INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X
Impact factor: 4.295
(Volume 4, Issue 2)
Available online at: www.ijariit.com

Effect of Process Parameters on Tensile Strength and Hardness Testing of Friction Stir Welding Joint of Aluminium Alloys with Different Tool Pin Profile

Pawan Parashar
NIIST Bhopal, Madhya Pradesh

Prof. Arun Patel
NIIST Bhopal, Madhya Pradesh

ABSTRACT

In this project, CNC Milling Machine is used to weld the parts together. The parts being welded are made up of dissimilar materials aluminum alloy AA5086 H32-AA6061 T6. The rotational speed is varied from 900 rpm to 1500 rpm while the welding speed is varied from 20 to 40 mm/min. The other parameter involved is the tool profile. The dimensions of the parts are (300mmx30mmx5mm) which are welded to form a butt joint. The effect of different tool pin profiles on the quality of the welded joint is also studied for welding. Different tool pin profiles considered are round threaded, circular/round and square. The tools are designed using Pro/E and are manufactured on a Lathe machine. After the parts are welded, various practical tests are performed on the welded parts that include the tensile strength and the Vickers's hardness test. The experimental results proved that the highest tensile strength of the welded joint i.e., 28.65 N/mm2 was achieved with the square tool profile at speed 1200 rpm with feed 40 mm/min and the highest hardness value of 58 HV was achieved with the round tool profile at 1500 rpm and feed of 40 mm/min.

Keyword: *Friction Stir Welding (FSW) Tool, CNC Milling Machine, Aluminium Alloy AA5086 H32-AA6061 T6, Minitab18, Tensile Test, Hardness Test.*

1. INTRODUCTION

Friction stir welding is a dynamical version of pressure welding processes. It was recently developed in England by welding institute (TWI) in 1991. Friction stir welding can be created high-quality weld by using milling machine because using same movement conditions but the tool is different. Friction stir welding is extensively used for Al, Mg .Cu, Ti, for work pieces that could not weld by conventional types of welding and different applications because of economical and quality consideration [2]. This technique has been extended to similar as well as dissimilar welding of the above-mentioned alloys and also to the welding of steels [3]. FSW can do on CNC milling machine for small work pieces to the professional single purpose robotic machine in orbital FSW in steel pipes welding in oil industries [4]. The schematic of friction stir process shown in Figure 1.

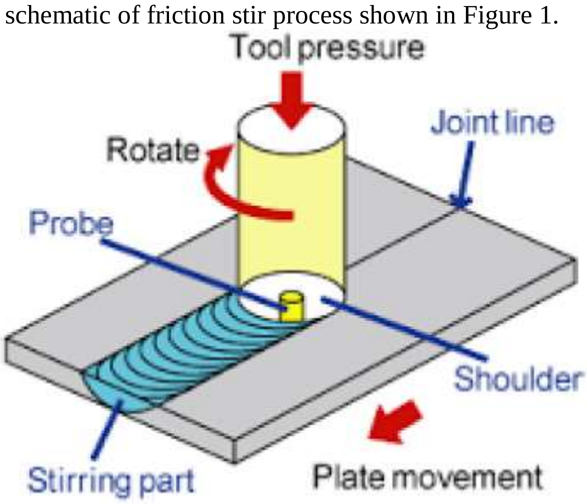

Fig. 1 Schematic of Principle of Friction Stir Weld

Friction Stir Welding has been widely used in the aerospace, shipbuilding, automobile industries and in many applications because of many of its advantages over the conventional welding techniques some of which include very low distortion, no fumes, porosity or spatter, no consumables (no filler wire), no special surface treatment and no shielding gas requirements.

2. MATERIALS AND METHOD

The current experimental investigation is an attempt to explore the feasibility of employing FSW method in joining dissimilar AA5086 H32-AA6061 T6 grade aluminum alloy sheets of 5 mm thickness. Two workpieces, one from each alloy, of size, are 300 mm x 30mm x 5mm are butted together to ensure square butt configuration. The composition and material properties of aluminum alloys are given in Table 3.1 and Table 3.2 respectively.

Table 3.1 Chemical Composition by wt%

Material	Mg	Mn	Si	Fe	Cu	Zn	Cr	Ti	Ni	Al
AA5086 H32	4.2	0.59	0.07	0.16	0.05	0.15	0.08	0.06	0.01	Balance
AA6061 T6	0.91	0.09	0.52	0.32	0.21	0.095	0.11	0.04	-	Balance

Accordingly, the present study has been done through the following plan of the experiment.

