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To study the effect of tool pin profile on mechanical properties and micro structure of friction stir welding magnesium alloy

Sai Krishna Praneeth Duggirala
krishnapraneeth066@gmail.com
CVR College of Engineering, Hyderabad, Telangana

ABSTRACT

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 material. This is performed by using a milling machine. Heat is generated by friction between the rotating tool and the workpiece material, which leads to a softened region near the FSW tool. Magnesium alloy is the most widely used due to its excellent corrosion resistance, high ductility and reflective finish, lightweight material used in industries and aerospace, the selected material was welded with Friction Stir Welding (FSW) process, by using a combination of different tool rotation speed (1500 rpm, 2500 rpm, 3500 rpm) and welding speed (10 mm/min, 30 mm/min, 50 mm/min) as welding parameters. The weldments are welded by changing the tool length, the material of tool, depth of indentation, by changing tilt angle and the welded joints were tested using the universal testing machine, Ultimate Tensile Strength and hardness test. By using the above testing methods various parameters and grain structure of welded joints are studied.

Keywords: *FSW , MAGNESIUM AZ31*

1. INTRODUCTION

Friction Stir Welding (FSW) is comparatively new joining process which has been attracting significant interest. It is a solid-state joining process that uses a third body for joining two facing surfaces. It uses a specially designed tool that rotates at high speeds over the seams that need to be weld together. As the tool rotates over the metal, heat is generated by friction between the rotating tool and the workpiece material, which leads to a softened region near the FSW tool. It is capable of joining aluminium alloys, copper alloys, titanium alloys, mild steel and stainless steels. More recently, it was successfully used in the welding of polymers. Besides, joining of dissimilar metals such as aluminium to magnesium alloys has been recently achieved by FSW.

In this study, we investigated FSW on Magnesium AZ31. This study especially characterized and compared the microstructures of the Magnesium base metal with those of the residual FSW zones using optical metallography(OM) and Transmission Electron Microscopy (TEM). Microhardness profiles through the weld zone and corresponding tensile strength test data were also correlated with these microstructures.

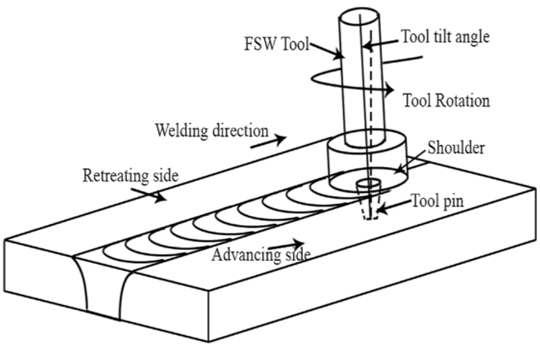


Fig. 1: Schematic Diagram of Friction Stir Welding

Fig. 2: Magnesium AZ31before Welding

Fig. 3: FSW on Magnesium AZ31.

1.1 Working Principle

The adjacent metal sheets are joined by a tool that is a non-consumable tool and is made up of a pin and a shoulder. The non-consumable tool used in friction stir welding performs two functions. Firstly, it heats the workpiece to raise its temperature sufficiently to the stage at which it is not molten but plastically melted and secondly it moves along the edges of the workpiece to weld it or to make a joint. The heating is achieved by friction between the tool and the workpiece and because of the plastic deformation of the workpiece. The localized heating softens the material around the pin and shoulder. The tool rotation leads to the movement of material from the front of the pin to the back of the pin. And this completes the welding and a strong solid-state joint is ready.

The surface of the finished weld is smooth more or less flush with the surface of the parts. The top surface of the weld shows characteristic from a rotating friction stir welding tool. Some zones were formed by welding in weld portions and surroundings.

