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Influence of Tool Profile on Friction Stir Welded Al-2014 Joints

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Abstract: Friction stir welding (FSW) is a solid-state joining process that uses a non-consumable tool to join two facing work pieces without melting the work piece material. The materials which can be joined using this welding are copper and its alloys, lead, magnesium and zinc. The materials used are Aluminium (2014) It is easily machined in certain temperatures, and among the strongest available aluminium alloys, as well as having high hardness. Electrolyte Copper enhances the qualities of copper as an electrical conductor. Electrical equipment often contains electrolytic copper.
Keywords: Aluminium, work piece, hardness, temperature, equipment.

I. INTRODUCTION

Friction stir welding is a solid state automatic process in which the joining is being done by specially designed non consumable rotating tool.Heat is generated by friction between the rotating tool and the workpiece material, which leads to a softened region near the FSW tool. While the tool is traversed along the joint line, it mechanically intermixes the two pieces of metal, and forges the hot and softened metal by the mechanical pressure, which is applied by the tool, much like joining clay, or dough. It is primarily used on wrought or extruded aluminium and particularly for structures which need very high weld strength. The tool consists of elements such as pin and shoulder that is rotated and travelled at certain speeds, which subsequently produces plastic deformation due to intense friction under the shoulder.

The deformed material inside the shoulder is swirled by pin and lead to the joint as tool is traveled. Hence, the tool pin profiles affect material flow, plastic deformation and temperature variation that consequently influence the properties of the joint. Different tool pin profiles such as cylindrical, triflute, trivex, conical, triangular, square, pentagonal, hexagonal, octagonal, thread-less and with threads have been reported in the literatures for different FSW systems.

Optimum pin profile depends on types of materials and variations in thicknesses.

The conventional fusion welding of aluminum and its alloys has always been a great challenge for designers and technologists. The difficulties associated with this kind of joints are mainly related to the presence of a tenacious oxide layer, high thermal conductivity, high coefficient of thermal expansion, solidification shrinkage, and high solubility of hydrogen and other gases in molten state. Friction stir welding joining technique has been shown to be viable for joining aluminum alloys, Cu, Ti, Mg, steel and plastics.The most important class of materials has been aluminium. A range of virtually all classes of aluminium alloys have been successfully friction stir welded. These include the 1xxx, 2xx, 3xxx, 4xxx, 5xxx, 6xxx and 7xxx alloys, as well as the newer Al-Li alloys.

Applications of aluminum 2 series include airplane fuselage, automobile chassis, body, engine blocks. Dissimilar materials like Cu-Al have special properties such as good thermal and electrical conductivities Therefore; it can be applied for applications such as bus-bars, connectors, foil conductors of transformers, windings of capacitors and condensers, refrigeration and heat-exchangers tubes, etc.

The defects formation is major factor in friction stir welding which includes onion rings, flash, tunnel defects, cracks and oids. FSW tool plays a major role to obtain quality join. It is mandatory to see the effect of tool design on formation of defects in dissimilar FSW system.

Materials: Aluminium 2014alloy is an aluminium based alloy often used in the aerospace industry.

It is easily machined in certain temperatures, and among the strongest available aluminium alloys as well as having high hardness. However it is difficult to weld as it is subjected to cracking.

2014 is the second most popular of the 2000- series aluminium alloys, after 2024 aluminium alloy as shown in fig.2.It is commonly extruded and forged.The corrosion resistance of this alloy is particularly poor.Aluminium (2014T6) is easily machined in certain temperatures, and among the strongest available aluminium alloys, as well as having high hardness.

Composition of aluminium

COMPONENT	WEIGHT PERCENTAGE
Al	90.4 – 95
Cr	Max 0.1
Cu	3.9 – 5
Fe	Max 0.7
Mg	0.2 - 0.8
Mn	0.4 - 1.2
Si	0.5 - 1.2
Ti	Max 0.15
Zn	Max 0.25

A. Tool geometry

Tool geometry is the most influential aspect of process development. The tool geometry plays a critical role in material flow and in turn governs the traverse rate at which FSW can be conducted

