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Experimental Analysis of AL6061 based Aluminium Metal Matrix composite by FSW

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Abstract: Friction stir welding (FSW), a highly efficient solid-state joining technique used for coalescence of metals with different melting points. Metal matrix composite, in particular can eliminate some welding defects such as crack and porosity. Aluminum matrix composites are gaining increasing attention for applications in aerospace, defense and automobile industries. The use of aluminum metal matrix composites has generated considerable interest as the manufacturing of complicated contours such as dies.

This approach is energy efficient , the environment friendly, easy and defect free welding process. Fabrication of components with vast difference in mechanical, thermal and electrical properties is a challenging task to weld in gas or other normal type of welding.

Heat is required to weld and due to the low melting point of aluminum (660^{o}C), it required minimum amount of heat to weld, so due to heat affected zone in the welded component increases loses its mechanical and thermal properties. Here the rotation speed of spindle, feed rate and pin depth or chosen as process parameters, to investigate the mechanical performance and analysis of the friction stir welding in the Al 6061 reinforced material. The tensile test conducted for four work pieces with varying process parameters, the high rotation speed, medium feed rate and reasonable pin depth gives good quality of weld.

Keywords: FSW, Aluminium matrix, Fabrication, Thermal Properties, Quality of weld

I. INTRODUCTION

A. Friction Stir Welding

Friction stir welding (FSW) is a solid state joining process that uses a non-consumable tool to join two facing workpieces without melting the workpiece materials. Heat is created by friction between the rotating tool and the material of the workpiece which leads to a softened region close to the FSW tool.

While the tool is traversed along the joint line, it mechanically intermixes the two piece of metal, and forges the hot and softened metal by the mechanical pressure, which The device is added, just like joining clay, or dough. It is primarily used on wrought or extruded aluminum and particularly for structure which need very high weld strength.Friction stir welding (FSW) is comparably a new welding process which was developed by The Welding Institute, Cambridge, UK in 1999.

This is a solid state welding process utilizing a specially designed tool to achieve a joint.The tool is made up of a shoulder and pin.The rotating tool is plunged along the intersection of two metal plates which are rigidly fixed on a backing plate.FSW process is shown as shown in the Figure 1.1.

When the upper surface of the plates comes in contact with the shoulder surface the friction is developed. Plastic metal deformation occurs along the weld path at the joint region. This is influenced by the combined action of shoulder and pin.

The pin creates a stirring movement at the intersection area, and then moves metal from the advancing side to the withdrawing side and vice versa. The plates to be joined are to be clamped tightly to the machine bed.Faying surface melting is not required in this process for achieving a joint.Filler metal, shielding gas, flux etc are not used in this process.The primary experiments with Friction stir welding were on aluminum and its alloys.

Later successful welds achieved on Magnesium and its alloys. Still researches are underway to establish this process on the primarily used industrial metal, steel. The FSW process generates three distinct microstructural zones: the nugget, the thermomechanically affected zone (TMAZ) and the heat-affected zone (HAZ).The nugget is the region through which the tool pin passes, and thus experiences high deformation and high heat.

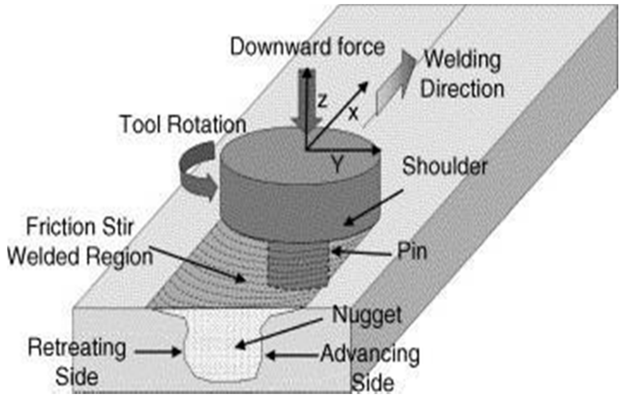

Figure 1.1 FSW process

It generally consists of fine equi-axed grains due to full recrystallisation. The TMAZ adjacent to the nugget is the region where the metal is plastically deformed as well as heated, but this is not sufficient to cause recrystallisation. action of the pin. Frictional heat produced by the tool makes the plastic deformation of material and grain boundary sliding. Excessive heat formation leads to tool wear which result in loss of material in the tool

