Effect of Friction Stir Welding Process Parameters on Tensile Strength of AA 6082-T6

Omesh Raktate[1], Dhananjay Dolas[2],

1. PG student, Jawaharlal Nehru Engineering College, Aurangabad,MS,India.
(omesh.engineer@gmail.com)
2. Professor, Jawaharlal Nehru Engineering College, Aurangabad, MS, India.
(dhananjay_dolas@rediffmail.com)

Abstract:

FSW Process is an Innovative solid state joining process which has been employed in different applications like Automotive, Rail, Aerospace, Marine industries for joining the various Aluminum, Magnesium, Zinc & Copper alloys. The various parameters such as tool rotational speed (TS), welding speed (WS), tool geometry (TG) and contact angle play vital role in the FSW process, in order to analyze the weld quality. The aim of this study is to investigate the effect of tool rotational speed/spindle speed, welding speed and tool pin profile i.e. Three different factors on weld strength, as well as to investigate the optimum tool geometry for maximum ultimate tensile strength at 5 mm plate thicknesses of AA6082-T6 aluminium alloy by using friction stir welding process. AA6082-T6 aluminum alloys were fabricated using the friction stir welding technique to improve the tensile properties such as ultimate tensile strength (UTS). The Central Composite Face Centered method with Three significant factors—Tool rotational speed (TRS)), Welding speed (WS), and Tool geometry (TG) each having three levels—was used with response surface methodology to develop a mathematical model.

Key words: *Friction Stir Welding, Process Parameters, Response Surface Methodology.*

1. Introduction

Friction stir welding is a solid state welding process in which the frictional heat produced by the rotating tool is utilized to create a weld joint. Now those metals are now can be joined easily which are difficult to join in the past. Wayne Thomas and his colleagues developed FSW In 1991 and they suggest that joint efficiency obtained by the process is 90% acceptable and defect free and doesn't melt the workpiece as in case of fusion welding processes. Thus, its eco-friendly and energy efficient behavior establish FSW as a green technology[1].

According to the previous experimental study it shows that optimum process parameters for welding the AA6082-T6 aluminium alloy are tool rotation speed 750-1700 Rpm, welding speed 0.5-3inch/min and various tool pin profiles. Tool pin profile plays an important role in welding of Aluminium alloy. Tool with different pin profiles are widely used for friction stir welding process. Tool pins with conical, taper, threaded, and square profile are much efficient to transfer the metal from one side to another side due to its shoulder and stirring action[11].

2. Experimental Work

Aluminium alloy AA6082-T6 is a medium strength alloy with excellent corrosion resistance. AA 6082-T6 is most widely used in heavy-duty forgings, plate, extrusions for aircraft fittings, wheels, major structural components, space booster tankage, truck frame and suspension components. In this experimentation AA 6082-T6 Al alloy material is used as a base material. AA 6082-T6 plates having 5 mm thickness was used in the experimental work. Samples of rectangular shape were cut from the plates into size of 175×90 mm and then friction stir welding was done using vertical milling machine[5].

Table: 1 Chemical composition of AA6082-T6

Weight%	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al	Other Each	Others Total
6082-T6	0.7-1.3	0.50	0.10	0.40-1.0	0.60-1.20	0.25	0.20	0.10	Bal	0.05	0.15

To apply Friction Stir welding for Aluminum & its alloy the considerations are mainly associated with the finding proper Tool Material, the material that can withstand with the higher temperatures, wear resistance and durability, good oxidation resistance, strong & tough cheap enough for mass production. Hot worked tool steel such as H-13 has proven perfectly acceptable for welding Al Alloy within thickness ranges of 0.5 to 50 mm[4][6]. Different types of tool pin profiles were used in the work which includes conical pin, square pin and trapezoidal pin as shown in Figure (1b).

Figure: 1 (a) FSW Process, (b) Conical, Square and Trapezoidal Tool pins

Before performing actual experimentation of friction stir welding, various combinations related to trail experiments have been conducted in which Tool Rotational Speed 410-1700 rpm, Welding Speed 0.5-4.0 inch/min along with three different tool geometries are used as various input parameters. From trail experiments it was observed that tool rotational Speed 910-1400 rpm and Welding Speed 1-2 inch/min gives excellent ideal welding without any defects like tunnel defects, abnormal stirring and pin holes. It was also observed that sufficient heat is generated for ideal welding by using these parameters[7-10]. Hence following parameters shown are considered for experimentation work.

