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## Effect Of Friction Stir Welding On Hardness And Surface Roughness Of AA-6061 T6 Aluminum Alloy

Dr. B. SrinivasaVarma\*  
YalamanchiliSomeswarRao\*\*  
Pawan Kumar\*\*\*

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### Abstract

The objective of this paper is to exhibit the attractive features of the joint through friction stir welding (FSW), a solid state joining technique, extensively used for joining Aluminum alloys. FSW is used to fabricate products with superior mechanical properties. Presently, aluminum alloys have been widely used in engineering applications such as aerospace and automobile owing to their light weight, superior mechanical properties and high oxidization resistance.

In this work, two process parameters such as spindle speed and welding speed are considered for friction stir welding. The optimum level setting and the major parameters that influence the strength are obtained through Taguchi techniques. Several tests like Liquid penetration, hardness, surface roughness and three-point bend test have been performed to evaluate the properties of the weld joint.

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### Keywords:

Friction stir welding;  
Hardness;  
Liquid penetration test;  
Surface roughness;  
Three-point bend test.

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### Author correspondence:

Dr.B.SrinivasaVarma\*  
Department of Mechanical Engineering,  
CMRCollege of Engineering &Technology,  
Kandlakoya,Medchal Road ,  
Hyderabad- 501401, India.

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### 1. Introduction (10pt)

Friction stir welding (FSW) is reasonably a recent solid-state joining process. This fusion technique is environment affable, energy efficient and adaptable. In particular, it can be used to

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\*Professor of Mechanical Engineering, Department of Mechanical Engineering, CMRCollege of Engineering &Technology, Hyderabad- 501401, India

\*\*Graduate Student, Department of Mechanical Engineering, CMRCollege of Engineering &Technology, Hyderabad- 501401, India

\*\*\*Graduate Student, Department of Mechanical Engineering, CMRCollege of Engineering &Technology, Hyderabad- 501401, India

join high-strength aerospace aluminum- alloys and other metallic alloys that are hard to weld by conventional fusion welding techniques.

FSW has evolved as a preferred process in the usual joining of aluminum components. The application for joining difficult metals besides aluminum is growing. The widespread benefits resulting from the applications of FSW in aerospace, shipbuilding, automotive and railway industries have been noticed. The difficulty of making high-strength, fatigue and fracture resistant welds in aerospace aluminum alloys, such as 2XXX and 6XXX series, has long restrained the extensive exploitation of other welding methods for joining aerospace structures prior to FSW.

As compared to the conventional welding methods, FSW consumes drastically less energy. The joining does not involve any use of filler metal and consequently any aluminum alloy can be joined without concern for the compatibility of electrode composition, which is a major issue in fusion welding. No enveloping gas or flux is used, thereby making the process environment friendly. When required, dissimilar aluminum alloys and composites can be joined with equal ease. These characteristics make the joining of these alloys by conventional welding processes unattractive. Rotational speed, welding speed, tool pin length, and tool shoulder diameter play a key role in deciding the joint properties in FSW welding. The mechanical properties of welded materials are characteristically measured in terms of tensile strength and hardness through Vickers/Rockwell hardness techniques.

## 2. LITERATURE REVIEW

Anil Kumar K. S., et al [1] have stated that rotational speed, welding speed and tool tilt angle will influence ultimate tensile strength and hardness of the Joints when similar metals of AA2024-T351 were joined .

SquillaceA.,et al [2] have stated that mechanical properties of friction welded joints depend on rotating and welding speeds while working on AA6056.

Wayne Thomas., et al [3] who worked on the Friction Stir Welding and related friction process characteristics explained different tools and joints for joining aluminum alloys.

Jayaraman M., et al [4] have observed that Tensile Strength of Aluminum Alloy A319 in FSW is predominantly influenced by welding speed.

## 3. WORK MATERIAL

6061 is a precipitation-hardened aluminum alloy, which exhibits good mechanical properties and weldability. It is one of the most common alloys of aluminum for general-purpose use and available in pre-tempered grades such as 6061-O (annealed), tempered grades such as 6061-T6 and 6061 T651.

### 3.1 SPECIFICATIONS

#### Mechanical and chemical properties of aluminum

The mechanical properties of 6061 depend greatly on the temper, or heat treatment, of the material. Young's Modulus is 69 GPa regardless of temper. The Mechanical and Chemical compositions are shown in Tables 1 and 2.