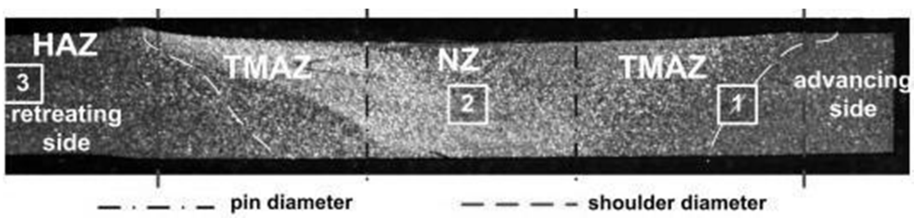

Figure 1.2 Microstructure of FSW weld

Loss of tool material will be formed as an inclusion in the weld region. Feed rate, material flow and heat transfer favors the tool wear to emerge along the weld direction. Tool wear can be reduced by preheating the work piece and by choosing appropriate tool material for the particular work piece.

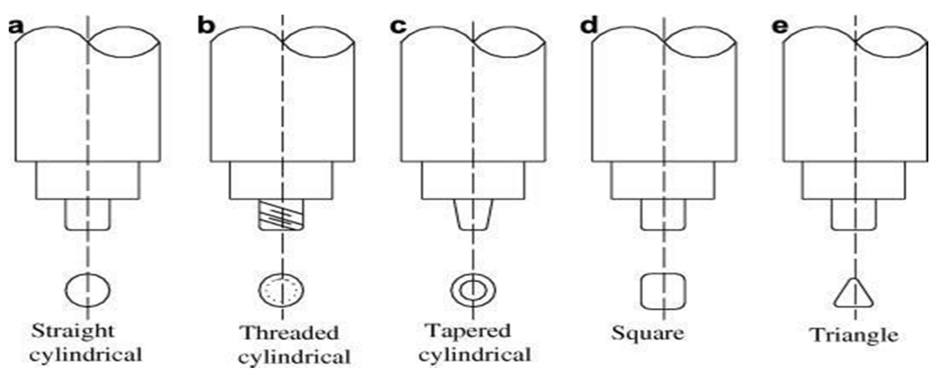

Figure 1.3 Different tool pin profiles

The tool for FSW was initially used with threaded pin. The compaction of plasticized material is given by the bottom of the tool shoulder and prevents the material from escaping. The shoulder has different profile such as flat, concave, smooth or grooved, with concentric or spiral grooves. A concave shoulder has the advantage over flat shoulder because of directing material flow to the centre close the pin. A Grooved Instead of a smooth edge, it has the same effect Based on the thickness of the plates to be welded the application of tool pin profile varies. The different shapes of tool profile are as shown in Figure 1.3. As an example for a commercial aluminium plate tool shape of cylindrical pin having both pin with threaded and without threaded can be applied. The formation of friction stir welded joints is mainly depended on the tool shapes and size.

B. Two Modes Of Metal Transfer

The fluid flow at the bottom of the shoulder and the pin is impacted. The first mode of transferring metal is by shoulder while the second mode of transfering metal is attributable to pin. When the tool rotates the work piece is touched by the hand, friction heat is produced, and plastic deformation occurs at the weld zone. When the material flow occurs around the shoulder and pin area, the compaction of the material is due mainly to the shoulder and this determines the first mode of metal transfer. This prevents defect formation in weld region, thus increasing its tensile strength. Metal-flow extrusion is affected by the pin's stirring behavior. Layer by layer of material flow occurs at the top region as shown in Figure 1.4, while pattern of the onion ring is observed below the layers as shown in Figure 1.5.