An FSW tool consists of a shoulder and a pin. As mentioned earlier, the tool has two primary functions: (a) localized heating, and (b) material flow. In the initial stage of tool plunge, the heating results primarily from the friction between pin and work piece. The tool is plunged till the shoulder touches the work piece. The friction between the shoulder and work piece results in the biggest component of heating. From the heating aspect, the relative size of pin and shoulder is important, and the other design features are not critical. The shoulder also provides confinement for the heated volume of material. The second function of the tool is to 'stir' and 'move' the material. The uniformity of microstructure and properties as well as process loads is governed by the tool design. With increasing experience and some improvement in understanding of material flow, the tool geometry has evolved significantly. Complex features have been added to alter material flow, mixing and reduce process loads. Tool geometry affects the heat generation rate, traverse force, torque and the thermo mechanical environment experienced by the tool. The flow of plasticized material in the work piece is affected by the tool geometry as well as the linear and rotational motion of the tool .Important factors are shoulder diameter, shoulder surface angle, pin geometry including its shape and size.

B. Tool Material Used In Friction Stirs Welding Joints

FSW, the tool profile mainly influences the mixing and recombining of the plasticized material. Process parameters and tool geometries affect the FSW forces which are important for heat generation. An important part of the tool is a pin (probe). Tool pin protrudes from the base of the tool shoulder and its length is marginally smaller than the plate thickness .Literature clearly indicates that researchers have employed different kinds of tool pin profile for their study.

Friction stir welding was carried out on similar AA2014 Vs AA2014 by two different tool designs. Present investigation provides an insight on formation of defects under the effect of different tool pin designs. The tool pin profiles such as hexagonal as shown in fig.1 and octagonal as shown in fig.2 were used in the present experimental investigation by keeping other parameters constant. These tool pin profiles were designed based on its static and dynamic constant areas from best suitable profile. Besides, the defects were analyzed through visual observation, macrostructure, microstructure investigation and scanning electron microscope. AA 2014-T6 materials of 5mm thickness were used to make but joint via friction stir welding technology. There were two different tool designs used in this experimental study, which was made up from tool H13 grade. Experimental part was divided into three set of experiments wherein hexagonal and tool pin profiles were used in first set of experiments. Pin diameter was 6 mm and in the second set of experiment octagonal tool was used by keeping same dimensions.Whereas the tool geometries which play an important role in friction stir welding include cylinder, taper, pin, threaded, internal taper etc. Wide varieties of heat flux to be produced also depend on tool geometry. The type of tool geometry to be used depends on the type of metals to be joined and other properties during welding.

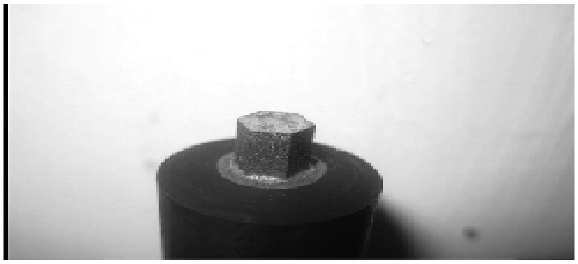

Fig.1: Hexagonal shaped tool

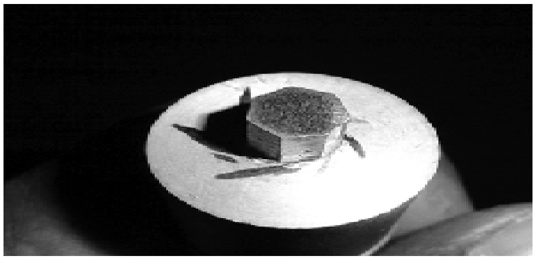

Fig.2: Octagonal shaped tool

The microstructure of the weld produced can be influenced by the interaction with the eroded tool material. The strength of the work material determines the stresses induced to the tool. Tool material properties influence the heat generation in the tool and thus the temperatures attained. Such properties like thermal conductivity are then important in tool material selection to attain particular properties in the final joint. Thermal stresses experienced in a tool are dependent on the coefficient of thermal expansion. Tool material selection may also be based on hardness, ductility and reactivity of the work materials.

