Influence of Flat Friction Stir Spot Welding Process Parameters on Quality Characteristics of AA 6082 Weld

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Abstract: *In this article Flat FSSW of three sheets of AA6082 was carried out having thickness of 1mm for each plate. The tool with probe and tool without probe were used for welding process. The use of these tools helps in obtaining the sound quality weld free from keyholes and cracks. The process parameters considered are tool rotational speed of 400, 975 and 1550 rpm, dwell time of 4, 6 and 8 s and plunge depth of 2.6, 2.8 and 3.0 mm. Taguchi analysis was used to optimize the parameters of this investigation for obtaining high tensile strength. An orthogonal array, L9 was applied and analysis of variance (ANOVA) was done to explore the importance of process parameters on various response. Various tests were carried out to investigate the mechanical properties of the weld. Optical microscopy out turn in fine distribution of grains in zones i.e. SZ, TMAZ, HAZ and BM. Scanning electron microscopy of weld was done to investigate the shear fracture in various zones i.e. SZ, TMAZ, HAZ, and BM. Scanning electron microscopy of tool is done before and after welding to investigate the change in microstructure, wear and tear of the tool. X-ray diffraction results in compressed residual stress which helps in obtaining the weld free from cracks. Previously Flat FSSW of AA 6061-T6 aluminum alloy was done which results as the weld free from keyholes and Taguchi method was not applied in this welding process for optimizing the process parameters. As the sound quality of weld is obtained with weld free from keyhole defect and cracks it has future application in light weight cars, aerospace.*

Keywords: Friction stir welding, Stif zone, Al-Cu metal, resistance spot welding.

1. INTRODUCTION

FSSW is a type of welding process used for joining similar and dissimilar metals with the help of rotating tool which is cylindrical in shape. This tool plasticizes and stirs the material during welding process to form a joint. This process is derived from friction spot welding. It is a kind of welding process that works on the pressure and the temperature lower than the work piece melting temperature. In this paper Flat FSSW process uses tool with probe and tool without probe for welding the material. The tool used in this process is (a) Tool having probe (b) Tool without probe or probe less tool. In step 1 tool having probe is used to join three layers of 6082 aluminum alloy sheets having a thickness of 1mm each. Protuberance is formed on the weld in step 1 while placing the three layer of aluminum sheets on predrilled dent base plate of diameter 6 mm and depth of drill is 3 mm. In step 2 tool without probe is used for removing the protrusion by placing the weld sample on the flat surface base plate. The weld obtained from flat friction stir spot welding is of higher strength, well mixing of molten material and improved mechanical properties. The tool without probe is used for removing the keyholes and protrusion obtained in step 1. FSSW is used for manufacturing the parts which bears heavy loads, automobile industries and rail vehicle construction industries, aerospace industries, welding of Al-Cu in the electrical industry, furniture manufacturing, Façade and welding natural space material like meteorites.

Applications

The various applications of FSSW are as follows:

- It is used for manufacturing parts which are exposed to high loads.
- It is used in automobile industries, rail vehicle construction industries and in aerospace industry for manufacturing of cockpit doors.
- FSSW can be used for welding of aluminum and copper.
- It can also be used in domestic way for making of Façade and furniture.

2. PREVIOUS WORK

There are different types of friction welding. One of its types is friction stir spot welding. Many research and investigations were carried out on FSSW with the help of tool with probe and tool without probe. Sometimes the tool probe with different profiles was also used for investigations and research. This literature review contained the work carried out by different researchers and authors on FSSW are as:

Chu et. al. (2018) optimized the tensile/shear strength of 1.8 mm thick sheet of AA 2198 probe less FSSW joint with the help of Response Surface Methodology (RSM).optimal failure load of 7.83kNwas achieved at the dwell time of 7.2s, rotational speed 950 rpm and plunge rate 30mm/min. Tensile/shear strength of probe less FSSW welded joint increased with stir zone depth (SZD) initially and after that it decreased due to hook defect.

Siddhartha and kumar (2018) investigated the effect of process parameters such as tool rotational speed, dwell time and plunge depth on tensile strength for constructing the windows of Al-Cu joint. A maximum tensile shear failure (2.234kN) was obtained at rotational speed of 1100 rpm, plunge depth of 2.05mm and dwell time of 11.5 s .

