition to the welding process and it is a solid state joining technique (R.S. Mishra et al., 2005), it was performed on Al and its alloys is now carried out on copper, magnesium and different material combinations. Different tool pin profiles have been used to weld aluminum alloys (A. Scialpietal. 2007), and it has been found that the tapered pin gave defective welds when compared to other profiles. When FSW of steels is performed by straight pin profiles, pin failure takes place before the complete insertion, and moreover, theweld joint could not be formed due to rapid tool wear. The amount offriction heat produced for a better weld depends mainly on the process parameters, such as the tool rotational speed, plunge depth, plunge force, tool tilt angle and travel speed (A. S. Vagh et al., 2012). Apart from the highest influencing process parameters, such as the rotating speed of the tool and traverse speed in FSW, the tool tilt angle is an added process parameter which could give better results in the FSW of steel (A. Pradeepet al., 2013). Tensile strength is the powerful mechanical property to optimize the process parameter of the weld to achieve a better joint (Z.Y. Ma et al., 2006).

The most efficient and simple way of designing an experiment can be achieved by the Taguchi method (B.T. Gibson et al., 2013) which helps to find out the most significant process parameter among the parameter combinations, by using the analysis of variance (ANOVA) and signal-to-noise ratio (S/N) (Vijianet al., 2007). The effect of the process parameters by welding with a shorter conical pin on the strength properties has been studied with the influence of the process parameters and their combinations to produce a defect free weld. L9 orthogonal array of the Taguchi design method has been used, because it is easy to use and solve complex problems more efficiently. The Calculation of the S/N ratio and mean response, by the ANOVAgives the most influential process parameter, while the mean effect of the plot for the S/N ratio and mean response predictsthe optimum process parameter. Thus, the present optimization serves main objective is to estimate the contribution of the individual process parameters, and to determine the optimum combination of the process parameters for better possible strength.

ShrikantG.Daluand M. T. Sheteinvestigatedeffect of various process parameters on friction stir welded joint. This paper investigates the effect of various process parameters on quality of the welded joint. Investigates the effect of welding speed and tool pin profile on friction stir processing zone formation in AA2219 aluminum alloy. They found that the square pin profile tool at a welding speed 45.6mm/min, produced mechanically sound and metallurgical defect free welds with maximum tensile strength, higher hardness

From the above review it is observed that The Tool rotation speed, traverse speed, axial force and tool design are the most significant process parameters in friction stir welding. The rate of heat generation as well as the peak temperature is relatively higher in the case of non-circular pin profiles, increasing with the number of flats. Also some papers results show strong relation and robust comparison between the weldment strength and process parameters. Tensile strength is found to increase with increase in rotational speed. Maximum Tensile strength of 172 Mpa was observed at 1350 rpm (for 115 mm/min feed) for IS 64430 AA6351 Al alloys, higher range of rotational speed is best suited to achieve maximum tensile strength. Tensile strength is higher with lower weld speed. This indicates that lower range of weld speed is suitable for achieving maximum tensile strength.The hardness variations also correlate well with the mechanical property characterisation of different welds, through tensile testing experiments for strength and ductility of the welds (both in the transverse and longitudinal test), as the tool pin profiles changes from circular to hexagonal. The influence of pin profile on weld quality in FSW may have even greater significance when joining relatively thicker plates. The experiments based on three process parameters, namely, the tool rotational speed, tool tilt angle and the travel speed.

After studding the above papers we came to the conclusion that the main process parameters on which the welding strength depends are feed, angle of tilt, and spindle speed. Further the results can be optimised by using various optimisation techniques such as Analysis of Variance and Particle Swarm Optimisation technique. This result has to be implemented to test the specimen by taking the optimum parameters for friction stir welding and results should be compiled with the optimum values.