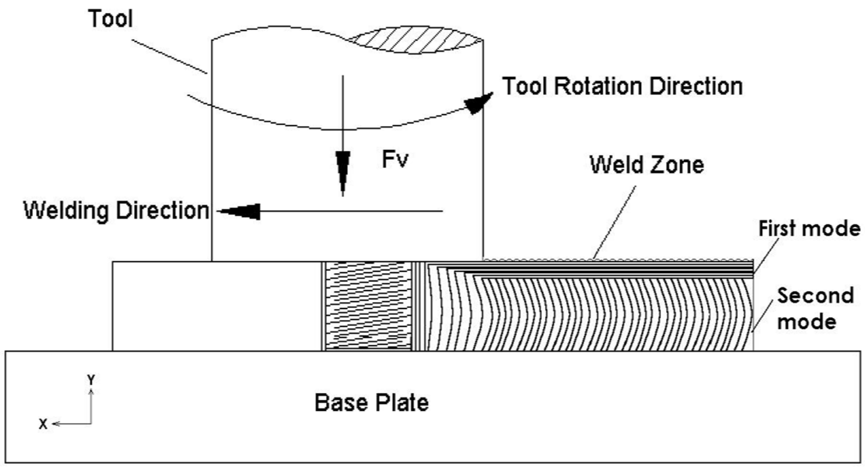

Figure 1.4 Two modes of metal transfer

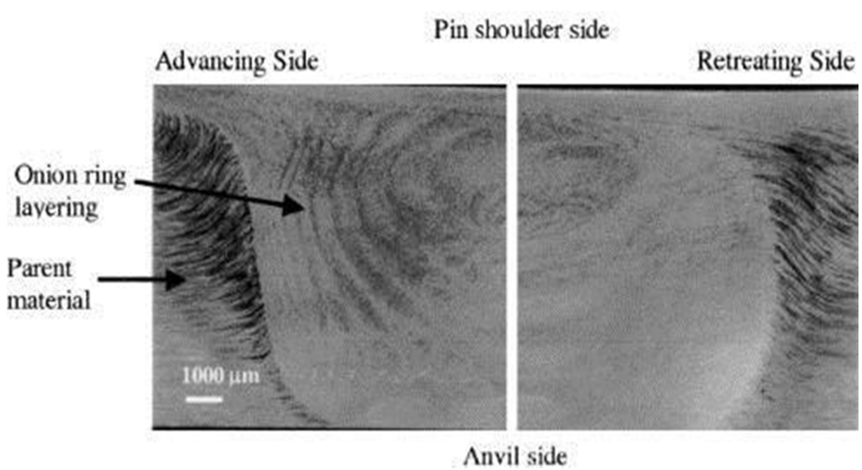

Figure 1.5 Onion ring pattern

When the material flow occurs around the shoulder and pin area, the compaction of the material is due mainly to the shoulder and this determines the first mode of metal transfer. This prevents defect formation in weld region, thus increasing its tensile strength. Metal-flow extrusion is affected by the pin's stirring behavior. Layer by layer of material flow occurs at the top region as shown in Figure 1.4, while pattern of the onion ring is observed below the layers as shown in Figure 1.5. Second mode of metal transfer is a combined effect of both material flow layer by layer and extrusion of material in plasticized condition. When macro structural observation on the specimen is carried out perpendicular to the weld direction concentric ring patterns were observed. The structure resembles the onion ring pattern and hence the mechanism of flow patter is named as “onion ring The cumulative effect of the effects of two metal transfer modes for making the onion rings. At each rotation of the tool screw, the extrusion of material and shoulder compaction together establish the structure of the onion rings.

C. Weld Parameters of FSW

For FSW, two parameters are very important: tool rotation rate (v, rpm) in clockwise or counter clockwise direction and tool traverse speed (n, mm/min) along the line of joint. The motion of the tool generates friction..

1) Tool rotation speed
2) Feed rate
3) Pin depth

Therefore, the tool rotation speed, feed rate, pin depth and the tool design are the main independent variables that are used to control the FSW.