Piccini and Svoboda (2017) investigated the FSSW for joining two dissimilar metals i.e. aluminum and carbon steel. AA5052 of thickness 1mm and low carbon steel of thickness 0.65mm were welded with the tool made of H13(tool steel). The tool with different geometry was used in this process. The weld obtained was defect free and excellent in appearance .

Mubiayi and Akinlabi (2017) investigated the effect of various process parameters such as tool geometries, rotational speed of tool, plunge depth of tool shoulder for AA1060 and C11000 copper FSSW welded joint. The results showed the correlation between the Energy Dispersive Spectrometry (EDS) and X-Ray Diffraction (XRD) and identified the presence of intermetallic compounds like Al_4Cu_9, $AlCu_3$, and Al_2Cu in the Stir Zone (SZ). The microstructure showed a uniform mixing.

Sun et. al. (2018) analyzed the 2.0 mm thick cold rolled low carbon steel plate FSSW welded joint at low rotational speed (5-50 rpm) and the low welding temperature (160°C). The fine microstructure analysis consist of an average grain size of about 0.41µm at the stir zone. No heat affected zone could be identified. Maximum shear load of 10kN at a welding condition of 8 tonnes, 20 rpm and 2 s was identified.

Hangoi et. al. (2019) developed a Friction Stir Welding(FSW) Foaming Process for foaming the precursor with the help of friction heat generated during FSW. The Precursor followed by

FSW foaming process can be fabricated with the help of FSW Foaming process. It is expected that Al foam can be fabricated only with the help of energy saving FSW Foaming process.

3. FABRICATION AND EXPERIMENTAL SETUP

3.1. Selection of Material

Work piece Material

AA6082 is selected for FSSW. It has the highest strength among 6xxx series alloy. It is mostly used in automotive parts and aircraft applications. The chemical composition of AA6082 is represented in Table 3.1 and Table 3.2 represents the mechanical behaviour of AA6082, Fig 3.1 represents the AA6082 raw material respectively.

Table 3.1. Chemical composition of AA6082

Al	Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr
Balance	0.7-1.3	0.0-0.5	0.0-0.1	0.4-1.0	0.6-1.2	0.0-0.2	0.0-0.1	0.0-0.25

Table 3.2. Mechanical properties of AA6082

Base Material	Ultimate Tensile Strength (MPa)	Yield Strength (MPa)	Elongation
AA6082	140-330	280	10%

Tool Material

H13, hot die steel is used as a tool with probe and without probe. The chemical composition of H13 die steel is shown in Table 3.3. It has good hardness characteristics such as red hardness, wear hardness and it also have high toughness that are the most requisite Flat FSSW. The tool along with its dimensions is represented in Fig.3.2.

Table 3.3. Chemical compositions of H13 die steel

Element	C	Mn	Si	Cr	Mo	V
Percent Composition	0.40	0.40	1.00	5.25	1.35	1.00

Figure 3.1. Represents AA6082 raw material

Fig.3.2 Tool with probe and without probe

Figure 3.2. Tool with probe and without probe

3.2.Experimental Procedure

In this study three sheets of AA6082of area 100x30x1mm are subjected to Flat FSSW. Firstly, the surface of aluminum sheets is cleaned with the help of acetone to remove dirt and organic impurities attached to its surface. Two plates of same dimension i.e. 100x30x1 mm and third plate of dimension 50x30x1 mm is used for the experiment. Plate having dimension (50x30x1) mm is placed below the two plates as shown in Fig3.4.

