International Journal of Research in Engineering and Innovation
(IJREI)
journal home page: http://www.ijrei.com
ISSN (Online): 2456-6934

Friction stir welding of aluminum alloy 6082-T6-t651 for improving tensile strength, hardness and wear rate properties

R.S. Mishra[1], Shaambhavi Ratnapriya[2]

[1] *Department of Mechanical Engineering, Delhi Technological University, Delhi, India*
[2] *P.G. Scholar, IIM Indore*

Abstract

Regression analysis is a powerful tool used for determining the relationship between dependent and one or more independent parameters. In this paper, Friction Stir Welding (FSW) was carried out on 6082-T6-T651 aluminum alloy with the aim of deriving the regression equation for the dependent variables of Tensile strength, Hardness and Wear rate with respect to the independent variables of tool speed, tool feed and tool tilt angle using Taguchi analysis in Minitab 17 software. Plots for means and S-N ratios were also obtained for the above mentioned parameters of Tensile strength, Hardness and Wear.

Key words: Friction Stir Welding, Regression analysis, Taguchi analysis, Tensile strength, Hardness, Wear rate.

1. Introduction

Friction Stir Welding (FSW) i.e. the solid state technique of joining metals has gained wide popularity in the automotive, marine and air-craft industries primarily owning to its highly positive eco-friendly energy coefficient. The mechanism of FSW is also quite simple wherein it employs a non-consumable rotating tool comprising of a pin and a shoulder. The pin is plunged to the requisite depth inside the work-piece and local heat and plastic deformation produced help to weld the given two pieces together.

A thorough analysis and comparison of FSW with the traditional electric arc welding process highlighted the following advantages of FSW:

- No toxic fumes/ gases released
- Less residual wastes generated
- No shielding gases or extra pipelines required for gas transportation as these are eliminated in FSP/FSW
- Less post-welding/ processing treatments thus reducing cost and energy requirements considerably
- Clean technology

Invented in 1991 by “The Welding Institute UK”, this technique has now come a long way forward and has evolved into the famous processing technique Friction Stir Processing (FSP). FSP is used primarily as a microstructural refinement technique which it achieves by the mechanism of dynamic recrystallization as studied by Mishra et al [1]. It also helps in improving wear rates and hardness of the sample [2-3].

In this paper, FSW was carried out on 6082- T6- T651 aluminum alloy. This alloy is considered one of the best for machining operations and is widely employed in highly stressed applications like making bridges, truss, frame-works, etc. Thereafter a regression analysis was performed on the tensile strength, hardness and wear rate data to study their dependence on experimental parameters tool feed, tool speed and tool tilt angle.

Work- pieces of dimension 200X40X7 mm were used and H13 tool steel was employed as the tool material. The cylindrical pin had dimensions of 4X5mm. while the tool shoulder had a diameter of 20 mm [4].

The major objectives of this paper were as follows:

- Derive regression equation for tensile strength of the specimen in the welded region
- Derive regression equation for hardness of the specimen in the welded region
- Derive regression equation for wear rate of the specimen in the welded specimen

All the above equations were derived using Taguchi Analysis in Minitab 17 software.

Welding parameter such as tool rotation, transverse speed and axial force have a significant effect on the amount of heat generated and strength of FSW joints. Microstructure

Corresponding author: R.S. Mishra
Email Id: hod.mechanical.rsm@dtu.ac.in

evaluation of FSW joints clearly shows the formation of new fine grains and refinement of reinforcement particles in the weld zone with different amount of heat input by controlling the welding parameter [5-7]

2. Experimental Procedure

6082- T6- T651 aluminum alloy work- pieces of dimensions 200X40X7 mm. in sets of two were clamped in the FSW machine as shown below and a total of nine readings were taken.

Figure 1: FSW machine

The feed in this machine could be adjusted in the +/- X direction. The tool speed could be adjusted using a digital switches provided behind the machine. The machine was hydraulically operated.
H 13 tool steel was used for conducting the experiment. The tool speed, tool feed and tool tilt angle parameters were varied as follows.