II. METHODOLOGY

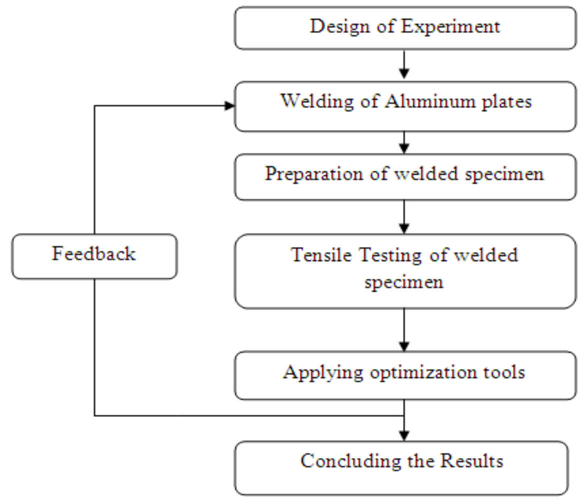

Fig.1. Flowchart Methodology of FSW Process

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. Thus optimum values were found.

III. EXPERIMENTAL METHOD

A. 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 thebutting 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 1-4°, to facilitate better consolidation of the material in the weld.

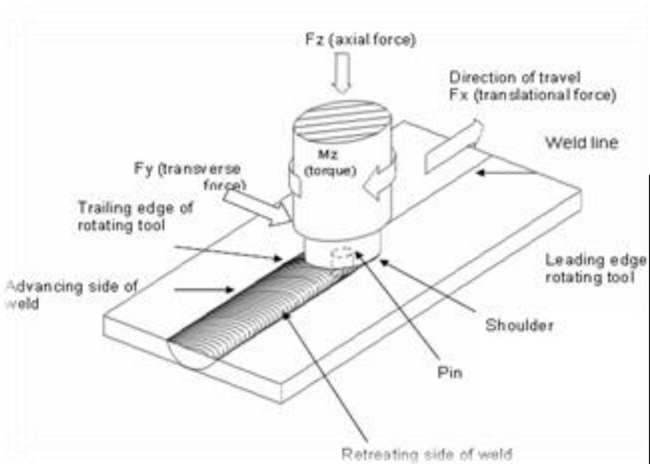

Fig.2.Schematic representation of FSW process

According to the L27 orthogonal array, nine experiments in each set of process parameters have been performed on AA6082 T6 plates with all three tools having different shoulder geometry. The three factors used in this experiment are the rotational speed, weld speed i.e. feed and tool tilt angle. The factors and the levels of the process parameters are presented in Table II for three tools with different shoulder diameter. The experiment's notation is also included in the L27 orthogonal array which results in an additional column, in order to represent the parameters, as presented in Table III. 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. For the thickness of 5mm plate, and hence 1°, 2° and 3° tool tilt angles were taken.

TABLE I

PROCESS PARAMETERS AND THEIR LEVELS

Process parameters	**Levels**		
	1	**2**	**3**
Tool	1	2	3
Tool rotational speed(rpm)	580	700	910
Weld speed(inch/min)	1	2	3
Tilt angle(degrees)	1	2	3

TABLE II

L27 (3^4) ORTHOGONAL ARRAY FOR FINAL EXPERIMENTATIONS

Sr. No.	**Tool No**	**Tool rotational speed(rpm)**	**Tilt Angle (degrees)**	**Weld speed (inch/min)**
1)	1	580	1	1
2)	1	580	2	2
3)	1	580	3	3
4)	1	700	1	2
5)	1	700	2	3
6)	1	700	3	1
7)	1	910	1	3
8)	1	910	2	1
9)	1	910	3	2
10)	2	580	1	1
11)	2	580	2	2
12)	2	580	3	3
13)	2	700	1	2
14)	2	700	2	3
15)	2	700	3	1
16)	2	910	1	3
17)	2	910	2	1
18)	2	910	3	2
19)	3	580	1	1
20)	3	580	2	2
21)	3	580	3	3
22)	3	700	1	2
23)	3	700	2	3
24)	3	700	3	1
25)	3	910	1	3
26)	3	910	2	1
27)	3	910	3	2

B. Tool Selection

According to K.Ramanjaneyulu, G. Madhusudhan Reddy, A. Venugopal Rao, and R. Markandeya,[8] Experiments were conducted with different tool pin profiles (conical, triangular, square, pentagon, and hexagon cross sections) maintaining the same swept volumeduring 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 our project work we had studied various papers and finally we have selected square pin profile with different shoulder diameters and. Fig. 3 shows these tools.