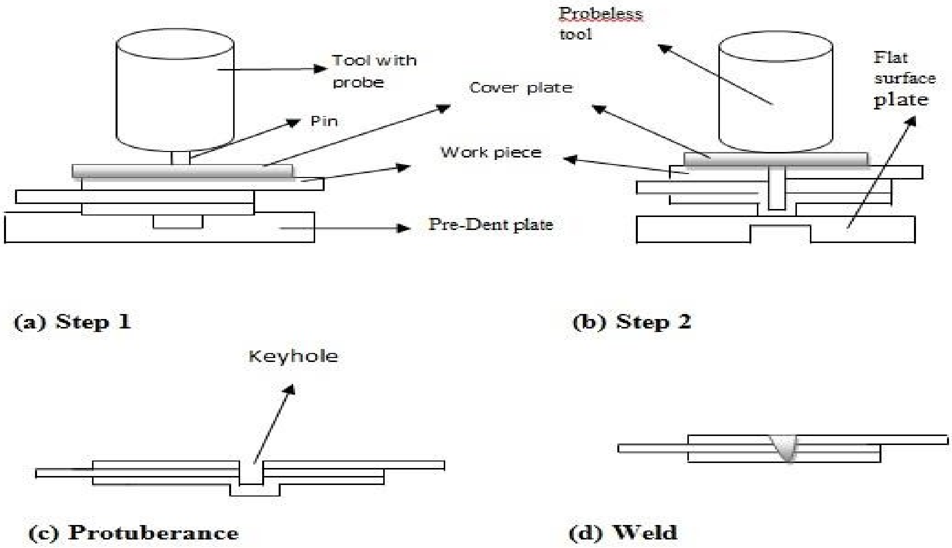

Figure 3.4. Experimental Tool and workpiece arrangement

3.3.Experimental Setup

The Flat FSSW process is done with vertical milling machine. This machine welds the plates of AA6082 with the help of drilling process and the weld is created by frictional heat generated by the rotation of the tool(with probe and without probe) on the workpiece are shown in Fig. 3.5

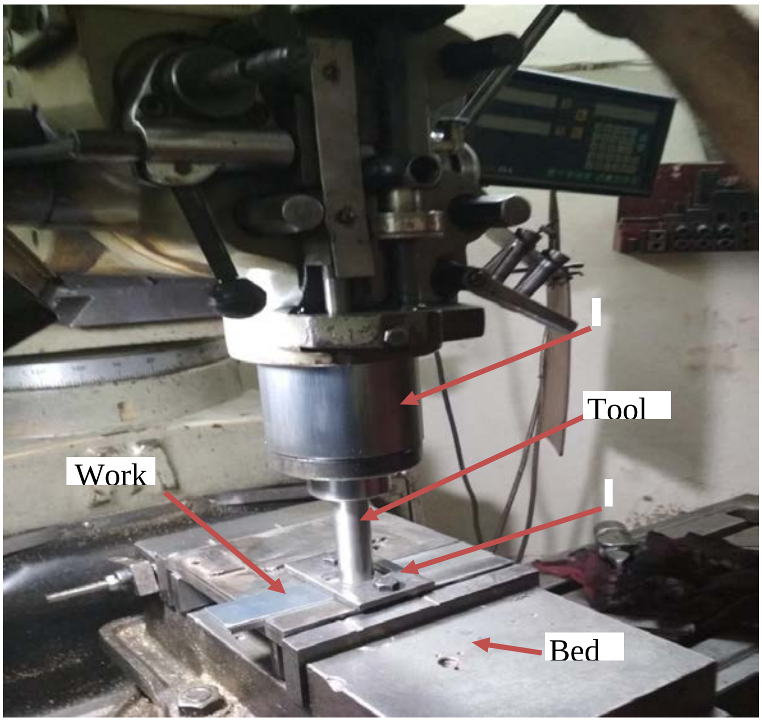

Figure 3.5. Flat Friction Stir Spot Welding Setup

For measuring the mechanical strength of the welded joint nine samples of three layers are prepared with the help of flat FSSW process. The nine samples are represented in Fig. 3.6, Pre-drilled cavity Base Plate is represented in Fig. 3.7 and Fixture with Three AA 6082 plates is represented in Fig 3.8