- Checking and preparing the power hacksaw and Lathe ready for performing the machining operation.
- Cutting of aluminum, stainless steel-304 according to required length of power hack saw.
- Fix the cutting tool on tool post & fix the stainless steel-304 in rotating chuck on the lathe for the preparation of different welding tool pin profile.
- Aluminum alloys AA5086 H32-AA6061 T6 have been cut into the required size are by power hacksaw cutting.
- Turning of tool to get the required diameter

Fig. 3.2 Welding Tool Preparation on Lathe

- Checking of required diameter with the help of vernier caliper
- Tool and Sample are ready for welding.
- Conduct tensile test and hardness test on Universal Testing Machine (UTM) and vicker’s hardness testing machine.

3. DESIGN OF TOOLS

The welding tool of FSW plays a prominent role welding process which has an impact on the mechanical properties and quality of microstructure of the material. Therefore the tool is designed carefully which may alter the weld quality. The tool should have idealistic and higher mechanical properties than weld materials.The difficulty associated are mainly with finding proper tool material;

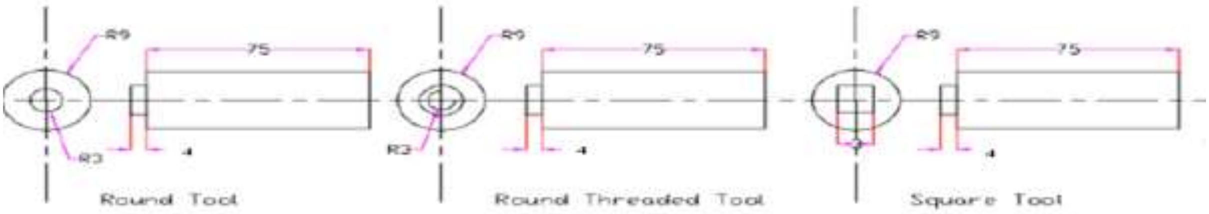

Fig. 2 Schematic diagram of different types of FSW pin profile (a) Round (b) Round threaded (c) Square

Fig. 3.5: Manufactured Tool Profile (a) Round (b) Round with Threaded (c) Square

4. PROCESS VARIABLES AND THEIR LIMITS

The working ranges of the parameters for the subsequent design of the experiment, based on Taguchi's L9 Orthogonal Array (OA) design have been selected using MINITAB 15 software. In the present experimental study, spindle speed, feed rate, and tool profile have been considered as process variables. The process variables with their units (and notations) are listed in Table 3.3.

Table 3.3: Process Variables and their Limits

Parameters/Factors		level		
		1	2	3
A	Spindle speed (rpm)	900	1200	1500
B	Feed rate (mm/min)	20	30	40
C	Tool Profile	Round	Round with threaded	Square

5. FRICTION STIR WELDING PROCEDURE:

Three experiments in each set of process parameters have been performed on aluminum alloy AA5086 H32-AA6061 T6 plates by L9 orthogonal array. The three factors used in this experiment are the rotating speed, feed rate, and tool profile. The factors and the levels of the process parameters are presented in Table.3 and these parameters are taken based on the previous trials to weld the FSW of aluminum alloy plate. The experiments are performed on a vertical milling machine.

Table 3.4: Experiment Layout

Experiment no.	Spindle speed (rpm), N	Feed rate (mm/min), f	Tool Profile
1	900	20	Round
2	900	30	Round with threaded
3	900	40	Square
4	1200	20	Round with threaded
5	1200	30	Square
6	1200	40	Round
7	1500	20	Square
8	1500	30	Round
9	1500	40	Round with threaded

Fig. 3.7 Rotating Tool for Friction Welding

Fig. 3.8 Friction stir weld samples

6. WELD TESTING PROCEDURE

6.1 TENSILE TEST

After friction stir welding tensile test performed on the universal testing machine. Testing performed in temperature between 10 to 30°C if A is the cross-sectional area and F is the maximum force and tensile strength calculated by:
Tensile strength=F/A