D. Tool Rotation and Traverse Speed

Addition to the tool rotation rate and traverse speed, another important process parameters are tool tilt with respect to the work piece surface and plunge depth. A good tilt of the spindle toward the trailing direction ensures that the tool's shoulder retains the stir material by threaded pin and effectively pushes material from the front to the back of the pin. The tool normally has a low tilt angle and when it is inserted into the sheets, the blank material undergoes a local backward extrusion process up to the shoulder of the tool

E. Tool Pin Profile

There is various type of tool pin which is used for the welding process. The main parameters are tool configuration such as probe length, probe shape and shoulder size because it would affect the heat generation and the flow of plastic material. The tool is an important part of this welding process. It is composed of a pin and a shoulder. Pin profile plays a crucial role in material flow and in turn regulates the welding speed of the FSW process.The shoulder generates most of the heat and prevents the plasticized material from escaping from the work piece, while both the shoulder and tool pin affect the material flow.Friction stir welds are characterized by well-defined weld nugget and flow contours, almost spherical in shape, these contours are dependent on the tool design and Welding of parameters and conditions of the operation. The square pin will be used for our welding operation, which can be used to weld copper and aluminum together more effectively. The tool pin plays the important role in friction stir welding process. For this method the tool that is chosen is the square pin tool. Because it is the most efficient tool pin to join the two dissimilar material of various range of melting temperature

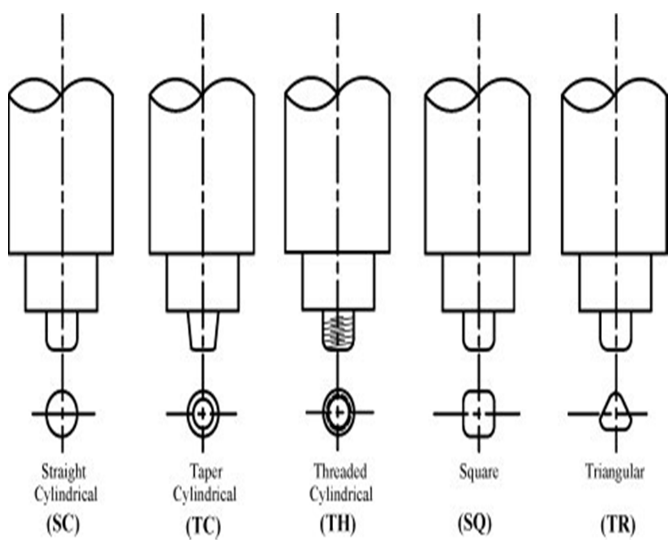

Figure 1.5 FSW Tool pin profiles

F. Aluminium

Aluminum is a chemical element with an Al symbol and an atomic number 13. In the boron group it is a silvery-white, strong, non-magnetic, and ductile metal. By mass, aluminum makes up about 8% of the Earth's crust; it is the third most abundant element after oxygen and silicon and the most abundant metal in the crust, though it is less common in the mentle below. The chief ore of aluminum is bauxite. Aluminum metal is so chemically reactive that native specimens are rare and limited to extreme reducing environments. Instead, it is found combined in over 270 different minerals.

G. Types of Aluminum Grades

1) Aluminum Alloy 1100 – Excellent Formability/Workability
2) Aluminum Alloy 2011 – Good Formability/workability
3) Aluminum Alloy 2024 – Good Formability/Workability
4) Aluminum Alloy 3003 – Excellent Formability/Workability
5) Aluminum Alloy 5052 – Good Formability/Workability
6) Aluminum Alloy 6061 – Good Formability/Workability
7) Aluminum Alloy 6063 – Good Formability/Workability
8) Aluminum Alloy 7075 – Poor Formability/Workability

H. Properties of Aluminum 6061

1) The mechanical properties of 6061 depend greatly on the temper, or heat treatment, of the material.
2) Un-heat-treated 6061 has maximum tensile strength no more than 130 MPa (19,000 psi), and no specified maximum yield strength.
3) The material has elongation (stretch before ultimate failure) of 18%.
4) T1 temper 6061 has an ultimate tensile strength of at least 120 MPa (17,00 psi) in thicknesses up to 12.7mm, and 110 MPa (16,000 psi) from 30 to 25mm thick, and yield strength of at least 62 MPa (9,000 psi) in thickness up to 13 millimeters (0.5 in) and 55 MPa (8,000 psi0 from 13mm (0.5 in) thick.
5) It has the elongation of 12%