Figure 3.6. Sample of Three Layer Flat Friction Stir Spot Welding plates

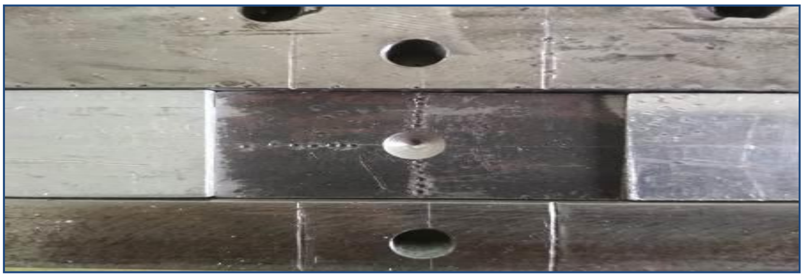

Figure 3.7. Pre-drilled cavity Base Plate

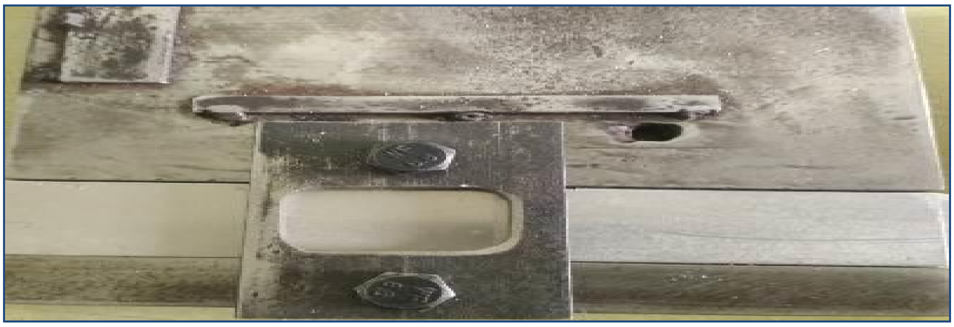

Figure 3.8. Fixture with Three AA 6082 plates

4. METHODOLOGY

4.1. Taguchi Method

Taguchi method is also known as robust design method was invented by Genichi Taguchi. This method helps in improving the quality of the manufactured goods. It uses two or three parameters to evaluate the effect of variability of particular process characteristics. The three categories of process parameter characteristics areas follow: i) Lower the Better ii) Nominal the Better iii) Higher the Better. The quality of the characteristics was calculated on the basis of signal to noise (S/N) ratio. The desirable value of the output is represented by Signal and the undesirable value of the output characteristics is represented by Noise. The main goal of S/N ratio is to expand the process that is not sensitive to noise and increases the tensile strength. The S/N ratio can be calculated as:

$$S/N \text{ ratio } (\eta) = -10 \log_{10}\left[\frac{1}{n}\sum_{i=1}^{n} y_i^n\right]$$

Where, n represents the number of replications and y_i represents the observed response value.

To study the process parameter's effect, tensile strength of the FSSW joint is used for analysis.

Selection of orthogonal array (OA)

The orthogonal array selection depends on the following items on the basis of their order of priority:

- The number of factors and interactions of interest.
- The number of levels for the factors of interest.
- The desired experimental resolution or cost limitations.

In this, three levels and three factors are taken into reflection. L9 OA is used in this investigation. 2 is the degrees of freedom (DOF) for each factor, where number of level is -1 i.e. 3-1=2) and 3×2=6 is the total degrees of freedom. The DOF of the OA should be greater than the total DOF of the factors. As the DOF of L9 is 8. The standard L9 orthogonal array is represented in Table 4.1.

Table 4.1. Standard L9 Orthogonal Array

Experimental Run	**Control Factors and levels**		
	1	**2**	**3**

1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

4.2. Analysis of Variance

ANOVA method was proposed by Sir Ronald Fisher to compare the outcome of the actual experiment. It is a numerical method which splits the total variation into liable sources. The main objective of ANOVA is to find out how the process parameters affect the response and the factors reviewed in the experiment. In this investigation rotational speed of tool, dwell time and plunge depth are considered as a significant factors affecting the hardness and tensile strength of the welded joint. Rotational speed of tool and plunge depth is considered as highly significant factors because 'p' value is less than 0.05.The dwell time (DT) plays a minor role in affecting the tensile strength.

5. RESULT AND DISCUSSION

5.1.Analysis of Tensile Strength

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For Tensile Test

The experimental design L9 OA is shown in Table 5.1.The investigational data is transform into S/N ratio. The S/N ratio and mean are represented in Table 5.2. The mean effect plot for S/N ratio and mean is shown in Fig 5.1 and Fig. 5.2. The main effects of process parameters are shown in Table 5.5. Larger value of S/N ratio is considered as sound quality of the weld joint. The rank of the process parameter with respect to S/N ratio and mean are represented by Response Table 5.3 and Table 5.4 for S/N ratio and mean based on levels average. The goal of this study is to maximize the strength of the weld and hence higher the better process character is considered as best.