Fig. 3.9 Process Setup for Tensile Test

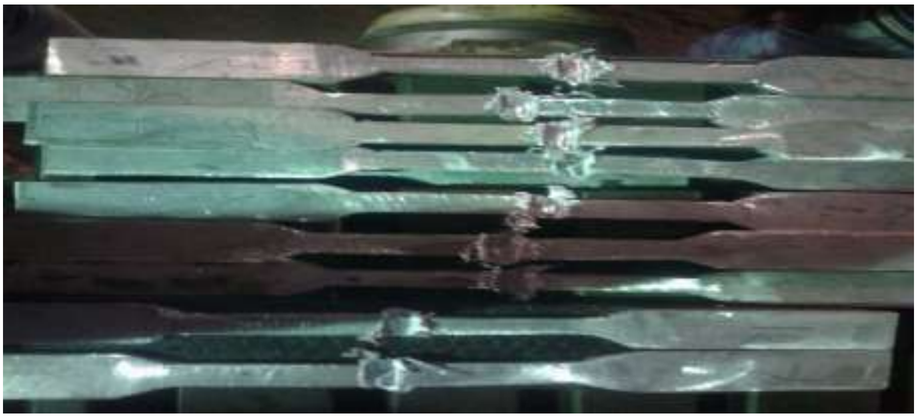

Fig. 3.11 Specimen before failure

Table 3.6 Tensile test result

Experiment no.	Spindle speed (rpm), N	Feed rate (mm/min), f	Tool Profile	Tensile strength (MPa)
1	900	20	Round	25.32
2	900	30	Round with threaded	27.05
3	900	40	Square	28.15

4	1200	20	Round with threaded	26.12
5	1200	30	Square	27.20
6	1200	40	Round	28.15
7	1500	20	Square	27.67
8	1500	30	Round	26.25
9	1500	40	Round with threaded	25.12

Fig. 3.12 Specimen after failure

6.2 VICKERS HARDNESS TEST

The Vickers hardness test method consists of indenting the test material with a diamond indenter as shown in Fig. 3.12, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 1 to 100 kgf. The full load is normally applied for 10 to 15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average calculated. The area of the sloping surface of the indentation is calculated. The Vickers hardness is the quotient obtained by dividing the kgf load by the square mm area of indentation. The load applied was 5 kg.

Fig. 3.13 Process Setup for Hardness Test

Table 3.7 Vicker's Hardness Results

Experiment no.	Spindle speed (rpm), N	Feed rate (mm/min), f	Tool Profile	HV
1	900	20	Round	52.3
2	900	30	Round with threaded	51.4
3	900	40	Square	56.2

4	1200	20	Round with threaded	53.4
5	1200	30	Square	54.6
6	1200	40	Round	57.1
7	1500	20	Square	53.6
8	1500	30	Round	54.2
9	1500	40	Round with threaded	56.7

7. RESULTS AND DISCUSSIONS

We weld the mention dimension of aluminum alloy AA5086 H32-AA6061 T6 with the mentioned process parameter was successfully done on CNC milling machine with different tool pin profile & then perform tensile strength test and hardness test to the welded joints, compare the results and make a conclusion.

7.1 S/N RATIO ANALYSIS

The term "Signal" represents the desirable value (mean) for the output characteristics and the term "noise" represents the undesirable value for the output characteristic. The S/N ratio is used to measure the quality characteristic deviating from the desired value in Taguchi method. The S/N ratios available depending on the type of characteristic: lower is better (LB), nominal is best (NB), larger is better (LB). Larger is better S/N ratio was used here.
Larger-the-Better

$$\frac{S}{N_{(Bigger)}} = -10\ \log\left(\frac{\Sigma\left(\frac{1}{y_i^2}\right)}{n}\right)$$

Table 3.7 S/N Ratio for Tensile Test Result

Experiment no.	Spindle speed (rpm), N	Feed rate (mm/min), f	Tool Profile	Tensile strength (MPa)	S/N ratio
1	900	20	Round	25.32	28.07
2	900	30	Round with threaded	27.05	28.64
3	900	40	Square	28.15	28.99
4	1200	20	Round with threaded	26.12	28.34
5	1200	30	Square	27.2	28.69
6	1200	40	Round	28.25	29.02
7	1500	20	Square	27.67	28.84
8	1500	30	Round	26.25	28.38
9	1500	40	Round with threaded	25.12	28.00

Table 3.8 S/N Ratio for Vicker's Hardness Test Result

Experiment no.	Spindle speed (rpm), N	Feed rate (mm/min), f	Tool Profile	HV	S/N ratio
1	900	20	Round	56.3	35.01
2	900	30	Round with threaded	55.4	34.87
3	900	40	Square	57.2	35.15
4	1200	20	Round with threaded	53.4	34.55