C. Machine used for this Friction Stir Welding Project

Vertical milling machine was used in the friction stir welding of aluminium 2014 t6 . In place of milling cutter the hexagonal and octagonal tools were inserted for friction stir welding. Milling machines are very versatile. They are usually used to machine flat surfaces, but can also produce irregular surfaces. They can also be used to drill, bore, cut gears, and produce slots. The type of milling machine most commonly found in student shops is a vertical spindle machine with a swivelling head. Although there are several other types of milling machines, this document will focus only on the vertical milling machine.
The tool can be fed up and down with a quill feed lever on the head. The bed in which the materials for welding are placed is moved in a horizontal plane. Once an axis is located at a desired position it is locked into position with the gibb locks. Most milling machines are equipped with power feed for one or more axes. Power feed is smoother than manual feed. Power feed also reduces operator fatigue on long cuts. On some machines, the power feed is controlled by a forward reverse lever and a speed control knob. The head of a vertical milling machine can be tilted from side to side and from front to back. This allows for providing various tilt angles.

D. Specifications

Overall dimensions (LxW)	mm	1520x310
Clamping area (LxW)	mm	1350x310
Power operated table traverses Longitudinal Cross Vertical	mm mm mm	800 265 400
Max. safe weight on table	kg	350(H&V), 250(U)
Number of speeds		18

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Speed range	rpm	35.5-1800
Main Motor	kW/rpm	5.5/1500
Feed Motor	kW/rpm	1.5/1500
Space required (LxBxH)	mm	255x250x207(H) 255x196x197(V) 255x313x201 U)
Packing Case (LxWxH)	cm	230x195x210
Weight-Net / Gross	kg	2400 / 3200 (H) 2500 / 3300 (V&U)

II. EXPERIMENTAL PROCEDURE

A. *Welding Of Aluminium 2014 T6 By Hexagonal Tool*

1) Two base metals of aluminum 2014-T6plate of 5mm thick and size 200 mm x 100 mm were welded by stirring them together with a hexagonal tool as shown in fig. 6a by using vertical milling machine. The aluminum plates are butt jointed.
2) H-13 tool steel is chosen as tool material because of its high strength at elevated temperature, thermal fatigue resistance and low wear resistance. The diameter of the shoulder and pin used were 24mm, 8mm respectively and length of the pin is 2.8mm.
3) Explanation of Friction Stir Welding Employed in this Study: A rotating pin is plunged into the aluminum. The feed given to the tool was 31mm/min and the tool is rotated at 1120 rpm. The rotating pin is pushed toward the faying surface of the aluminum plate and, consequently, the oxide film is mechanically removed from the faying surface by the rubbing motion of the rotating pin .Aluminum, which is in a fluid-like plastic state due to the heat generated by the friction of the rotating tool shoulder, adheres to the activated faying surface of the aluminum, so that joining between two aluminum plates is achieved .Welding by FSW is ordinarily completed through stirring by a rotating pin inserted around the center of the weld interface of lap base plates.
4) After welding, samples for determining tensile strength as shown in fig.6b, impact strength as shown in fig.6c, hardness as shown in fig.6d and microstructure are machined from the welded sample.

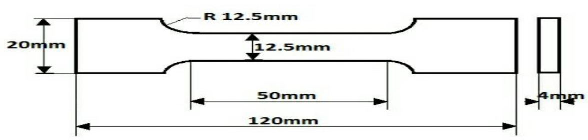

Fig.3: Tensile test specimen

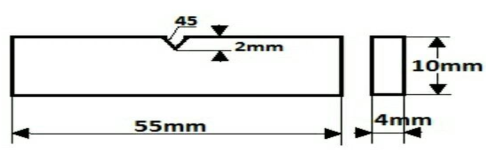

Fig.4: Impact test specimen

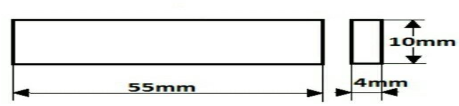

Fig.5: Hardness test specimen

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III.RESULTS AND DISCUSSIONS

A. *Hexagonal Tool*

1) *Aluminum 2014 T6:* Successfully joints were obtained by FSW processes for the all the process parameters used in the investigation. Typical example of FS welds is shown

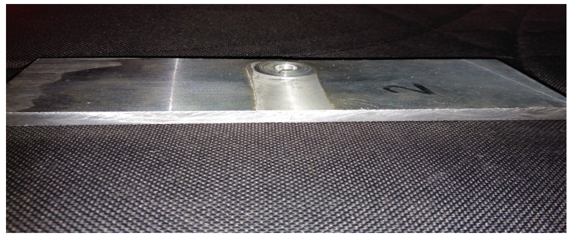

Fig.6:FSW joint of AA2014 T6

The surfaces of the weld are seen at the process condition of 1200rpm, 31mm/min of feed and 1^0 tilt angle. Usually, the FSW process leaves a pin hole at the weld end, as seen in Figure and the design of the weld is done in such a way that the part with the hole is cut and not used for further processes. The mechanical properties of AA 2014 t6 alloy FSW joints of such ultimate tensile strength, percentage of elongation and hardness are evaluated. At each condition three specimens are tested and average of the results of three specimens is presented.