TABLE III
FSW TOOL PARAMETER

Tool parameter	Dimensions
Pin length	4.7 mm
Shoulder diameter	**Tool 1**: 12 mm
	Tool 2: 14 mm
	Tool 3: 16 mm
Taper angle	14°

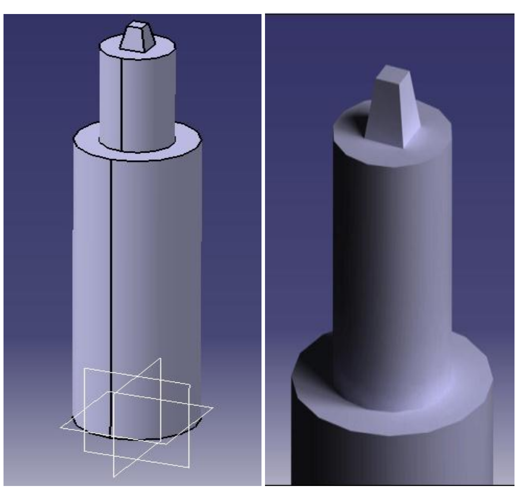

Fig.3. Square tool profile

Two dimensional geometries of tools are as follows,

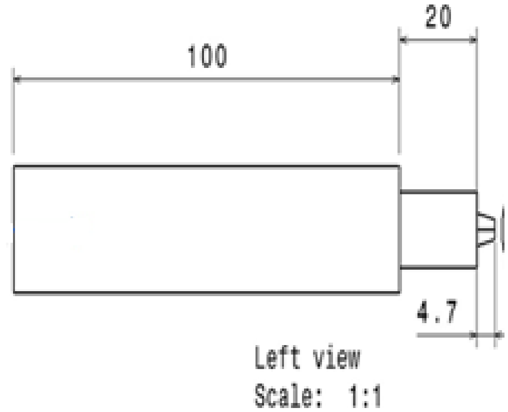

Fig.4. 2D drawing of square pin tool

C. Welding of aluminum alloy 6082 T6

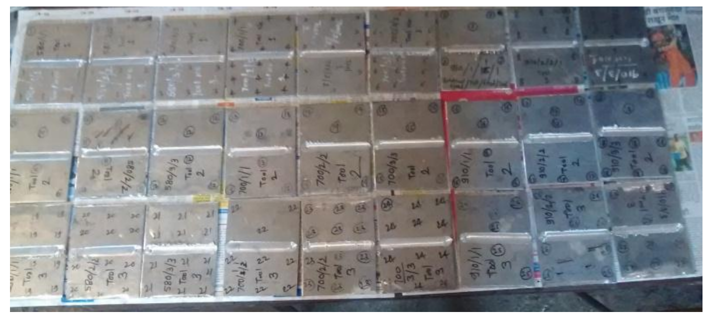

Fig.5.Welded Specimens

D. 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 vertical milling machine at R and R Associates at Kopargaon using specimen of two inch gauge length as shown in Fig 7. Twenty Seven tensile test specimens 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.

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

The tensile strength of parent material of Al 6082-T6 is 250 N/mm^2.

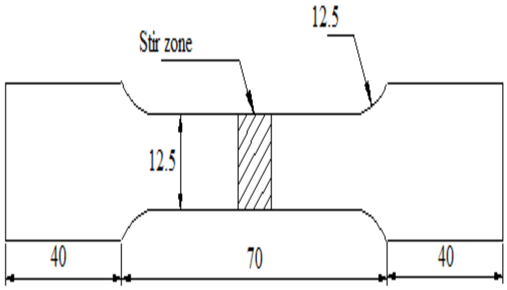

Fig 6. Dimensions of the Tensile Test Specimens [ASTM E8M-08]

Fig 7.Tensile Strength Specimen

E. Tensile Strength of Weld Specimens

Tensile strength of weld specimen is measured by Universal Testing Machine at VSP testing and calibration lab, MIDC Ambad, Nasik. Table 4 below shows tensile strength.