Table-1: Experimental Data

Tool Feed	Tool Speed	Tool Tilt Angle
60	500	0.0
60	700	2.5
60	900	5.0
80	500	2.5
80	700	5.0
80	900	0.0
100	500	5.0
100	700	0.0
100	900	2.5

Thereafter, tensile test, Vicker's hardness test and Wear rate tests were performed. The tensile test was performed on a 50 KN H50kS Universal testing machine shown below [4].

Figure 2: UTM machine

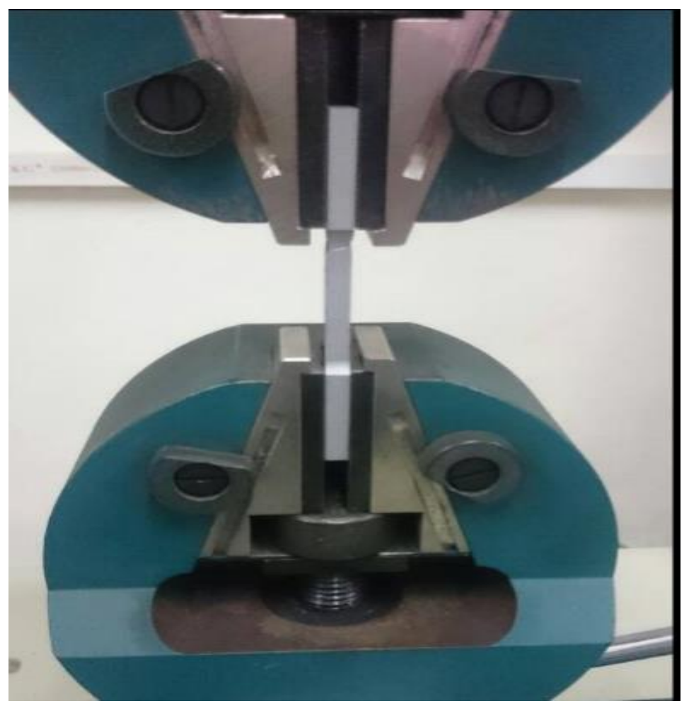

Figure 3: Clamped specimen in a UTM

The tensile test specimens were cut according to the following dimensions [4].

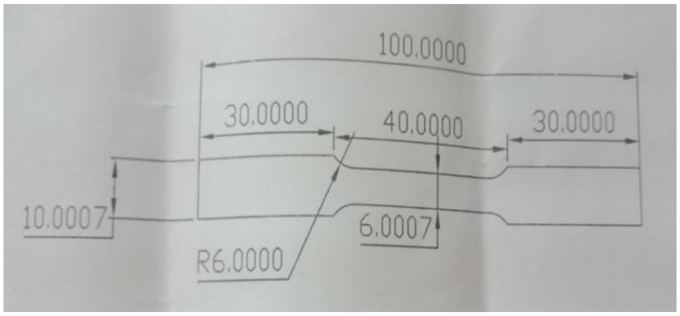

Figure 4: Tensile testing specimen

Hardness testing was carried out using Vickers hardness testing procedure. The results were obtained in the units HV 0.2 using testing method- ASTM E348.

Wear tests were carried out using Pin on disc (as shown) testing apparatus. A pin of diameter 10mm and length 32 mm was employed as the top wearing surface. The bottom wearing surface comprised of a disc of diameter 165 mm. and material EN31. A normal load of 5 Kg. (49.033 N) was applied.