The tensile strength of the welded aluminium 2014 t6 joint performed in UTN-40 was found to be 120.00N/mm^2 (taking average of 3 values of tensile strength) by using hexagonal tool profile. The percentage elongation of the specimens was found to be 1.18(taking average of 3 values of elongation).

Ref. No: REQUEST FORM **Ref. Date:** 03.03.17

Identification: ALUMINIUM 2014 WELD PLATE SAMPLE -1

Sample No : 1
Test Procedure : ASTM B 557:2006
Material Specification : AL ALLOY 2014

Stamped As:

Input Data			Results			Specified Values
Specimen Type	:	Flat	Ultimate Load	kN :	11.360	
Specimen Width	mm :	13.05	Ultimate Tensile Strength	N/mm² :	145.083	
Specimen Thickness	mm :	6	Elongation	% :	1.560	
C/S Area	mm² :	78.3	Yield Load	kN :	7.400	
Original Gauge Length	mm :	50	Yield Stress	N/mm² :	94.508	
Final Gauge Length	mm :	50.78				

Ref. No: REQUEST FORM **Ref. Date:** 03.03.17

Identification: ALUMINIUM 2014 WELD PLATE SAMPLE -2

Sample No : 2
Test Procedure : ASTM B 557:2006
Material Specification : AL ALLOY 2014

Stamped As:

Input Data			Results			Specified Values
Specimen Type	:	Flat	Ultimate Load	kN :	7.880	
Specimen Width	mm :	12.86	Ultimate Tensile Strength	N/mm² :	102.125	
Specimen Thickness	mm :	6	Elongation	% :	0.800	
C/S Area	mm² :	77.16	Yield Load	kN :	6.800	
Original Gauge Length	mm :	50	Yield Stress	N/mm² :	88.129	
Final Gauge Length	mm :	50.4				

Ref. No: REQUEST FORM **Ref. Date:** 03.03.17

Identification: ALUMINIUM 2014 WELD PLATE SAMPLE -3

Sample No : 3
Test Procedure : ASTM B 557:2006
Material Specification : AL ALLOY 2014

Stamped As:

Input Data			Results			Specified Value
Specimen Type	:	Flat	Ultimate Load	kN :	8.760	
Specimen Width	mm :	12.95	Ultimate Tensile Strength	N/mm² :	112.741	
Specimen Thickness	mm :	6	Elongation	% :	1.200	
C/S Area	mm² :	77.7	Yield Load	kN :	6.520	
Original Gauge Length	mm :	50	Yield Stress	N/mm² :	83.912	
Final Gauge Length	mm :	50.6				

The hardness of the weld of aluminium 2014 t6 using hexagonal tool by applying a load of 250 kgf by a RAB-250 brinell hardness test machine was found to be 92.7BHN(taking average of 3 values).

Ref.No: REQUEST FORM **Ref. Date:** 03.03.17

Machine Details
Name : BRINELL HARDNESS
Model No/Srl.No : 15/08/014 RAB-250
Calibration on Date : 01.10.2016
Calibration Due Date : 30.09.2017

Test Details
Test Procedure : IS 1500:2005
Type of Hardness : BHN
Indentor : 5 mm
Load Applied : 250 **Kgs**

Sl.No	Location	Observed Values in BHN			
		Impression 1	Impression 2	Impression 3	Average
1	WELD ZONE SAMPLE NO : 1	95.0	93.9	95.0	94.63
2	WELD ZONE SAMPLE NO : 2	96.1	95.0	97.2	96.10
3	WELD ZONE SAMPLE NO : 3	84.9	85.8	86.8	85.83

The energy the weld of aluminium 2014 t6 can absorb before fracture performed in KI-300 was found to be 6.6 joules using hexagonal pin profile.