We get maximum tensile strength of 190.55 N/mm^2 for tool no. 2 with tilt angle 2 ^{0} and rotational speed 700 rpm with weld speed 3 inch/min.

TABLE IV

TENSILE STRENGTH FOR SPECIMEN

Sr. No.	Tool No	Tool rotational speed(rpm)	Tilt Angle (degrees)	Weld speed (inch/min)	Tensile Strength N/mm^2
1)	1	580	1	1	158.82
2)	1	580	2	2	140.95
3)	1	580	3	3	137.13
4)	1	700	1	2	158.40
5)	1	700	2	3	179.76
6)	1	700	3	1	116.35
7)	1	910	1	3	168.45
8)	1	910	2	1	152.68
9)	1	910	3	2	164.08
10)	2	580	1	1	182.58
11)	2	580	2	2	148.40
12)	2	580	3	3	181.09
13)	2	700	1	2	169.03
14)	**2**	**700**	**2**	**3**	**190.55**
15)	2	700	3	1	169.74
16)	2	910	1	3	158.20
17)	2	910	2	1	169.52
18)	2	910	3	2	134.47
19)	3	580	1	1	155.48
20)	3	580	2	2	180.04
21)	3	580	3	3	145.33
22)	3	700	1	2	133.35
23)	3	700	2	3	131.27
24)	3	700	3	1	155.31
25)	3	910	1	3	146.68
26)	3	910	2	1	146.43
27)	3	910	3	2	144.70

IV. CONTRIBUTION OF VARIABLES FOR TENSILE STRENGTH USING ANOVA

A. 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.

Table V indicates the ANOVA for tensile strength, table VI shows the response table for Signal to Noise Ratio and the table 7 shows the table for means .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 tool shoulder diameter,weld speed, tilt angle and rotational speed.

TABLE V

ANOVA FOR TENSILE STRENGTH

Source	DF	Adj SS	Adj MS	F
Tool	2	1680.5	840.24	2.48
TR	2	107.0	53.50	0.16
WS	2	571.6	285.79	0.85
TA	2	242.3	121.15	0.36
Error	18	6086.5	338.14	
Total	26	8687.9		

Here, DF = Degree of freedom ;Adj SS = Adjusted sum of squares ; Adj MS = Adjusted mean square ; F = Test of hypothesis ; P = Value of hypothesis.

TABLE VI

RESPONSE TABLE FOR SIGNAL TO NOISE RATIOS

Level	Tool	TR	WS	TA
1	43.63	43.97	44.00	43.82
2	44.42	43.76	44.02	43.63
3	43.41	43.73	43.44	44.01
Delta	1.00	0.24	0.58	0.38
Rank	1	4	2	3

TABLE VII

RESPONSE TABLE FOR MEANS

Level	Tool	TR	WS	TA
1	153.0	158.9	159.1	156.3
2	167.2	156.0	160.0	152.6
3	148.7	154.0	149.8	159.9
Delta	18.4	4.8	10.2	7.3
Rank	1	4	2	3

A figure 8 below shows the main effect of means of SN ratios for tensile strength and figure 9 shows main effect plot of means