Table 1.8 Chemical composition of Al 6061 Alloy

Elements	Minimum (% wt)	Maximum (% wt)
Silicon (Si)	0.2	0.6
Iron (Fe)	0	0.35
Copper (Cu)	0	0.10
Manganese (Mn)	0	0.10
Nickel (Ni)	0	0.05
Zinc (Zn)	0	0.10
Titanium (Ti)	0	0.15
Tin (Sn)	0	0.001
Magnesium (Mg)	0.45	0.90
Chromium (Cr)	0	0.10
Aluminium (Al)	99.35	97.54

II. EXPERIMENTAL DETAILS

A. Stir Casting Process

Stir casting is a liquid state process for the manufacture of composite materials, whereby a dispersed layer (ceramic particles, short fibers) is mixed with a molten matrix metal by mechanical stirring. The liquid composite material is then casted using traditional casting methods and can be processed using modern metal forming techniques as well. The FSP is used when metals properties want to be improved using other metals for support and improvement of the first. This is a promising step for the automotive and aerospace industries in which new technology would need to be developed to improve wear, creep and fatigue resistance. Several of the considerations that require considerable attention are as follows in the preparation of metal matrix composites by stir casting process,

1) Achieving uniform distribution of the reinforcement content
2) Achieving wettability between the two main substances
3) Minimizing porosity in the cast metal matrix composite

2.1 Specification Of Stir Casting Apparatus

Casting temperature	1500°C
Voltage	240 V
Current	16 A
Stirring speed	300 rpm
Preheating temperature	950°C

B. Process Parameters

The current calculated value of a particular part of a process that is being tracked or managed is a process variable, process value, or process parameter.

1) *Stirrer Design:* The parameter which is needed for vortex formation is very significant in the stir casting process. The angle of the blade and the number of blades determine the liquid metal flow pattern. The stirrer is immersed in molten metal until two thirds deep. All of these are required for uniform distribution of reinforcement in liquid metal, perfect interface bonding, and clustering avoidance.
2) *Stirrer Speed:* Stirring speed is an important parameter for fostering matrix binding and reinforcement, i.e. wettability. Stirring speed determines vortex formation which is responsible for particulate dispersal in liquid metal. In our project the speed of stirring is 300 rpm
3) *Stirring Temperature:* Aluminium melts around 650°C, at this temperature semisolid stage of melt is present. Particle distribution depends on change in viscosity. The viscosity of matrix is mainly influenced by the processing temperature. The viscosity of liquid is decreased by increasing processing temperature with increasing holding time for stirring which also promote binding between matrix and reinforcement. Good wettability is obtained by keeping temperature at 800°C
4) *Stirring Time:* Stirring facilitates uniform partial reinforcement distribution and interface bonding between matrix and reinforcement, stirring time plays a vital role in stir casting process. More stirring results in non-uniform particle distribution and excess stirring causes at certain places clustering of particles. Stirring time is 20 seconds in our case
5) *Preheat Temperature Of Reinforcement:* ***Due to very low wettability of alumina particles*** and agglomeration phenomenon that results in non-uniform distribution and poor mechanical properties, the casting process of AMC's is difficult. For 40 minutes the reinforcement is heated up to 500 ° C. This eliminates all moisture and gases that are involved in strengthening.

C. Selection Of Tool

There are various type of the tool used in the process of the friction stir welding process. In this friction stir welding process the square pin type tool is used. The tool is selected from the paper that has been viewed during the literature survey. The tool used in the friction stir welding process in non-consumable. Tool pin profile influences heat generation, plastic flow, the power required, and the uniformity of the welded joint Tool geometry such as the length of the probe, the width of the probe and the shoulder size are important parameters as it will affect the heat generation and the flow of plastic material. The machine is an important part of the process of welding. This is made of a pin and a hand. Pin profile plays a critical role in material flow and in effect controls FSW process welding speed. The shoulder produces much of the heat and prevents the plasticized material from escaping from the work piece, while the material flow is influenced by both the shoulder and the tool pin. Friction stir welds are characterized by well-defined nugget welding and flow contours, nearly square,

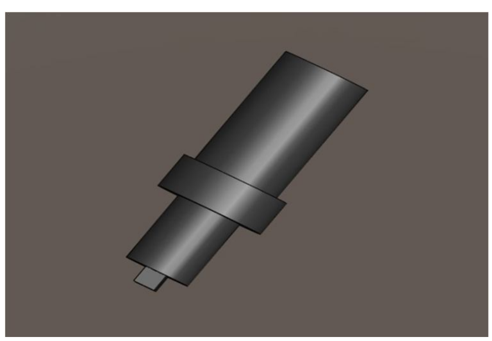

Figure 2.3 3d Diagram of square Tool

D. *Friction Stir Welding Parameters*

The joining that uses friction generated by a rotating cylindrical tool to heat plasticize metal on either side of a joint. Metals and metal alloy than other forms of fusion welding, FSW can be a much slower process.