Ref No: REQUEST FORM Order No: -- **Ref. Date:** 03.03.17

Machine Details
Equipment Used : KRYSTAL ELMEC
Srl.No : 2006/912 KI-300
Calibration on Date : 10.09.2016
Calibration Due Date : 09.09.2017

Test Procedure : IS 1757-1988
Type of Impact : CHARPY - V
Notch Depth : 2mm
Notch Angle: : 45°
Specimen Size : 10 x 5 x 55 mm
Impact Test Temp : At Room Temperature

Sl.No	Location of the Sample	Observed Values (Joules)			
		Impact 1	Impact 2	Impact 3	Average
1	WELD ZONE SAMPLE NO : 1	6	0	0	6.00
2	WELD ZONE SAMPLE NO : 2	8	0	0	8.00
3	WELD ZONE SAMPLE NO : 3	6	0	0	6.00

The microstructure of the weld of aluminium 2014 T6 was inspected in an area 0.5005mm^2 under ASTM E 112. The microstructure was found to be Equi axed grains and scripted like structure and grain size was found to be 5.5.

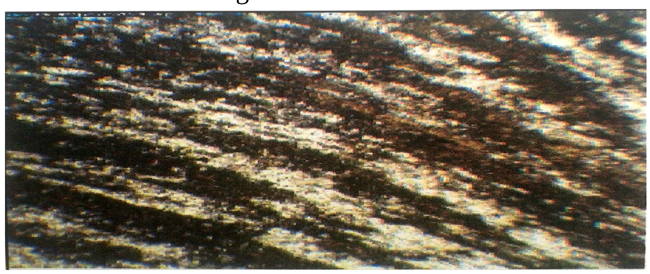

Fig.7: Microstructural view of AA 2014T6 FSW joint

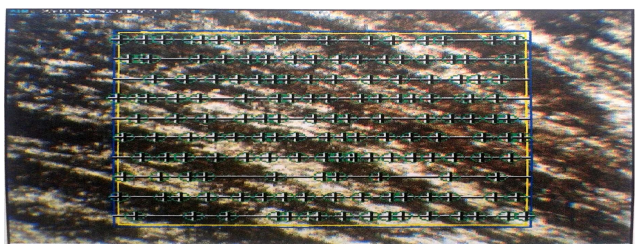

Fig.8: Microstructural view of AA 2014T6 FSW joint

GrainSize analysis :Results Summary

Fields measured	1
Analysed Area	.5005 sq mm
Standard used	ASTM E 112

	Grain size#
ASTM Grain size#	5.5
Intercepts	139
Mean Int.length(um)	50.9
Std dev.	-
95% CI	-

B. Octagonal Tool

1) *Aluminum 2014 T6:* Successfully joints were obtained by FSW processes for the all the process parameters used in the investigation. Typical example of FS welds is shown

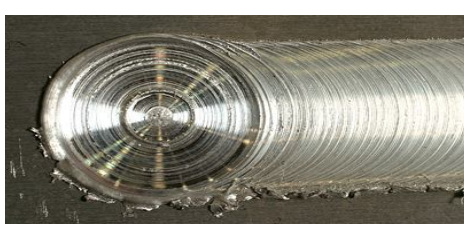

Fig.9:FSW joint of AA 2014T6 by octagonal tool

The surfaces of the weld are seen at the process condition of 1120rpm, 31mm/min of feed and 1^0 tilt angle. Usually, the FSW process leaves a pin hole at the weld end, as seen in Figure and the design of the weld is done in such a way that the part with the hole is cut and not used for further processes. The mechanical properties of AA 2014 t6 alloy FSW joints of such ultimate tensile strength, percentage of elongation and hardness are evaluated.

The tensile strength of the welded aluminium 2014 t6 joint performed in UTN-40 was found to be 225.69N/mm^2 by using octagonal tool profile. The percentage elongation of the specimens was found to be 1.96.