Table: 2 Parameters and their levels

Parameters	Level 1	Level 2	Level 3
Tool Rotation Speed (RPM)	910	1035	1400
Weld Speed (inch/min)	1	1.5	2
Tool Pin Geometry	Conical	Square	Trapezoidal

3. Development of mathematical model

3.1 Response surface methodology

Response surface methodology (RSM) is a collection of mathematical and statistical technique[6]. It is useful for analyzing problems in which several independent variables influence a dependent variable or response and the goal is to optimize the response[5]. In many experimental conditions, it is possible to represent independent factors in quantitative form as given in Eq.(1). Then these factors can be thought of as having a functional relationship or response as follows:

$$Y = f(X_1, X_2, X_3, X_{4,}..................,X_n) \quad (1)$$

Between the response Y and X_1, X_2, … X_n, of $_n$ quantitative factors, the function Y is called response surface or response function. The residual measures the experimental errors. For a given set of independent variables, a characteristic surface is responded. When the mathematical form of Y is not known, it can be approximate satisfactorily within the experimental region by polynomial. In the present investigation, RSM has been applied for developing the mathematical model in the form of multiple regression equations for the quality characteristic of the friction stir welded AA6082-T6 aluminium alloy[8-9].

Table: 3 Experimental Design Matrix and Result

Std	Run	Coded value			Real Value			Tensile Strength MPa
		TR	WS	TG	Tool Rotation RPM	Welding Speed Inch/Min	Tool pin Geometry	
1	18	-1	-1	-1	910	1	Square	189.897
2	3	1	-1	-1	1400	1	Square	194.025
3	19	-1	1	-1	910	2	Square	207.094
4	14	1	1	-1	1400	2	Square	205.286
5	6	-1	-1	1	910	1	Trapezoidal	186.269
6	11	1	-1	1	1400	1	Trapezoidal	191.983
7	8	-1	1	1	910	2	Trapezoidal	200.496
8	7	1	1	1	1400	2	Trapezoidal	198.854
9	13	-1	0	0	910	1.5	Conical	197.379
10	17	1	0	0	1400	1.5	Conical	198.839
11	12	0	-1	0	1035	1	Conical	190.463
12	20	0	1	0	1035	2	Conical	206.654
13	16	0	0	-1	1035	1.5	Square	190.643
14	10	0	0	1	1035	1.5	Trapezoidal	188.92
15	4	0	0	0	1035	1.5	Conical	191.781
16	9	0	0	0	1035	1.5	Conical	196.43
17	1	0	0	0	1035	1.5	Conical	196.057
18	5	0	0	0	1035	1.5	Conical	193.454
19	2	0	0	0	1035	1.5	Conical	193.65
20	15	0	0	0	1035	1.5	Conical	195.522

As per the design matrix of Response Surface Methodology, Central Composite Face Centered Design 20 welds are carried out, from each weld plate the specimens are sliced according to ASTM standards to measure the Tensile Strength as a Output Parameters[3]. The results indicates the optimize process parameters to obtain the Maximum Tensile Strength for AA6082-T6 and the final mathematical model to estimate tensile strength is given.

$$UTS=194.038+0.785(TR)+6.402(WS)-2.035(TG)+3.08(TR^2)+3.805(WS^2)-4.972(TG^2)-1.763(TR\times WS)+0.071(TR\times TG)-0.920(WS\times TG) \quad \ldots\ldots \quad (2)$$