5	1200	30	Square	55.6	34.90
6	1200	40	Round	57.1	35.13
7	1500	20	Square	56.6	35.06
8	1500	30	Round	57.2	35.15
9	1500	40	Round with threaded	55.7	34.92

7.2. ANOVA FOR TENSILE STRENGTH

Table 4.3 shows the ANOVA calculations for the S/N ratio. The analysis was carried out at a significance of α=0.05. The main effect is shown in figure 4.2. Table 4.4 shows the response table for S/N for tensile strength. Ranks have been given to the various factors. Higher is the rank higher is the significance so spindle speed is the most significant factor. It was found that only spindle speed is a significant factor with F value of 11.01.

Table 4.3: Analysis of Variance for S/N Ratio for Tensile Strength

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage Contribution
Spindle speed (rpm), N	2	0.11576	0.8560	0.4280	1.24	0.446	10.22 %
Feed rate (mm/rev), f	2	0.09769	0.8348	0.4174	1.21	0.452	8.62 %
Tool profile	2	0.41269	0.3665	0.1832	0.53	0.653	36.45 %
Error	2	0.50602	0.6886	0.3443			
Total	8	1.13216					
S = 0.5867 R-Sq = 74.92 % R-Sq (adj) = 0.25 %							

Table 4.4: Response Table for S/N Ratio for Tensile Strength

Level	Spindle speed (rpm), N	Feed rate (mm/min), f	Tool profile
1	28.57	28.42	28.49
2	28.68	28.57	28.33
3	28.41	28.67	28.84
Delta	0.28	0.25	0.51
Rank	2	3	1

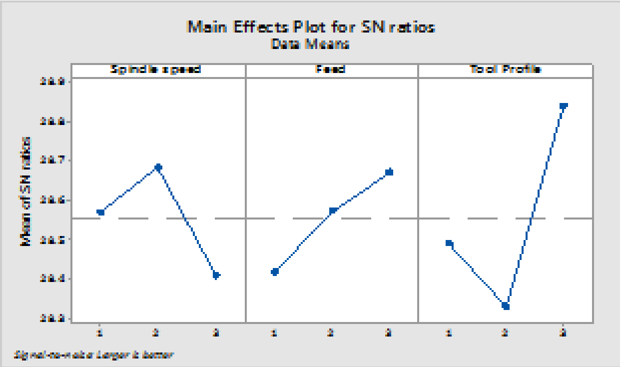

Figure 4.2: Main Effects Plot for S/N Ratio for Tensile Strength

7.3 ANOVA FOR HARDNESS TEST

Table 4.7 shows the ANOVA calculations for the S/N ratio. The analysis was carried out at a significance of α=0.05. The main effect is shown in figure 4.5. Table 4.8 shows the response table for S/N for vicker's hardness. Ranks have been given to the various factors. Higher is the rank higher is the significance so spindle speed is the most significant factor. It was found that only spindle speed is a significant factor with F value of 54.31.

Table 4.7: Analysis of Variance for S/N Ratio for Vicker's Hardness

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage Contribution
Spindle speed (rpm), N	2	0.05722	0.05722	0.02861	5.29	0.159	19.46 %
Feed rate (mm/rev), f	2	0.05609	0.05609	0.02804	5.18	0.162	19.08 %
Tool profile	2	0.16976	0.16976	0.08487	15.69	0.06	57.76 %
Error	2	0.01082					
Total	8	0.29389					
S = 0.475 R-Sq = 98.58 % R-Sq (adj) = 94.32 %							

Table 4.8: Response Table for S/N ratio for Vicker's Hardness

Level	Spindle speed (rpm), N	Feed rate (mm/min), f	Tool profile
1	35.01	34.87	35.10
2	34.86	34.97	34.78
3	35.04	35.07	35.04
Delta	0.18	0.19	0.32
Rank	3	2	1