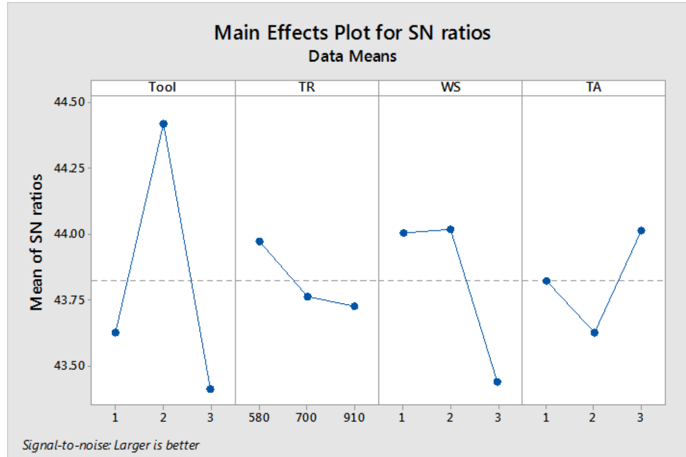

Fig.8. Main Effects Plotof Means of SN Ratios for Tensile strength

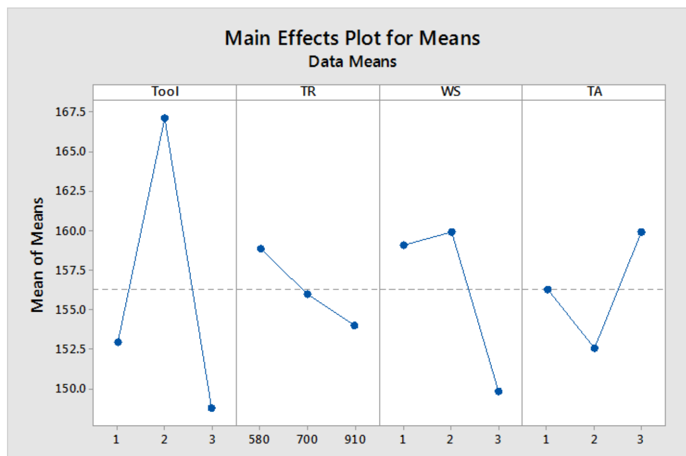

Fig.9.Main Effects Plot of Means

From the ANOVA it is found that tool no. 2 with shoulder diameter 14 mm is the most influencing parameter among all four parameter. Weld speed is second most influencing parameter and tilt angle is the third influencing parameter and rotational speed is the last influencing parameter.

V. RESULT AND DISCUSSION

1. The maximum tensile strength of 190.55 N/mm^2 is achieved for tool no. 2 with tilt angle 2 ^{0} and rotational speed 700 rpm with weld speed 3 inch/min with Universal Testing Machine.

2. Regression model based on response surface method of DOE was developed for Tensile strength.

3. ANOVA and statistical analyses confirms that model is adequate to predict the response.

4. The response for Signal to Noise ratio and means shows that the most influencing factor is tool no 2 with shoulder diameter 14 mm, second is the weld speed of 3 inch/min, third is the tilt angle of $2^0$and last is the rotational speed of 580 rpmas shown in figure 9.

5. As compare to tool 1 with shoulder diameter 12 mm, the tensile strength increases with tool 2 with shoulder diameter 14 mm but it again decreases with tool no 3 with 16 mm diameter.So we cannot conclude that the tensile strength is increases with increase in shoulder diameter.

6. From ANOVA the maximum strength of joint is found at 580 rpm tool rotational speed where as in UTM testing it is found at 700 rpm is due to less variation in strength at 580 rpm for all combinations and sudden rise in strength value for 700 rpm in three combinations.

VI. CONCLUSIONS

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 tool shoulder diameter, tilt angle, tool rotation and feed rate on tensile strength of friction stir welded joint, and it is found that tool shoulder diameter 14 mm is most influencing parameter.
2) As compare to tool 1 with shoulder diameter 12 mm, the tensile strength increases with tool 2 with shoulder diameter 14 mm but it again decreases with tool no 3 with 16 mm diameter. So we cannot conclude that the tensile strength is increases with increase in shoulder diameter
3) The maximum tensile strength of 190.55 N/mm^2 is achieved for tool no. 2 with tilt angle 2^{0} and rotational speed 700 rpm with weld speed 3 inch/minwith UTM.
4) The ultimate tensile strength of butt weld reaches to 70% to 80 %of the base metal ultimate tensile strength.A. Scialpi et al [2], suggested the acceptable percentage value for tensile strength must be more than 66% of base matel. Hence the quality of this weld is considered to be good.

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