4. Effect of process parameters

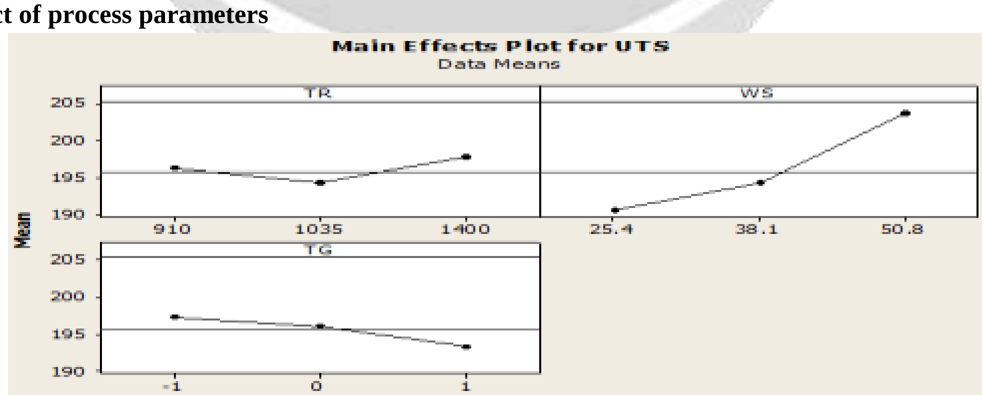

Figure 2 Main Effect Plot

The Main Effect plots shows that the higher (1400) Tool rotational speed, Higher (50.8) Weld speed and Square Tool Geometry gives a higher Tensile Strength. When the TR is increased from 910 rpm, the tensile strength decreases till a TR of 1035 rpm. When TR is increased further up to 1400 rpm, the tensile strength also increases. When the WS is increased from 25.4 mm/min, the tensile strength also get increased till a WS of 38.1 mm/inch. When WS is increased further up to 50.8 mm/inch, the yield strength also increases. The comparison between three different Tool Geometries shows that the Square tool pin profile gives higher tensile strength in comparison with other Conical and Trapezoidal tool pin profiles.