Table 2.4 Friction stir welding parameters

Speed	1000	1200	1400	1600
Pin Depth	4.3	4.4	4.5	4.6
Tool Rotation	3mm	6mm	9mm	12mm

E. *Wire Cut EDM*

Electrical Discharge Machining (EDM) is a process of metal machining in which a tool discharges thousands of sparks to a metal workpiece. A non-conventional process, EDM works on parts resistant to conventional machining processes, but only if these parts are electrically conductive; usually, they are non-ferrous, and include steel, titanium, super alloys, brass, and many other metals. Wire cut EDM equipment is run by computer numerically controlled (CNC) instruments, which can control the wire on a three-dimensional axis to provide greater flexibility. Wire cut EDM is able to cut metals as thin as 0.004”. At a certain thickness, wire EDM will simply cause the metal to evaporate, thereby eliminating potential debris.

Figure 2.5 Wire cut EDM

III. PROBLEM IDENTIFICATION

The work based on the effect of tool pin profile on aluminium and copper weld in friction stir welding is rarely found in the literatures. Friction stir welding can be done by using the vertical milling machine and considering the process parameters tool rotational speed, feed rate, and pin depth as constant. And high carbon steel tool (EN 31) is to be used. For the present work round tool pin profile is used. Then hardness and tensile tests are carried out on the work piece.

A. *Objectives of The Project Work*

To weld the aluminium using friction stir welding with suitable process parameters and to perform tensile tests on the welded work piece.

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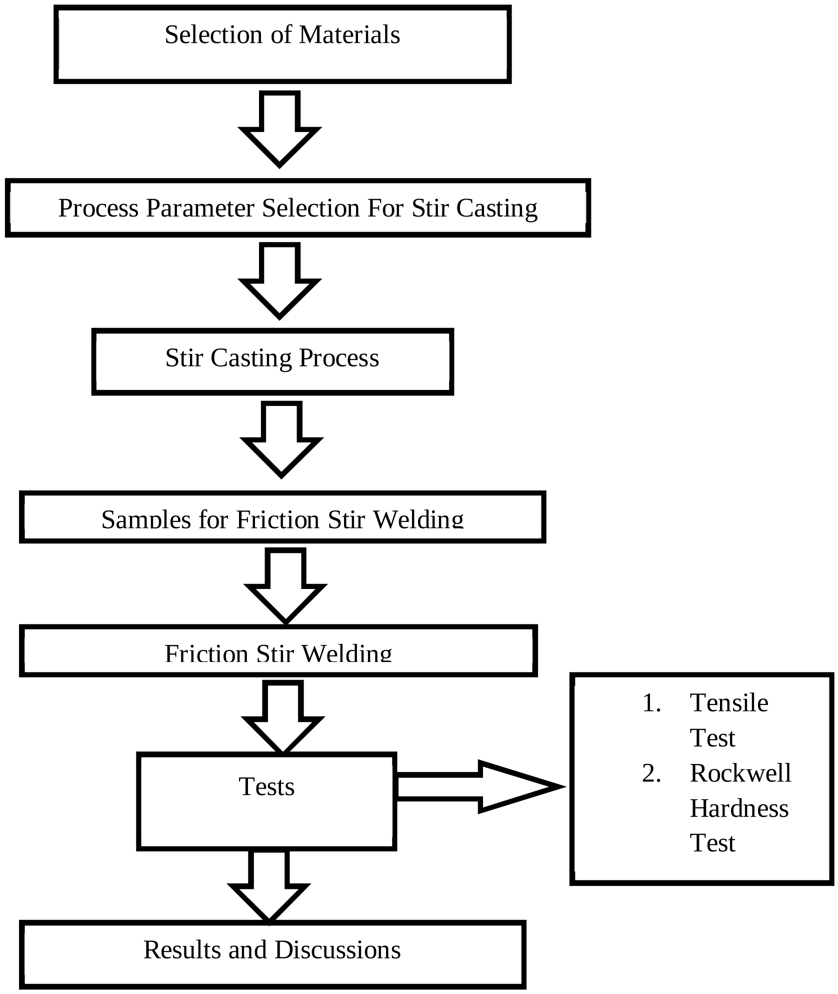
IV. METHODOLOGY