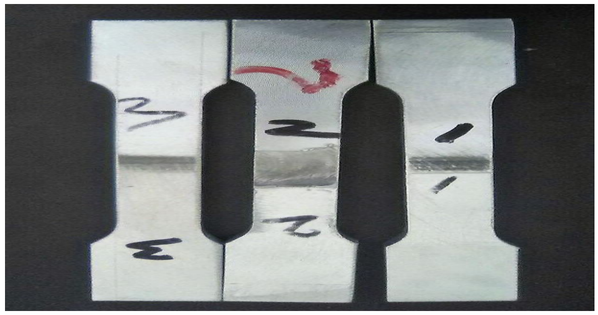

Fig.10:Tensile test specimen of AA 2014T6

Input Data			Results		
Specimen Type	:	Flat	Ultimate Load	kN :	15.880
Specimen Width	mm :	11.63	Ultimate Tensile Strength	N/mm² :	225.696
Specimen Thickness	mm :	6.05	Elongation	% :	1.960
C/S Area	mm² :	70.362	Yield Load	kN :	10.800
Original Gauge Length	mm :	50	Yield Stress	N/mm² :	153.496
Final Gauge Length	mm :	50.98			

The hardness of the weld of aluminium 2014 t6 using octagonal tool by applying a load of 250 kgs by a RAB-250 brinell hardness test machine was found to be 95.80BHN(taking average of 3 values).

Machine Details		Test Details	
Name	: BRINELL HARDNESS	Test Procedure	: IS 1500:2005
Model No/Srl.No	: 15/08/014 RAB-250	Type of Hardness	: BHN
Calibration on Date	: 01.10.2016	Indentor	: 5 mm
Calibration Due Date	: 30.09.2017	Load Applied	: 250 Kgs

Sl.No	Location	Observed Values in BHN			
		Impression 1	Impression 2	Impression 3	Average
1	WELD ZONE	95.0	96.1	96.3	95.80
	Specified Values:	--			

The energy the weld of aluminium 2014 t6 absorbed before fracture performed in KI-300 was found to be 12 joules using octagonal pin profile.

Machine Details		**Test Procedure**	: IS 1757-1988
Equipment Used	: KRYSTAL ELMEC	**Type of Impact**	: CHARPY - V
Srl.No	: 2006/912 KI-300	**Notch Depth**	: 2mm
Calibration on Date	: 10.09.2016	**Notch Angle:**	: 45°
Calibration Due Date	: 09.09.2017	**Specimen Size**	: 10 x 5 x 55 mm
		Impact Test Temp	: At Room Temperature

The microstructure of the weld of aluminium 2014 t6 was inspected in an area 0.5005mm^2 under ASTM E 112. The microstructure was found to be equi axed grains and scripted like structure and grain size was found to be 5.5.

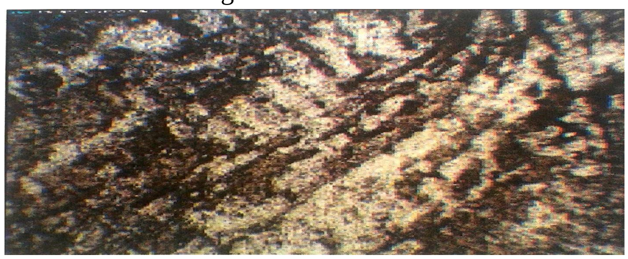

Fig.11**:**microstructural view of AA 2014T6

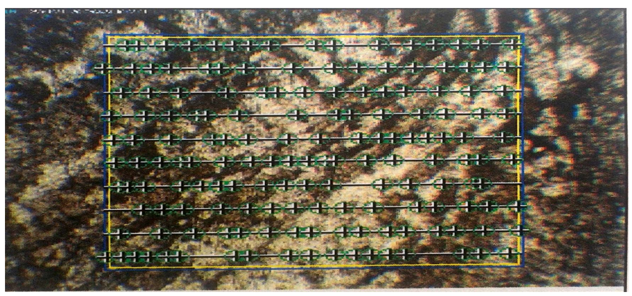

Fig.12**:** microstructural view of AA 2014T6

GrainSize analysis :Results Summary

Fields measured	1
Analysed Area	.5005 sq mm
Standard used	ASTM E 112

	Grain size#
ASTM Grain size#	5.5
Intercepts	139
Mean Int.length(um)	50.9
Std dev.	-
95% CI	-

IV. CONCLUSION

The following conclusions were drawn from the experimental study of friction stir welded joints using both hexagonal and octagonal tool.

A. When the tool is changed from hexagonal to octagonal, the tensile strength, hardness of weld and impact absorbed by welded joint increases in aluminium 2014 t6. However, the grain size in both the cases remained the same and is equal to 5.5.