Table 5.1. L9 Designed Experimental Layout (Tensile Strength)

Sr.No	Input Parameter Coded Values			Input Parameter Un-coded Values			
	A	B	C	RPM	DT	PD	TSS
1	1	1	1	400	4	2.6	48.1
2	1	2	2	400	6	2.8	20.5
3	1	3	3	400	8	3.0	46.6

4	2	1	2	975	4	2.8	19.1
5	2	2	3	975	6	3.0	13.7
6	2	3	1	975	8	2.6	35.0
7	3	1	3	1550	4	3.0	42.1
8	3	2	1	1550	6	2.6	19.4
9	3	3	2	1550	8	2.8	11.7

Table 5.2. Experimental values of Tensile strength on the basis of L9 OA

S.No	Input Parameter Coded Values			Tensile Strength (TSS)	SN Ratio (S/N)	Mean Value
	A	B	C			
1	1	1	1	20	26.0206	20
2	1	2	2	14	22.9225	14
3	1	3	3	17	24.6089	17
4	2	1	2	16	24.0824	16
5	2	2	3	19	25.5750	19
6	2	3	1	42	32.4649	42
7	3	1	3	33	30.3702	33
8	3	2	1	48	33.6248	48
9	3	3	2	49	33.8039	49
Average					**28.1636**	**28.6666**

Table 5.3. Response table for S/N Ratios

Level	**RPM**	**DT**	**PD**
1	24.52	26.82	30.70
2	27.37	27.37	26.94
3	32.60	30.29	26.85
Delta	8.08	3.47	3.85
Rank	1	3	2

Table 5.4. Response table for Means

Level	**RPM**	**DT**	**PD**
1	17.00	23.00	36.67
2	25.67	27.00	26.33
3	43.33	36.00	23.00
Delta	26.33	13.00	13.67
Rank	1	3	2

The optimal value on the basis of mean is $A_3B_3C_1$

5.2. Effects of process parameters

The effects of process parameters on flat FSSW of AA 6082 are indicated in Fig 5.1 and Fig 5.2 by arranging the main effects of the process parameters with respect to the tensile strength. Now the effect of each parameter on tensile strength of the weld joint is summarized below:

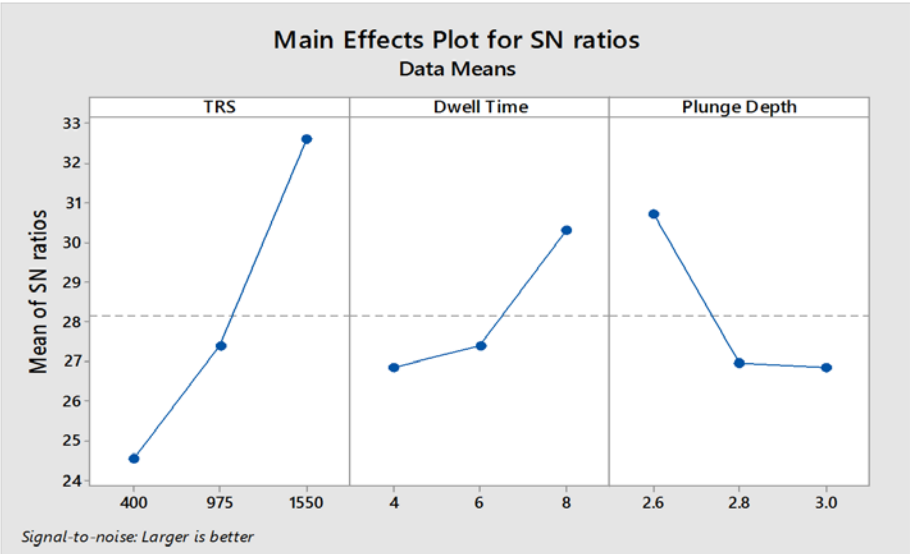

Figure 5.1. Effect of process parameters for S/N ratio (tensile strength)