V. RESULTS AND DISCUSSIONS

A. Tensile Test

Tensile test is a basic science of materials and engineering test in which a sample is subjected before failure to a controlled stress. Tensile experiments were carried out using friction stir welding for all four joints. The test results were compared based on the ultimate tensile strength of the weld produced by each pin profile. The welded pipes are pre drilled in drilling machine with 4mm drill bit and then machined into a required dimension using wire cut EDM to prepare tensile specimen as shown in figure American Society for Testing of Materials guidelines is followed for preparing the test specimens. Tensile machine used for the testing is UTM ASME SEC IX method.

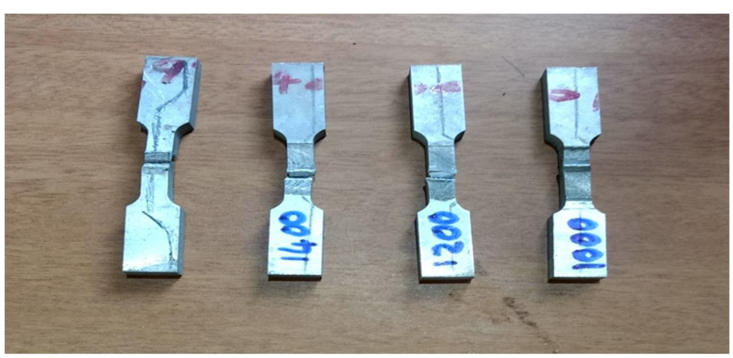


Figure 5.1.1 Tensile Tested samples

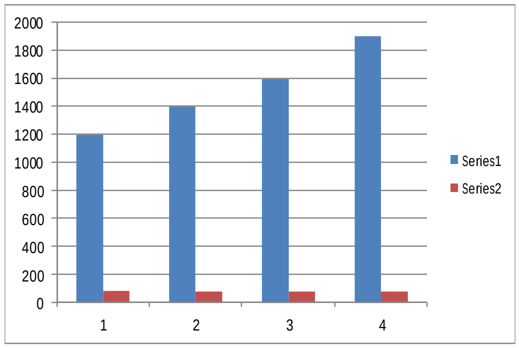


Figure 5.1.2 Tensile Tested Graph

Table.5.2.1.Tensile test Results

Sample	Feed rate mm/min	Rotation speed rpm	Pin depth mm	Load at peak N	Elongation at peak mm	Tensile strength N/mm^2
A	3	1200	4.3	755	5.06	80.88
B	6	1400	4.4	350	4.91	74.56
C	9	1600	4.5	614	2.12	73.26
D	12	1900	4.6	361	2.16	72.16

B. Hardness Test

Testing is essential part of any engineering activity. Testing is applied to materials, components and assemblies. It consists of measurement of fundamental properties or measurement of response to particular influences such as load, temperature and corrodents.

Figure 5.2 Hardness Test Results

S.NO	Sample Test Pieces	Observed Average Values HRB			
		1	2	3	4
1	Aluminium 6061 Composite	92.6	87.3	87.1	85.1

VI. CONCLUSION

Friction stir welding has been the effective welding process for the copper and aluminium material. Aluminium 6061 Composite were friction stir welded in the conventional vertical milling machine in the machine shop using square tool pin profiles with suitable process parameters. The following tests are carried out in the FSW samples.

A. Hardness test
B. Tensile test

The following conclusions are drawn from the experimental results: • The test shows that, in FSW, the weld joint property depends on the working parameters. The key parameter is the tool pin profile, since it plays a crucial role in the generation of material flow and heat.