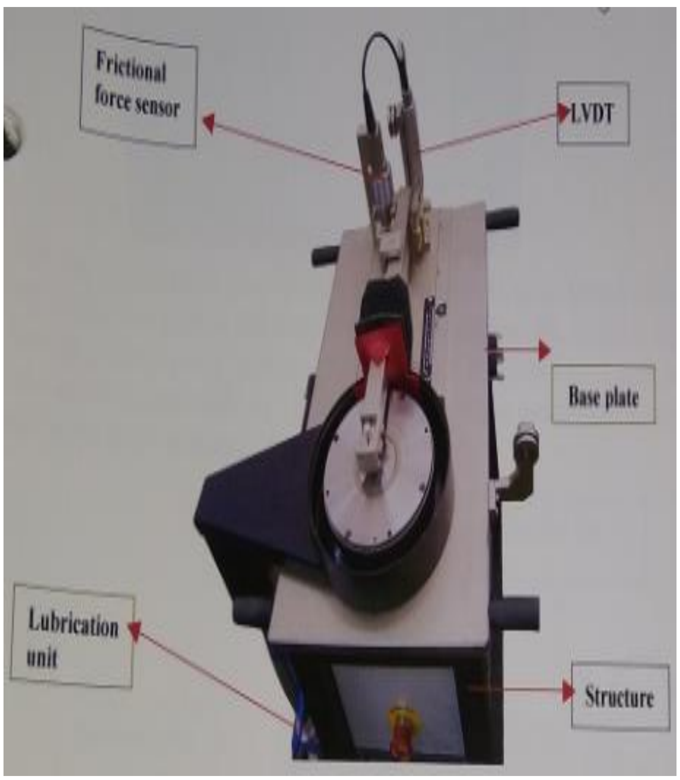

Figure 5: Pin on Disc wear apparatus

3. Result and Discussions

3.1 Tensile, Hardness and Wear rate analysis results

All the data was analyzed taking three steps of the concerned variables of tool feed (60mm/ min., 80 mm/min., and 100 mm/ min.); tool speed (500 rpm, 700 rpm, 900 rpm) and tool tilt angle (0º, 2.5º, 5º). The results of the tensile test were obtained as follows.

Table-2: Tensile Test Result Data

Feed	Speed	Tool tilt	Tensile strength
60	500	0	4540
60	700	2.5	6170
60	900	5	6280
80	500	0	4950
80	700	2.5	3560
80	900	5	6650
100	500	0	5600
100	700	2.5	6690
100	900	5	7280

Similarly, the results for hardness were

Table-3: Hardness Test Result Data

Feed	Speed	Tool tilt	Hardness
60	500	0	79
60	700	2.5	77
60	900	5	77
80	500	0	78
80	700	2.5	77
80	900	5	77
100	500	0	76
100	700	2.5	76
100	900	5	75

The wear rate data were calculated by taking into account the initial weight of the specimen and the final weight of the specimen using the following formulas:

Wear amount= Weight Loss= Initial Weight – Final Weight

$$\text{Wear Rate} = \frac{Weight\ Loss}{Test\ Duration}$$

Table-4: Wear Rate Test Result Data

Wear-rate(*10^{-5})	Weight Loss	Test Duration
2.1017	0.0215	1023
1.8107	0.0197	1088
1.6073	0.0185	1151
2.0154	0.0209	1037
1.8650	0.0199	1067
1.5004	0.0176	1173
2.1786	0.0222	1019
1.747	0.0192	1099
1.8904	0.0200	1058

Table-5: Tensile Test Result Data

Feed	Speed	Tool tilt	Tensile strength
60	500	0.0	4540
60	700	2.5	6170
60	900	5.0	6280
80	500	2.5	4950
80	700	5.0	3560
80	900	0.0	6650
100	500	5.0	5600
100	700	0.0	6690
100	900	2.5	7280

The above given tables (2-5) represent the table values formulated for Taguchi analysis performed in MINITAB 17 software.

3.2 Taguchi Analysis using MINITAB 17

Taguchi methods were developed to improve the quality of goods manufactured. In the MINITAB 17 software under Stat column DOE was selected followed by Create Taguchi Design to formulate an orthogonal array of size L9 (3 ^3) which designated the factors involved as levels as shown in the following tables 6-7.

Table- 6: Level for Tensile and Hardness Test

A	B	C
1	1	1
1	2	2
1	3	3
2	1	2
2	2	3
2	3	1
3	1	3
3	2	1
3	3	2

Table- 7: Factor Level Information

Factor	Type	Levels	Values
A	Fixed	3	1, 2, 3
B	Fixed	3	1, 2, 3
C	Fixed	3	1, 2, 3

Plot for Means shows the variation of means between different groups. The graphical means plots have been shown below for values of hardness, tensile strength and wear rate analysis.