**Table 1: Mechanical Properties of AA 6061**

Tensile Strength mpa		Yield Strength (.2%offset) mpa		Elongation	
Min	Max	Min	Max	Min	Max
42.0	-	35.0	-	6.0	-
46.0	47.0	41.0	43.0	11.0	11.8

**Table 2: Composition of**

**AA 6061**

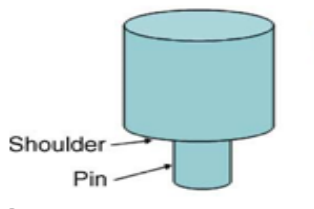
Element	Required	Contains
Si	0.4-0.8	0.62
Fe	0.7	0.45

Cu	0.15-0.4	0.2
Mn	0.15	0.18
Mg	0.8-1.2	1.05
Cr	0.04-0.35	0.09
Zn	0.25	0.03
Ti	0.15	0.07
Al	Reminder	Reminder

#### 4. Experimental Procedure

##### 4.1 TOOL MATERIAL SELECTION

Weld quality and tool wear are two vital considerations in the selection of tool material. The weld microstructure may also be affected as a result of interaction with eroded tool material. Significant tool wear affects the weld microstructure besides the processing cost of FSW. Thermal conductivity of tool material will influence temperatures in the workpiece besides other and processing parameters. The coefficient of thermal expansion may also affect the thermal stresses in the tool. Besides this, hardness, ductility and reactivity with the workpiece material may influence tool material selection. The details of the tool are shown in Figure-1 and tool material details are given in Table-3



**Figure 1: FSW Tool**

Ref: Anil Kumar K. S. [1]

**Table 3: Selected Tool material details**

##### 4.2 FRICTION STIR

BISS, Bangalore make stiffness, with 5 axis independently controlled 2370MS controller is used

Tool Material	Tool Shape and Size
H13 steel	Shoulder Diameter:25mm Pin Diameter:4-6mm

is also appropriate to weld steel and titanium. This machine can be used to weld thicknesses from 0.5mm to 65mm. The capacity of the machine is 50kN with maximum rotational speed of 3000 rpm at constant torque and having, stroke length of 500mm each in X and Y axis.

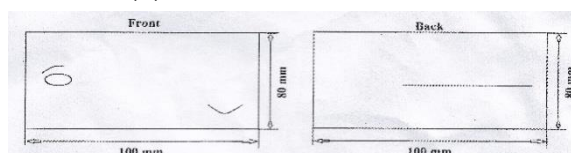
##### WELDING TEST RIG

Friction test rig with high-movements and servo-actuators with for welding. This machine is

#### 5. RESULTS AND DISCUSSION

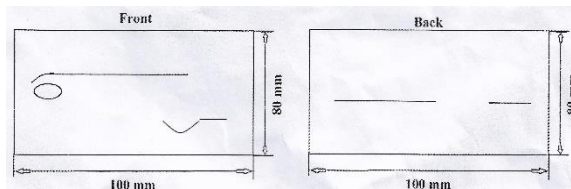
##### 5.1 LIQUID PENETRATION TEST

Liquid penetration tests have been done, defectogram for samples have been generated and defects are observed. Fixing of the work piece should rigid; if it is less tightened there may be chance of separation due to high initial torque and friction that lead to linear defect, surface crack, as shown in Figures 2,3,4 and 5 and defect lengths are given in Tables 4,5,6 and 7.



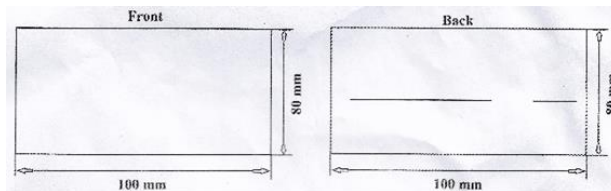
**Figure 2: Defectogram for Sample 1**  
**Table 4: Length of defect for sample 1**

S.no	Type of defect	Total length	Starting defect length
1	Linear	40mm	20mm
2	Linear	15mm	80mm
3	Linear	20mm	40mm