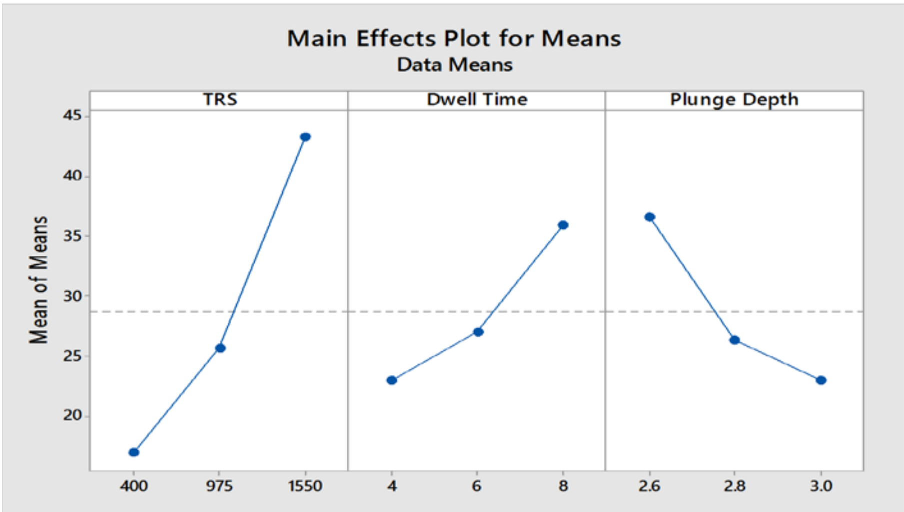

Figure 5.2. Effect of process parameters for Mean (tensile strength)

Table 5.5. Main effects of process parameters

Process Parameter	Level	S/N Ratio			Mean		
		RPM	DT	PD	RPM	DT	PD
Average Value	L1	24.52	26.82	30.70	17.00	23.00	36.67
	L2	27.37	27.37	26.94	25.67	27.00	26.33
	L3	32.60	30.29	26.85	43.33	36.00	23.00
Main	L2-L1	2.85	0.55	-3.76	8.67	4.00	-10.34

Effects	L3-L2	5.23	2.92	-0.09	17.66	9.00	-3.33
Difference	(L3-L2)-(L2-L1)	2.38	2.37	-3.85	8.99	5.00	-13.67

The ANOVA analysis as shown in Table 5.7 is calculated with the help of software known as Minitab 18 version.

Table 5.6. Experimental values of Hardness on the basis of L9 OA

S.No	Input Parameter Coded Values			Hardness (MHV)	SN Ratio (S/N)	Mean Value
	A	B	C			
1	1	1	1	60.75	35.6709	60.75
2	1	2	2	62.25	35.8827	62.25
3	1	3	3	65.25	36.2916	65.25
4	2	1	2	63.25	36.0212	63.25
5	2	2	3	64.75	36.2247	64.75
6	2	3	1	64.75	36.2247	64.75
7	3	1	3	65.25	36.2916	65.25
8	3	2	1	63.75	36.0896	63.75
9	3	3	2	66.25	36.4237	66.25
Average					**36.1245**	**64.02**

Table 5.7. Analysis of Variance for SN Ratio (Hardness test)

Source	Degree of Freedom	Adjusted sum of square	Adjusted mean square	F-Value	Percent Value (p-value)	Percentage contribution (%PC)
RPM	2	8.3889	4.1944	151.00	0.007	35.61%
DT	2	9.0556	4.5277	163.00	0.006	38.44%
PD	2	6.0556	3.0277	109.00	0.009	25.71%
Error	2	0.0556	0.02778			0.24%
Total	8	23.5556				100%
S = 0.166667 R-Sq = 99.76% R-Sq(adj) = 96.06%						
*Significance at 95% level						

6. CONCLUSION

In this work, AA6082 alloy was welded by the use of flat FSSW (F-FSSW). To analyse the process parameter's effect on tensile strength and hardness, various experimental analyses are carried out such as microstructural analysis, SEM analysis, X-ray Diffraction, Residual stress analysis. The various points can be concluded from tis experimental work is as follows:

1. Rotational speed of tool, Dwell time, and plunge depth are the significant parametersfor tensile strength.
2. The percentage contribution of rotational speed is 64.94%, Dwell time is 15.98% , and

plunge depthis18.31% in case of tensile strength.

3. The optimum values of tensile strength is 57.37< TS <59.14.
4. The percentage contribution of rotational speed, shoulder rotational speed is and welding speed for hardness are 35.61%, 38.44%, and 25.71% respectively.
5. The optimum values of hardness is 35.53< MH <36.71.
6. The defect-free joints were welded by F-FSW means keyhole and cracks areeliminated.
7. The result of the residual stress is compressive residual stress with negative values which helps in eliminating the cracks.
8. Protrusion formed in this welding process was removed to achieve the good strength ofweld

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