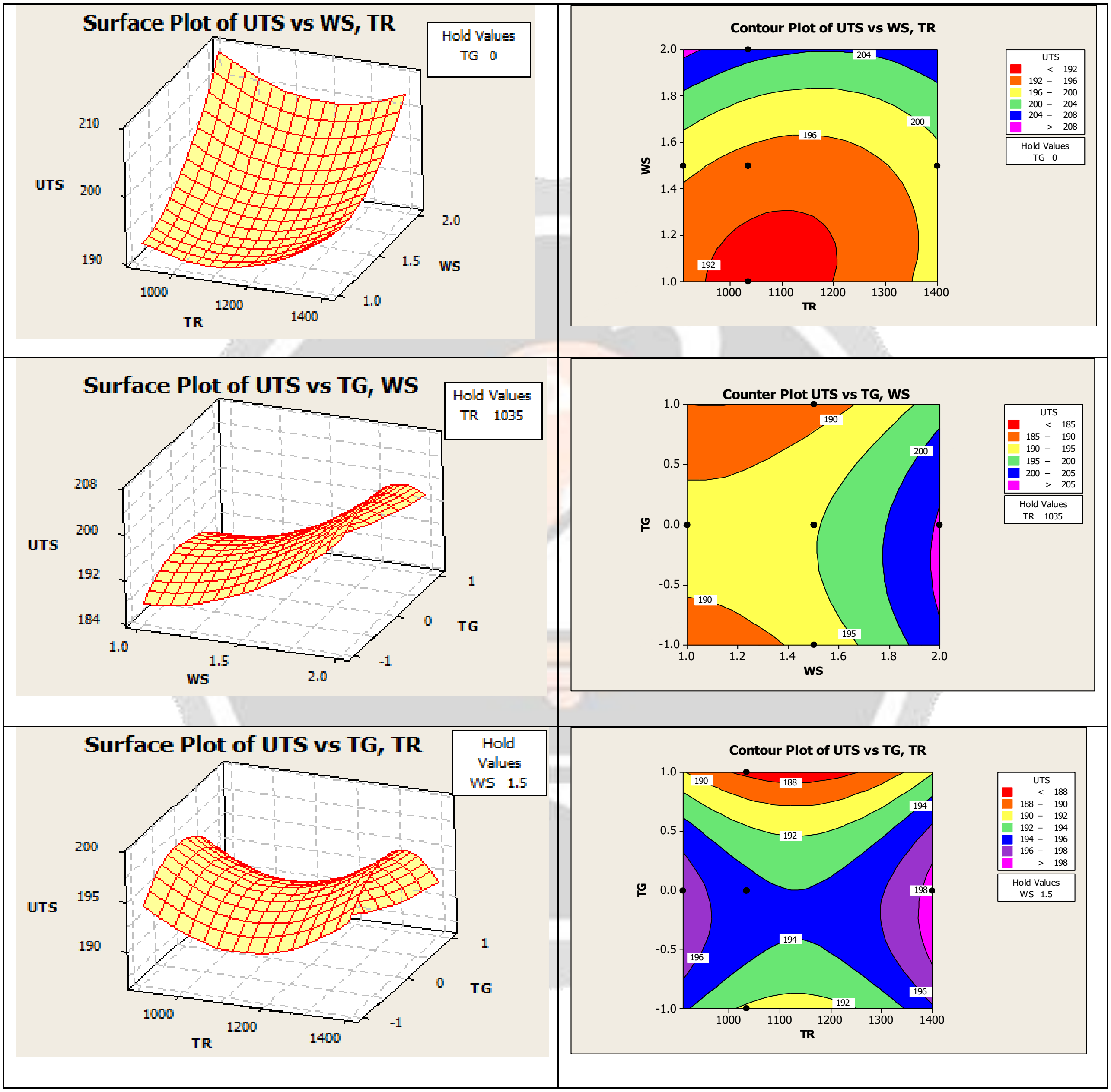

Figure: 3 Surface and Contour plots of process parameters on tensile strength

Contour plots play a very important role in the study of the response surface. By generating contour plots using software for response surface analysis, the optimum is located with reasonable accuracy by characterizing the shape of the surface. If a contour patterning of circular shaped contours occurs, it tends to suggest independence of factor effects while elliptical contours as may indicate factor interactions[3]. A contour plot is produced to visually display the region of optimal factor settings. For second order response surfaces, such a plot can be more complex than the simple series of parallel lines that can occur with first order models. Once the stationary point is found, it is usually necessary to characterize the response surface in the immediate vicinity of the point by identifying whether the stationary point found is a maximum response or minimum response or a saddle point. In the present investigation the process parameters corresponding to the maximum tensile strength are considered as optimum (analyzing the contour graphs). Hence, when these optimized process parameters are used, then it will be possible to attain the maximum tensile strength.

5. Results and Discussion

In this section, the discussion is about the effect of FSW process parameters (tool rotation speed, welding speed and tool pin geometry) on the basis of response characteristics (tensile strength). The model developed for the response variables tensile strength is tested by ANOVA (shown in table 4) on MINITAB 16 SOFTWARE. The determination coefficient R-Squared indicates the goodness of fit which means there is less difference between the predicted and actual data[12]. In this case, the value of the determined coefficient (R^2=96.54%) indicated that only less than 3.5% of the total variations are not explained by the model. The value of adjusted determination coefficient (R-Sq(adj) = 93.42%) is also high, which indicates a high significance of the model. Predicted R^2 (R-Sq(pred) = 89.50%) is also in a good agreement with the adj.R^2.

Table: 4 Analysis of Variance for UTS

Source	Sum of Sq.	DF	Mean Square	F value	Probability>F
Model	628.292	9	69.810	30.98	0.000
Tool Rotation TR	18.396	1	6.165	2.74	0.129
Weld Speed WS	432.267	1	405.216	179.81	0.000
Tool Geometry TG	41.710	1	40.957	18.17	0.002
TR^2	23.009	1	22.767	10.10	0.010
WS^2	12.046	1	39.810	17.67	0.002
TG^2	67.988	1	67.988	30.17	0.000
TR*WS	26.062	1	26.062	11.56	0.007
TR*TG	0.042	1	0.042	0.02	0.894
WS*TG	6.771	1	6.771	3.00	0.114
Residual	22.536	10	2.254		
Lack of fit	6.135	5	1.227	0.37	0.848
Pure error	16.401	5	3.280		
Total	650.828	19			
PRESS = 68.3657			R-Sq = 96.54%	R-Sq(adj) = 93.42%	
S = 1.50119			R-Sq(pred) = 89.50%		

The value of probability > F for model is less than 0.05, which indicates that the model is significant. In the same way, welding speed (WS) and tool geometry (TG), second order term of tool rotation (TR^2) welding speed (WS^2) tool geometry (TG^2) and interaction effect of tool rotation with welding speed (TR×WS) have significant effect. Lack of fit is non significant as it is desired. The normal probability plot of the residuals for tensile strength shown in Fig.4 revels that the residuals are falling on the straight line, which shows that the errors are distributed normally. Here all the considerations indicates an excellent adequacy of the regression model.

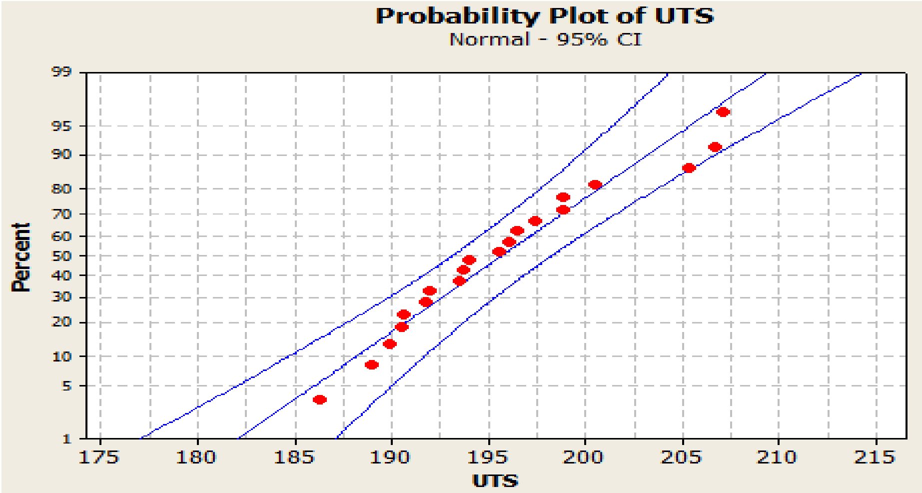

Figure: 4 Normal probability plot for Tensile strength

6. Conclusion

This paper has described the use of RSM for conducting the experiments as well as for predicting tensile strength of friction stir welding AA 6082-T6 Aluminum alloy. From this investigation the following important conclusion are derived.