**Figure 3: Defectogram for sample 2**  
**Table 5: Length of defect for sample 2**

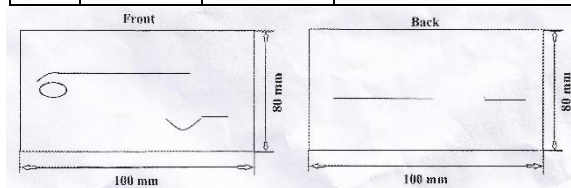
S.no	Type of defect	Total length	Starting defect length
1	Linear	40mm	20mm
2	Linear	15mm	80mm
3	Linear	75mm	30mm



**Figure 4: Defectogram for sample 3**

**Table 6: Length of defect for sample 3**

S.no	Type of defect	Total length	Starting defect length
1	Linear	15mm	15mm
2	Linear	40mm	40mm



**Figure 5: Defectogram for sample 4**

**Table 7: Length of defect for sample 4**

S.no	Type of defect	Total length	Starting defect length
1	Linear	30mm	15mm
2	Linear	50mm	80mm
3	Linear	20mm	30mm
4	Linear	40mm	50mm

**5.2 SURFACE ROUGHNESS**

Surface roughness tests have carried out and values of Ra (µm), Rq (µm), Rz (µm) were noted at advancing side, weld centre, retreating side. Ashok Babu. J et al [5] have stated that when the rotational speed is increased from 800 rpm, correspondingly the surface roughness increases and reaches good surface finish (minimum) at 950 rpm. However, when the rotational speed is increased above 950 rpm, the surface roughness of the joint also increases. The surface roughness details are shown in Table 8.

**Table 8: Values of Surface Roughness at various rpm and feeds for samples 1,2,3 and 4**

<b>Sample 1 at 1200rpm, 45mm/min</b>			
	<b>Ra(<math>\mu</math>m)</b>	<b>Rq(<math>\mu</math>m)</b>	<b>Rz(<math>\mu</math>m)</b>
Advancing Side	4.731	5.786	24.072
Centre	6.232	7.686	33.334
Retreating Side	10.541	12.552	46.188

<b>Sample 2 at 1200rpm, 60mm/min</b>			
	<b>Ra(<math>\mu</math>m)</b>	<b>Rq(<math>\mu</math>m)</b>	<b>Rz(<math>\mu</math>m)</b>
Advancing Side	4.294	5.432	23.435
Centre	3.552	4.468	19.324
Retreating Side	10.135	12.472	47.305

<b>Sample 3 at 1600rpm, 45mm/min</b>			
	<b>Ra(<math>\mu</math>m)</b>	<b>Rq(<math>\mu</math>m)</b>	<b>Rz(<math>\mu</math>m)</b>
Advancing Side	4.737	6.149	23.672
Centre	5.129	6.239	26.124
Retreating Side	5.872	7.301	31.298

<b>Sample 4 at 1600rpm, 60mm/min</b>			
	<b>Ra(<math>\mu</math>m)</b>	<b>Rq(<math>\mu</math>m)</b>	<b>Rz(<math>\mu</math>m)</b>
Advancing Side	3.932	4.929	22.625
Centre	4.692	5.718	25.282
Retreating Side	5.926	7.236	30.104

### 5.3 ROCKWELL HARDNESS

Rockwell hardness B tests have been conducted on welded samples and hardness value is noted at advancing side, weld centre, retreating side and shown in Table 9. When Rotation speed increases from 1200rpm, hardness in the weldment also increases. This was also confirmed by Stephen Leon. J, et al [6]. It was observed that as speed increases, hardness is also increased due to quick solidification of dispersed metal at the joint.

**Table 9: Rockwell Hardness Values in B Scale**

	<b>Advancing side</b>	<b>Weld centre</b>	<b>Retreating side</b>
<b>Sample 1</b>	42.5	47	46.5
<b>Sample 2</b>	42.8	42.6	42.5
<b>Sample 3</b>	40.5	40.2	40.5
<b>Sample 4</b>	42.5	42	42

### 5.4 COMBINED EFFECT OF HARDNESS AND SURFACE ROUGHNESS

A comparative figure of all samples has been drawn by taking hardness and surface roughness as parameters at advancing side, weld centre and retreating side and Combined Effect of Hardness and Surface Roughness are given in Table 10. It has been observed that Surface roughness is better at advancing side to weld centre because there will be high torque and high friction at the starting, consequently high heat generation. Therefore, dispersion of metal is better compared to retreating side as the metal is getting solidified.