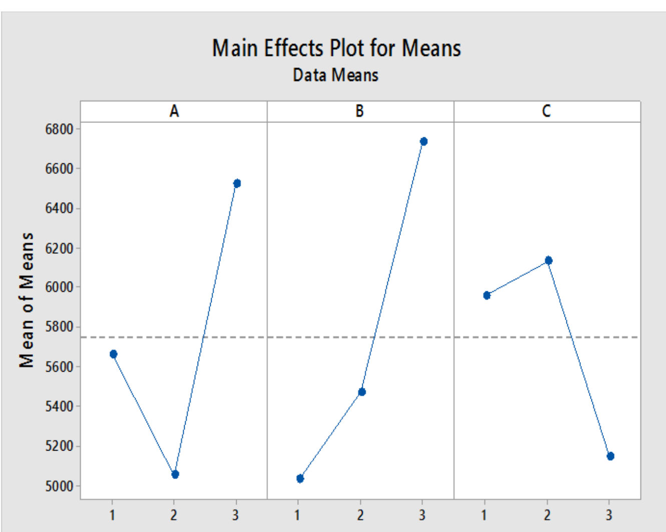

Figure 6. Plot for Means for Tensile strength

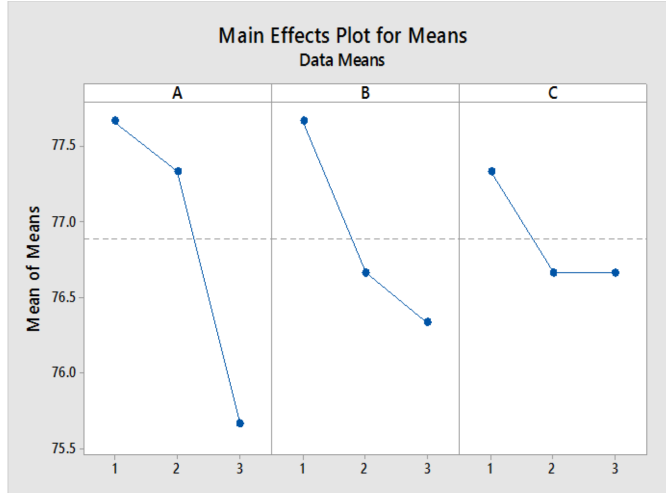

Figure 7. Plot for Means for Hardness values

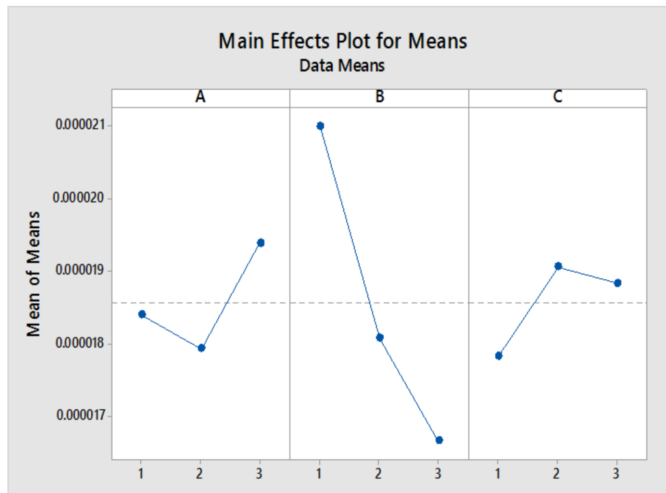

Figure 8: Plot for Means for Wear rate values

Similarly the S/N plots i.e. the signal to noise ratio plots were obtained as follows