1. Welding speed is the factor that has greater influence on Tensile strength, followed by Tool rotation speed and Tool Geometries.
2. A maximum tensile strength of 207 MPa is exhibited by the FSW joints fabricated with the optimized parameter of 910 rpm rotational speed, 2inch/min welding speed and by using Square tool geometry.
3. From ANOVA results, the contribution ratio of each parameter indicates that Welding speed is major significant factor and tool rotational Speed is minor significant factor.
4. It is also noticed that Square tool geometry has good agreement to produce maximum tensile strength when Weld speed is higher.

References:

[1] Verma, S. M. & Misra, J.P. " A Critical Review of Friction Stir Welding Process," DAAAM International Scientific Book 2015 pp. chapter 22, 249-266.

[2] Balasubramanian V, Lakshminarayanan A K, "Comparison of response surface model with neural network in predicting the tensile strength of friction stir welded RDE-40 aluminium alloy," Journal on Design and Manufacturing Technologies, Vol.1, No.1, November 2007 PP- 41-46.

[3] A. K. Lakshminarayanan, V. Balasubramanian "Comparison of RSM with ANN in predicting tensile strength of friction stir welded AA7039 aluminium alloy joints" Trans. Nonferrous Met. Soc. China 19 (2009) 9-18

[4] Xiaocong He, Fengshou Gu, Andrew Ball, "A review of numerical analysis of friction stir welding," Progress in Materials Science 65 (2014) 1–66.

[5] D. Trimble, J. Monaghan, G.E. O'Donnell "Force generation during friction stir welding of AA2024-T3" CIRP Annals - Manufacturing Technology 61 (2012) 9–12

[6] Marek Stanisław Weglowski "Experimental study and response surface methodology for investigation of FSP process" Archive of Mechanical Engineering vol. LKI 2014 number 4 10.2478/meceng-2014-0031.

[7] S. Cui, Z.W.Chen, J.D.Robson. "A model relating tool torque and its associated power and specific energy to rotation and forward speeds during friction stir welding/processing" International Journal of Machine Tools & Manufacture 50 (2010) 1023–1030.

[8] GunaraJ V, Murugan N. "Application of RSM for predicting weld bead quality in submerged arc welding of pipes." Journal of Material Processing Technology, 1999, 88: 266−275.

[9] Liu H J, Fujii H, Maedaa M, Nogi K. Tensile properties and fracture locations of friction-stir-welded joints of 2017-T351 aluminum alloy [J]. Journal of Materials Processing Technology, 2003, 142: 692−696.

[10] Elangovan K, Balasubramanian V. Influences of pin profile and rotational speed of the tool on the formation of friction stir processing zone in AA2219 aluminium alloy [J]. Materials Science and Engineering A, 2007, 459: 7−18.
[11] T. Long, W. Tang, A.P. Reynolds, "Process response parameter relationships in aluminium alloy friction stir welds", Science and Technology of Welding and Joining 12 (2007) 311–317.
[12] Grum J, Slabe J M. The use of factorial design and response surface methodology for fast determination of optimal heat treatment conditions of different Ni-Co-Mo surfaced layers [J]. Journal of Materials Processing Technology, 2004, 155: 2026−2032.

Biography :

 **Omesh U. Raktate**	is currently pursuing his M.E. in Mechanical (Manufacturing), from Jawaharlal Nehru Engineering College Aurangabad. *Email: omesh.engineer@gmail.com*
 **Dr. Dhananjay R Dolas**	is currently Associate Professor in Mechanical engineering in MGM'S JNEC, Aurangabad (MS) India. B.E. (Mech.), from Govt. Engineering, Aurangabad, M.E. Mechanical (Design Engg) from RIT Sangli , Shivaji university Kolhapur and Ph.D. degrees from Dr. BabasahebAmbedkarMarathawada university, Aurangabad. *Email: dhananjay_dolas@rediffmail.com*