We can also notice from the Fig.6 that hardness is increased from advancing side to weld centre and decreasing towards retreating side.

**Table 10: Combined Effect of Hardness and Surface Roughness**

	<b>Sample 1 @ 1200rpm, 45mm/min</b>	<b>Sample 2 @ 1200rpm, 60mm/min</b>	<b>Sample 3 @ 1600rpm, 45mm/min</b>	<b>Sample 4 @1600rpm,60mm/min</b>

	Surface Roughness, Ra in $\mu\text{m}$	Hardness, HRB	Surface Roughness, Ra in $\mu\text{m}$	Hardness, HRB	Surface Roughness, Ra in $\mu\text{m}$	Hardness, HRB	Surface Roughness, Ra in $\mu\text{m}$	Hardness, HRB
Advancing Side	4.731	34.4	4.294	31.5	4.737	35.5	3.932	35
Weld Centre	6.232	47	3.552	42.6	5.129	40.2	4.692	42
Retreating Side	10.541	30.5	10.135	34.6	5.872	30	5.926	32

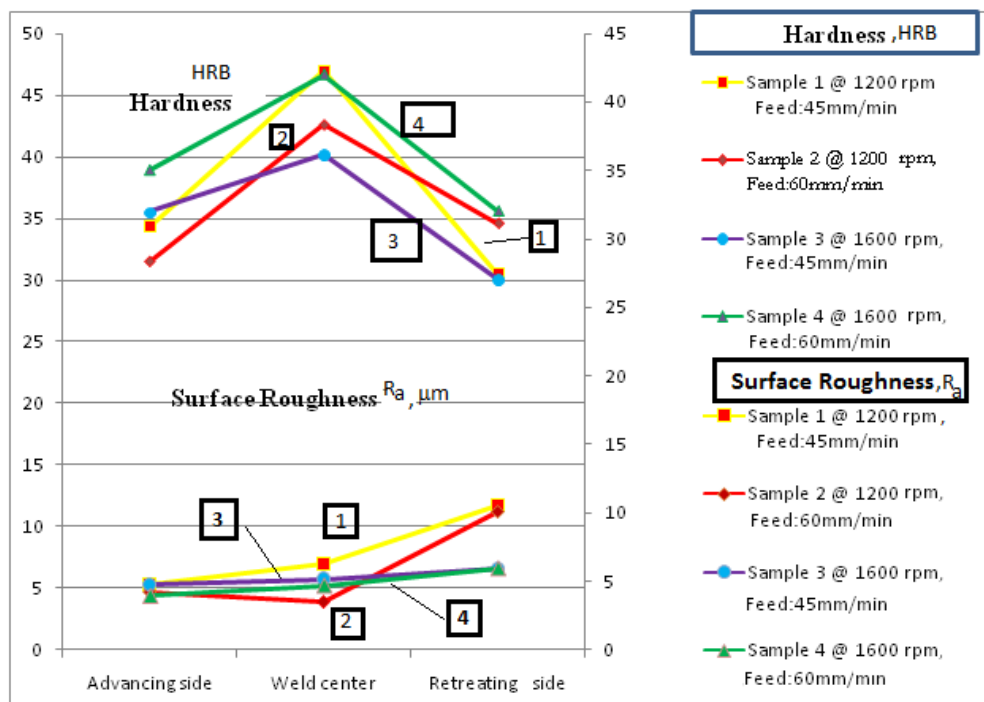


Figure 6: Showing Graph of Hardness Vs Surface Roughness

### 5.5 THREE POINT BEND TEST

Three Point bend tests have been performed and value of deformation and standard force has been noted and maximum force and maximum deformation have been obtained and are as shown in Table 11. Graphs of standard force versus deformation have been plotted and are shown in Fig. 7. A comparison has been made for deformation and standard force at different speeds and feeds. This was confirmed by AkshayValate et al [7] and Threadgill et al [8].