B. The tensile strength was increased from 120N/mm^2 to 225.69N/mm^2, hardness from 92.7BHN to 95.80BHN and impact absorbed from 6.6 joules to 12 joules in aluminium 2014 t6 welded joint.

C. So, it can be concluded that has no. of sides of tool in a friction stir welding increases(keeping other parameters like speed of tool, feed of tool and shoulder diameter constant), the mechanical properties of aluminium joint is increased.

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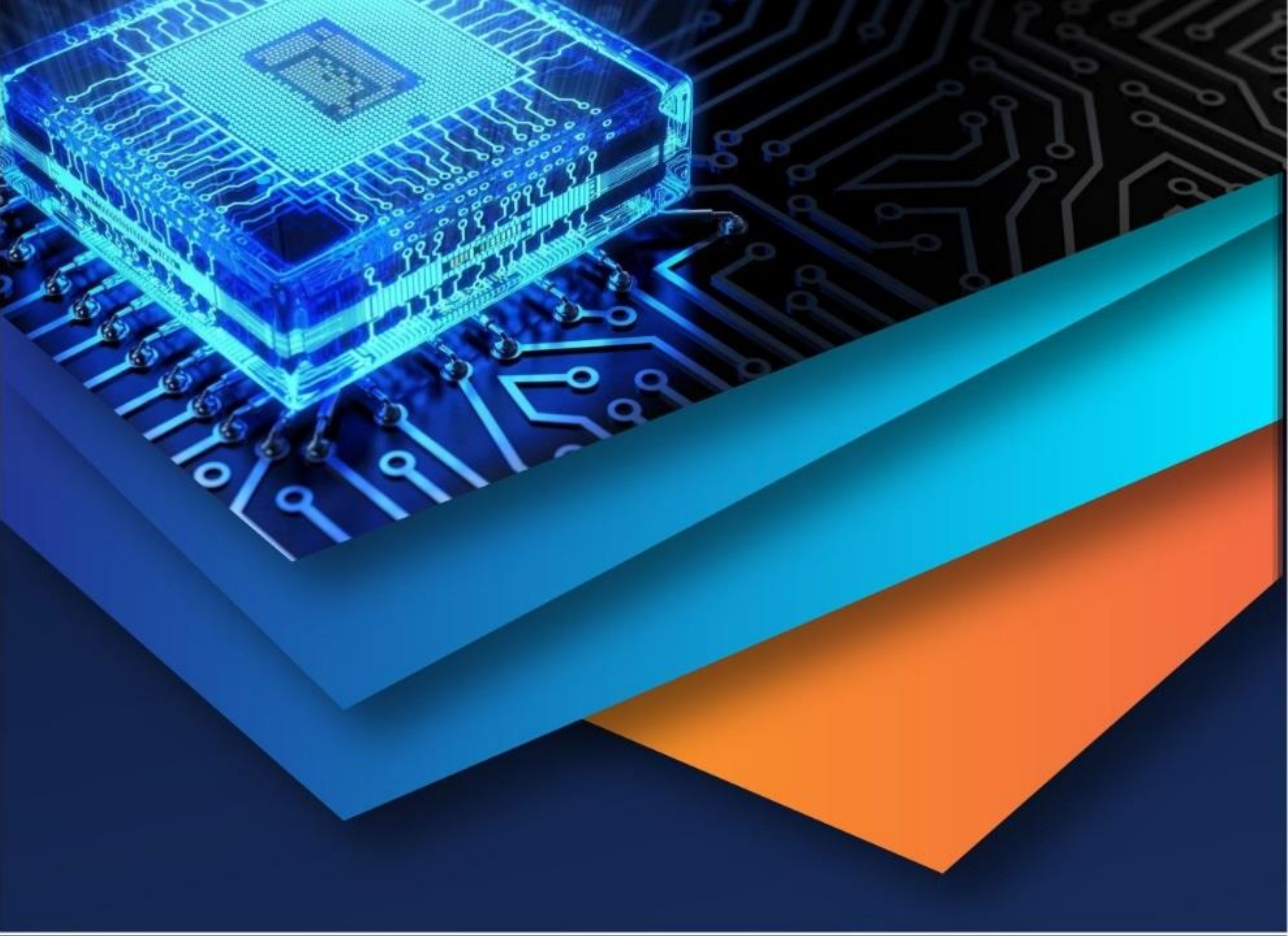

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