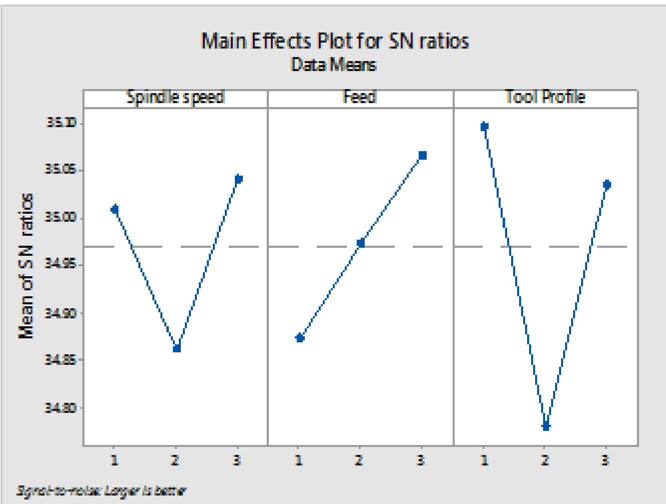

Figure 4.5: Main Effects Plot for S/N Ratio for Vicker's Hardness

8. DETERMINATION OF OPTIMUM SOLUTION

Optimum parameter setting for higher tensile strength and higher hardness value with tool profile has been identified in Fig. 4.2 & 4.5. The best configurations are determined individually through Taguchi's approach. Table 4.9 & 4.10 indicates these individual maximum values and its related settings of the method parameters for the described performance characteristics.

Table 4.9: Parameters and their Selected Levels for Maximum Tensile Strength

Parameter designation	Process parameters	Optimal levels
A	Spindle speed (rpm), N	2 (1200 rpm)
B	Feed rate (mm/min), f	3 (40 mm/min)
C	Tool profile	3 (Square)

Table 4.10: Parameters and their Selected Levels for Maximum Hardness Value

Parameter designation	Process parameters	Optimal levels
A	Spindle speed (rpm), N	3 (1500 rpm)
B	Feed rate (mm/min), f	3 (40 mm/min)
C	Tool profile	1 (Round)

9. CONFIRMATION TEST

Larger the better characteristic

$$\frac{S}{N_{(Bigger)}} = -10\ \log\left(\frac{\Sigma\left(\frac{1}{y_i^2}\right)}{n}\right)$$

Where yi are the responses and n is the number of tests in a trial. The level of a factor with the highest S/N ratio was the optimum level of responses measured. In order to test the predicted result, confirmation experiment has been conducted by running three trials at the optimal setting of the process parameters determined from the analysis i.e. A2, B3, C3 for tensile strength and A3, B3, C1 for hardness value.

Table 4.11: Confirmation Test for Maximum Tensile Strength

S.no	Trials			Avg. Tensile strength (MPa)
	1	2	3	
1	28.26	28.65	28.35	28.42

Table 4.12: Confirmation Test for Maximum Hardness Value

S.no	Trials			Avg. Hardness value
	1	2	3	
1	53.9	58	58	56.63

10. CONCLUSIONS

10.1 FOR TENSILE STRENGTH

The subsequent conclusions are finished via the analysis

- It can hence be concluded that use of round tool profiles yield better results than that of the square tool and round with thread tool profiles.
- The tensile strength increases with increase in the tool feed. The optimum value of process parameters such as spindle speed, feed rate, and tool profile is found to be 1200 rpm (level 2), 40 mm/min (level 3) and square tool pin (level 3) respectively.
- The maximum tensile strength achieved was 28.42 MPa while welding at 900rpm with 40 mm/min feed using the round tool.

- The analysis of variance for the tensile result concludes that the tool profile is the most significant parameter with a percentage of 36.45 %, followed by the feed of 8.62 % and spindle speed 10.22 %.
- Friction stir welding is applied successfully for AA5086 H32- AA6061 T6 grade aluminum alloy by a milling machine.

10.2 FOR HARDNESS VALUE

- It can hence be concluded that use of square tool profiles yield better results than that of the round tool and round with thread tool profiles.
- The hardness increases with increase in the tool feed rate. The optimum value of process parameters such as spindle speed, feed rate, and tool profile is found to be 1500 rpm (level 3), 40 mm/min (level 3) and round tool pin profile (level 1) respectively.
- The maximum hardness value achieved was 56.63 HV while welding at 1500 rpm with 40 mm/min feed using the square tool.
- The analysis of variance for the hardness value result concludes that the tool profile is the most significant parameter with a percentage of 57.76 %, followed by the spindle speed 19.46 % and feed rate 19.08 %.
- Friction stir welding is applied successfully for AA5086 H32- AA6061 T6 grade aluminum alloy by a milling machine.