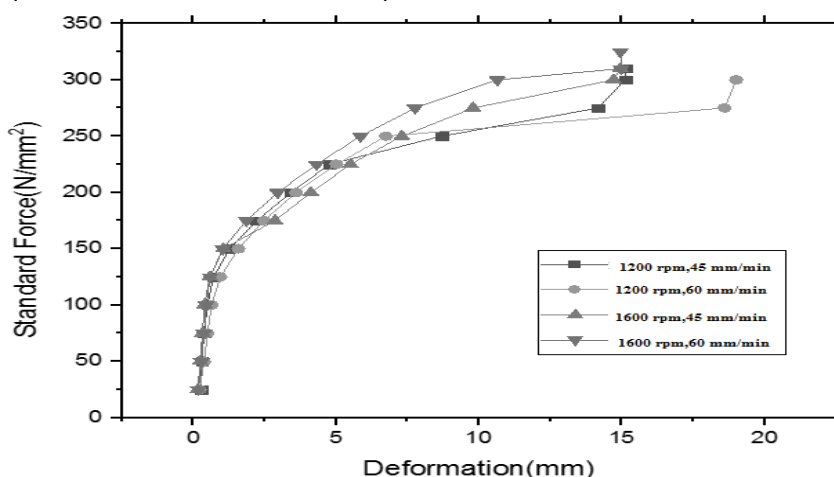
Table 11: Values of Deformation Vs Standard force for Samples 1,2,3and 4

Sample 1 at 1200rpm, 45mm/min		Sample 2 at 1200rpm, 60mm/min		Sample 3 at 1600rpm, 45mm/min		Sample 4 at 1600rpm, 60mm/min	
Deformation (mm)	Standard force(N/mm <sup>2</sup> )	Deformation (mm)	Standard force(N/mm <sup>2</sup> )	Deformation (mm)	Standard force(N/mm <sup>2</sup> )	Deformation (mm)	Standard force(N/mm <sup>2</sup> )

0.28	25.91	0.22	25.73	0.18	25.9	0.16	25.84
0.30	50.60	0.38	50.75	0.28	50.8	0.24	50
0.38	75.16	0.5	75.87	0.37	75.89	0.32	75.96
0.49	100.7	0.64	100.97	0.46	100.9	0.39	100.2
0.71	125.8	0.95	125.96	0.59	125.6	0.58	125.88
1.28	150.9	1.58	150.92	1.04	150.9	1.05	150.9
2.22	175.9	2.47	175.96	2.95	200.9	2.86	200.93
3.42	200.9	3.6	200.96	4.31	225.5	4.12	225.98
4.77	225.9	4.22	215.23	5.85	250.9	5.5	250.97
8.69	250.9	5.01	225.99	7.76	275.9	7.3	275.99
14.16	275.9	6.74	250.96	10.64	300.9	9.79	300.96
15.12	300.9	18.59	297.4	14.97	316.3	14.7	321.63
15.12	300.32	19	278	15	310	14.95	320.89

**4. Conclusion (10pt)**

Provide a statement that what is expected, as stated in the "Introduction" chapter can ultimately result in "Results and Discussion" chapter, so there is compatibility. Moreover, it can also be added the prospect of the development of research results and application prospects of further studies into the next (based on result and discussion).



**Figure 7: Deformation Vs Standard Force for Samples 1,2,3 And 4**

**6. APPLICATIONS**

The application areas are plenty such as Ship building, Marine Industries, Aerospace, Railway Industry, Land Transportation, Fuel tank for rockets, Hydro aluminum chassis etc.

**7. LIMITATIONS**

The limitations of this process are clearly evident since the absence of a filler metal; the process cannot be applied to fillet welds. The fully mechanized nature of the process may pose a problem where access or complex weld shape is best suited to a manual process. Welding speeds are reasonably slower as work pieces must be rigidly clamped. When welding materials of varying thickness, different length pin tools are required.

**8. SCOPE OF FUTURE WORK**

In the present work, the rotational speed, traversing speed and axial force are considered as main influencing parameters. Tool geometry, vibration and temperature effects can also be taken as influencing parameters.

The same welding procedure may be adopted for dissimilar materials. Microstructure can be analyzed for the joints. FEA can also be conducted to predict the strength of the joint.

## 9. CONCLUSIONS

The following conclusions are made HSS is chosen as tool material. A tapered cylindrical tool profile has been chosen for FSW because it gives more stirring effect and equiaxed grains in the weldment.

1. The weld joints made at rotational speed of 1600 rpm, traversing speed, of 60 mm/min have yielded maximum hardness when compared to other joints.
2. Initially, Hardness increases from advancing side till weld centre and decreases towards retreating side compared to the hardness of parent metal.
3. In Three Point Bend test, it is evident that as Speed and feed increases, deformation decreases. This is because of increase in hardness of the joint.

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