1) The hardness tests are shows that the hardness value of the all two welded workpieces is less than that of its base metal.
2) The visual inspection and tensile tests are shows that welded workpiece having blow holes. So that mechanical strength in all two welded pieces having lower value than the base material.
3) In this there are some other factor which influences the welding is rotational speed, welding speed, and axial load.

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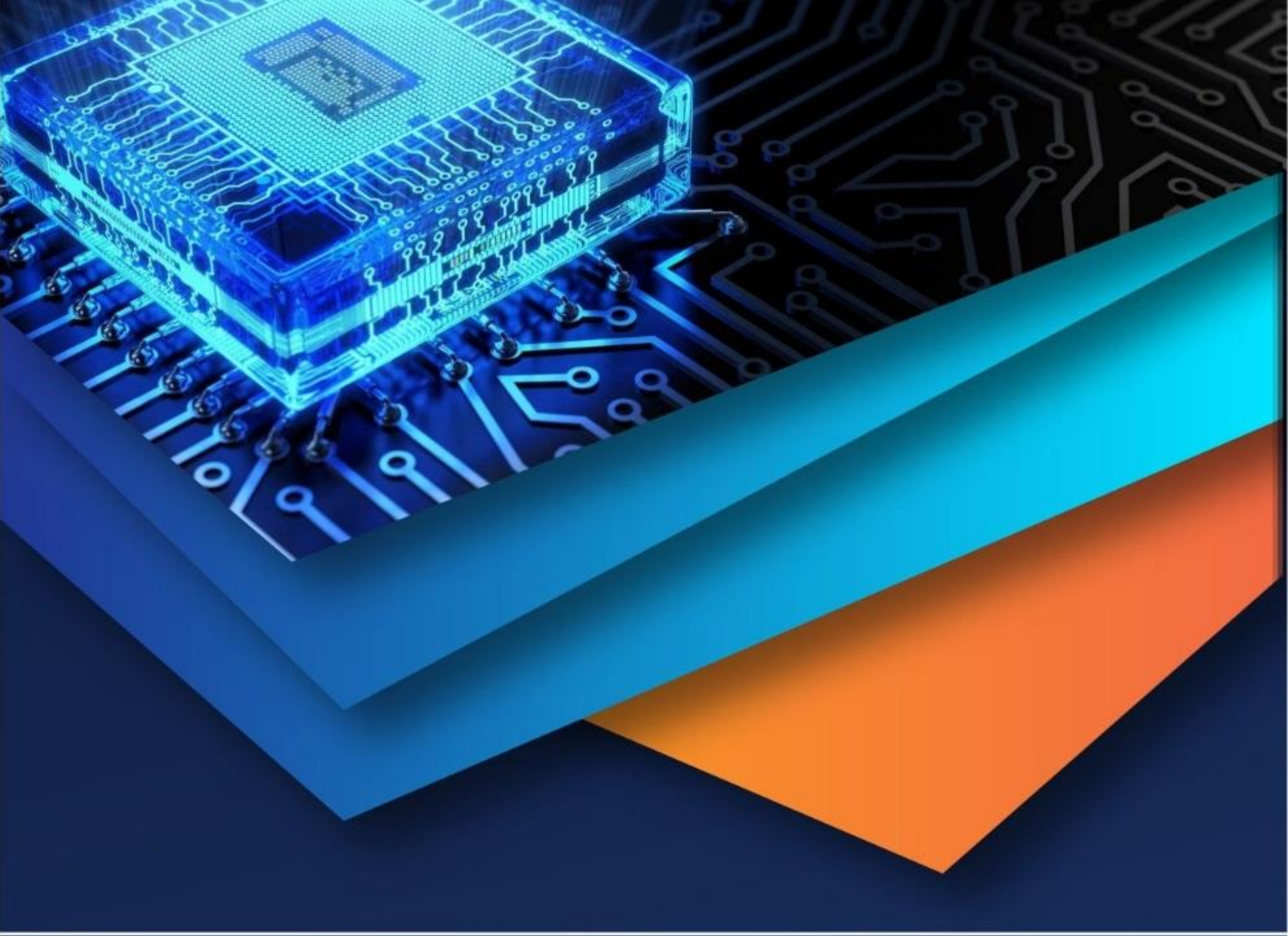

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