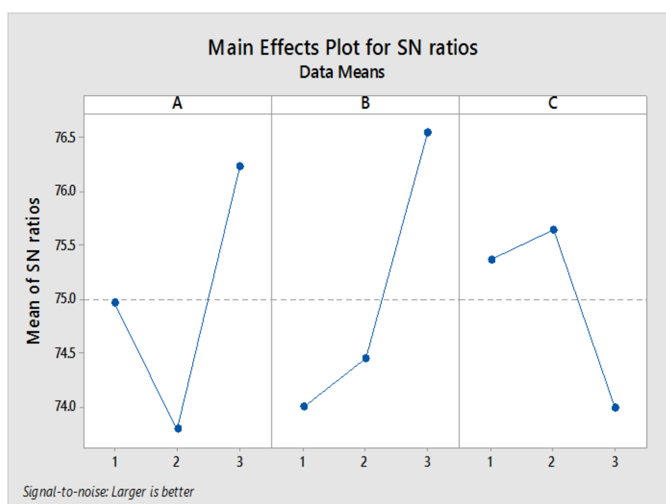

Figure 9: S/N ratio plot for Tensile strength

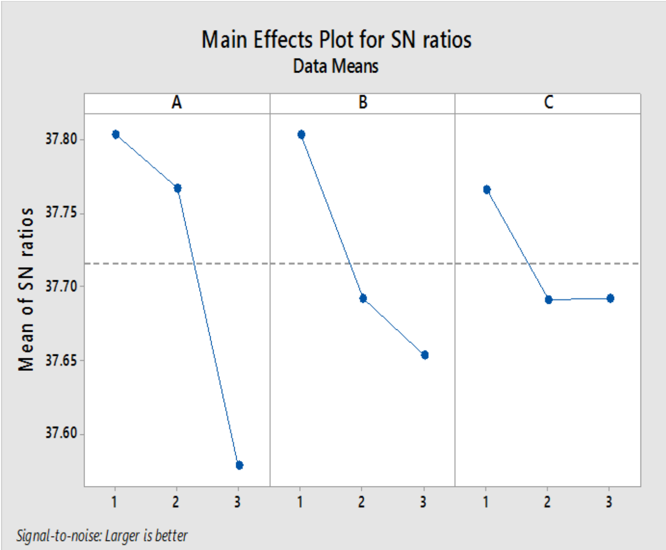

Figure 10: S/N ratio plot for Hardness

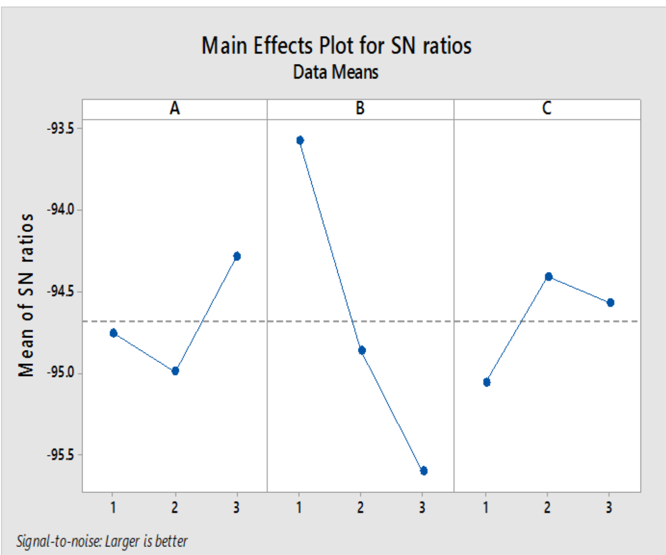

Figure 11: S/N ratio plot for Wear rate

The above graphs were obtained on the scale of Larger is Better.

3.3 Variance Analysis

Variance analysis for Tensile, Hardness and Wear analysis respectively values were obtained as given below

Table 8: Analysis of Variance for Tensile strength

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Feed	2	3272600	1636300	1.85	0.351
Speed	2	4705267	2352633	2.66	0.274
Tilt	2	1665067	832533	0.94	0.515
Error	2	1771467	885733		
Total	8	11414400			

Table 9: Analysis of Variance for Hardness:

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Feed	2	2.889	1.111	13	0.071
Speed	2	6.89	3.44	31	0.031
Tilt	2	0.889	0.44	4	0.2
Error	2	0.22	0.11		
Total	8	10.889			

Table 10: Analysis of Variance for Wear rates

Source	DF	Adj SS	Adj MS	F-Value	P-Value
A	2	0	0	0.77	0.566
B	2	0	0	6.79	0.128
C	2	0	0	0.6	0.627
Error	2	0	0		
Total	8	0			

4. Conclusions

Taguchi analysis conducted using the software MINITAB 17 gave the following equations were developed for tensile strength, hardness and wear rate of aluminum alloy (6082- T6-T651) using regression analysis. These equations clearly show their dependence on the parameters of tool feed, tool speed and tool tilt angle.