11. REFERENCES

[1] F. Rotundo, L. Ceschini, A. Morri, T. S. Jun, A. M. Korsunsky (2010), "Mechanical and micro structural characterization of 2124Al/25 Vol.% SiCp joints obtained by linear friction welding (LFW)", International Journal of Innovative Research in Science, Engineering, and Technology, Vol. 3, Issue 11, PP: 17261-17268.

[2] Ali Akbar Nadim, Hakeemuddin Ahmed (2014), "Design, Fabrication, and Testing of Friction Stir Welded Joints", International Journal of Innovative Research in Science, Engineering and Technology, Vol. 3, Issue 11, PP: 17261-17268.

[3] Sivakumar, Vignesh Bose (2014), "Review Paper on Friction Stir Welding of various Aluminium Alloys", IOSR Journal of Mechanical and Civil Engineering, Vol. 3, Issue 4, PP: 46-52.

[4] G. Gopala Krishna, P. Ram Reddy, M. Manzoor Hussain (2014), "Mechanical Behaviour of Friction Stir Welding Joints of Aluminium alloy of AA6351 with AA6351 and AA6351 with AA5083", International Journal of Engineering Trends and Technology, Vol.10, Issue 4, PP: 161-165.

[5] Sadeesh P, Venkatesh Kannan M, Rajkumar V, Avinash P, Arivazhagan N, Devendranath Ramkumar K and Narayanan S (2014), "Studies on friction stir welding of AA 2024 and AA 6061 dissimilar metals", 7th International conference on materials for advanced technology, 2014, pp. 145–149.

[6] Sachin Kumar, Deepak Bhardwaj, Jagdeep Sangwan (2014), "A Research Paper on Temperature Modelling of Friction Welding of Aluminium and Stainless Steel-304", International Journal of Enhanced Research in Science Technology & Engineering, Vol. 3 Issue 6, PP: 319-327.

[7] Prakash Kumar Sahu, Sukhomay Pal (2015), "Multi-response optimization of process parameters in friction stir welded AM20 magnesium alloy by Taguchi grey relational analysis", Journal of Magnesium and Alloys 3, Vol. 5, Issue 1, PP: 36-46.

[8] Vanita S. Thete, Vijay L. Kadlag (2015), "Effect of Process Parameters of Friction Stir Welded Joint for Similar Aluminium Alloys H30", Int. Journal of Engineering Research and Applications, Vol. 5, Issue 5, PP: 10-17.

[9] Sirajuddin Elyas Khany, S.N.Mehdi G.M.Sayeed Ahmed (2015), "An Analytical Study of Dissimilar Materials Joint Using Friction Welding and its Application", International Journal of Scientific and Research Publications, Volume 5, Issue 2, PP: 12-20.

[10] Raktate Omesh, Dhananjay Dolas (2016), "Optimization of Process Parameters of Friction Stir Welding– Critical Review", International Advanced Research Journal in Science, Engineering, and Technology, Vol. 3, Issue 1, PP: 235-242.

[11] Sushant Sukumar Bhate (2016), "A Literature Review of Research on Rotary Friction Welding", International Journal of Innovative Technology and Research Volume No.4, Issue No.1, PP: 2601-2612.

[12] Gurmukh Singh, Gaurav Mittal, Dinesh Bhadhan (2017), "Study the Effect of Elongation in Single Sided Friction Stir Welding on Aa6063 Aluminium Alloy", International Journal of Engineering Sciences & Research Technology", Vol 6, Issue 1, PP: 347-352.

[13] Gaurav Verma, Sandeep Kumar, Bharat Raj Bundel, (2016), "A Research Paper on the Comparison of Weld Strength of Friction Welding of Different Materials At Two Different RPM", International Journal of Mechanical Engineering and Technology, Volume 7, Issue 6, PP:123–127.

[14] Santosh N. Bodake, A. J. Gujar (2017), "Review paper on optimization of friction stir welding process parameters", International Journal of Engineering Research and Technology, Vol. 10, Issue 1, PP: 611-620.

[15] Anitesh Mukherjee, Nikunj Vasantbhai Patel, Kailash Chand Gurjar (2017), "Review Paper on Friction Stir Welding and Its Impact on Environment", International Research Journal of Engineering and Technology, Vol. 4, Issue 3, PP: 1481-1490.

[16] Arjun Verma, Ankit Kumar Dubey, Abhijeet Ganguly (2017), "Parameter Optimization of Friction Stir Welding for Aluminium Alloy", IOSR Journal of Mechanical and Civil Engineering, Volume 14, Issue 2, PP: 8-12.