Regression Equation for Tensile strength

Tensile strength = 5747-83 Feed _1- 693 Feed_2 + 777 Feed_3 -717 Speed _2 +990 Speed_3 + 213 Tilt _1 + 387 Tilt_2- 600 Tilt _3.

Regression Equation for Hardness

Hardness= 76.889 + 0.778 Speed_1- 0,222 Speed_ 2- 0.556 Speed_3 + 0.778 Feed_1 + 0.444 Feed_2- 1.222 Feed _3 + 0.444 Tilt _1- 0.222 Tilt _2- 0.222 Tilt_3

Regression Equation for Wear rate

Wear Rate= 0.000019 - 0.000000 A_1 - 0.000001 A_2
+ 0.000001 A_3 + 0.000002 B_1 - 0.000000 B_2
- 0.000002 B_3 - 0.000001 C_1 + 0.000000 C_2
+ 0.000000 C_3

References

[1] V. Jegannathan Arulmoni, Ranganath M.S., R.S.Mishra: "Effect of process parameters on friction stir processed Copper and Enhancement of the mechanical properties of the composite material: A Review on Green Process Technology", International Journal Of Sustainable Science & Engineering, Vol.2(4), (2014), pp. 1-10

[2] V. Jegannathan Arulmoni, Ranganath M.S., R.S.Mishra, Experimental Investigations on Friction Stir Processed Copper and Enhancement of Mechanical Properties of the composite Material, International Journal of Advance research and innovation, Vol. 2(3), (2014), pp. 557-563

[3] A.G. Rao, B.R.K. Rao, V.P. Deshmukh, A.K. Shah, B.P. Kashyap(2009)- Microstructural refinement of a cast hypereutectic Al-

[4] 30Si alloy by friction stir processing, Vol.-Materials Letters, pp. 2628-2630

[5] R.S.Mishra, Z.Y. Ma, I. Charit (2002), Friction stir processing: a novel technique for fabrication of surface composite International journal of Material Science and engineering, Vol-A341,, pp.307-310.

[6] Husain Mehdi, R.S. Mishra, Mechanical properties and microstructure studies in Friction Stir Welding (FSW) joints of dissimilar alloy- A Review, Journal of Achievements in Materials and Manufacturing Engineering 77/1 (2016) 31-40.

[7] Husain Mehdi, R.S. Mishra, Influences of Process Parameter and Microstructural Studies in Friction Stir Weldingof Different Alloys: A Review, International Journal of Advanced Production and Industrial Engineering, IJAPIE-SI-MM 509 (2017) 55–62.

[8] Husain Mehdi, R.S. Mishra, Mechanical and microstructure characterization of friction stir welding for dissimilar alloy- A Review, International Journal of Research in Engineering and Innovation, vol-1, Issue-5 (2017), 57-67.

[9] Mehdi Zohoor, M.K. BesharatiGivi, PSalami (2012) Effect of processing parameters on fabrication of Al-Mg/Cu composites via friction stir processing , International journal of Materials and design, Vol-39, pp.358-365.

[10] H.J.Liu, X.L. Feng(2012): Effect of post-processing heat treatment on microstructure and micro hardness of water-submerged friction stir processed 2219-T6 Aluminium alloy, International journal of Materials and design, Vol-47, pp.101-105

[11] A.Orozco-Caballer, C.M. Cepeda-Jimenez, P. Hidalgo-Manrique, P.Rey, D. Gesto, D. Verdera, O.A. Ruano, F. Carreno(2013): Lowering the temperature for high strain rate super plasticity in an AL-Mg-Zn-Cu alloy via cooled friction stir processing, Materials Chemistry and Physics, Vol.-142 pp. 182-185

[12] Adem Kurt, Ilyas Uygur, Eren Cete(2013)- Surface modification of aluminium by friction stir processing, Jounal of Materials Processing Technology, Vol.- 211, pp.313-317

[13] T. Dieguez, A. Burgueno, H. Svoboda (2012)- Superplasticity of a Friction Stir Processed 7075-T651 aluminum alloy Vol.- Procedia Materials Science, pp. 110-117

[14] B. Zahmatkesh, M.H. Enayati, F. Karimzadeh (2010)- Tribological and microstructural evaluation of friction stir processed Al2024 alloy, Vol.-Materials and Design 31, pp. 4891-4896.