Fig. 4: Weld portions and it's surrounding

HAZ =Heat Affected Zone
TMZ =Thermo Mechanically Affected Zone
UAZ =Unaffected Zone
SZ =Stirring Zone

- **Weld Nugget:** The fully recrystallized area sometimes called the stir zone, refers to the zone previously occupied by the tool pin. The term stir zone is used in friction stir processing where large quantities of material are processed.
- **Thermomechanically affected zone(TMAZ**): In this region, the FSW tool has plastically deformed the material and the heat from the process will also have exerted some influence on the material. In the case of magnesium, it is possible to obtain significant plastic strain without recrystallization in this region and there is generally a distinct boundary between the recrystallized zone and the deformed zones of TMAZ.
- **The Heat affected Zone(HAZ):** In this region, which lies closer to the weld centre, the material has experienced a thermal cycle that has modified the microstructure and the mechanical properties. However, there is no plastic deformation occurring in this area.

1.2 Friction Stir Welding Parameters

FSW involves complex material movement and plastic deformation. Welding parameters, tool geometry, and joint design exert a significant effect on the material flow pattern and temperature distribution, thereby influencing the microstructural evolution of the material. A few major factors affecting the FSW process, such as tool geometry, welding parameters are addressed. The strength of friction stir welding depends on the following parameters:

- Spindle speed
- Feed rate
- Insertion depth
- Welding pressure
- Tool geometry
- Tool material
- Material flow behaviour
- Joint design
- Preheating or cooling.

These parameters are discussed in the following Sections.

Spindle Speed: The spindle speed is the rotational frequency of the spindle of the machine, measured in revolutions per minute (RPM). The preferred speed is determined based on the material being cut. Excessive spindle speed will cause premature tool wear, breakages, and can cause tool chatter, all of which can lead to potentially dangerous conditions. Using the correct spindle speed for the material and tools will greatly affect tool life and the quality of the surface finish. The speed at any point on the periphery (outside edge) of a cutter must always be equal to the ideal speed for the material for it to work at its optimum performance. The spindle speeds may be calculated for all machining operations once the welding speed is known. The best speed depends on the following conditions: Desired weld strength and quality of the weldment: Higher quality of weld and strength can be obtained at high-speed operations. Material to be welded: Hard material requires a high-speed operation.

Size of weld: Large welds require a low-speed operation. The thickness of the workpiece to be welded.

Feed Rate: Feed rate is the velocity at which the cutter is fed, that is, advanced against the workpiece. It is expressed in units of distance per revolution for turning and boring (typically inches per revolution (CPR) or millimetres per revolution). It can be expressed thus for milling also, but it is often expressed in units of distance per time for milling (typically inches per minute (ipm) or millimetres per minute)

Insertion Depth: The insertion depth of pin into the workpieces (also called target depth) is important for producing sound welds with smooth tool shoulders. The insertion depth of the pin is associated with the pin height. When the insertion depth is too shallow, the shoulder of the tool does not contact the original workpiece surface. Thus, the rotating shoulder cannot move the stirred material efficiently from the front to the back of the pin, resulting in the generation of welds with an inner channel or surface groove. When the insertion depth is too deep, the shoulder of tool plunges into the workpiece creating excessive flash. In this case, a significantly concave weld is produced, leading to local thinning of the welded plates

Welding Pressure: It depends on the thickness of the material and the type of material to be joined. The applied pressure differs with rotational speed. Stir welding is also safer compared to other welding techniques. It does not create or use fumes, radiation, high voltages, liquid metals, or arcing. It also does not require welder certification.

Tool Geometry: The performance of FSW tools vary with tool geometry. The tool generally has circular section except at the end where there is a threaded probe or more complicated flute, the junction between the cylindrical portion and the probe is known as the shoulder. Generally, the tool rotates with a speed of several hundred rpm. Pin diameter is one third to two-thirds of the cylindrical tool diameter. Pin length is slightly less than the thickness of the workpiece

Table 1: Key benefits of FSW

Metallurgical Benefits	Environmental Benefits	Energy Benefits
Solid-phase process	No shielding gas required	Improved material use

Low distortion	Minimal Surface cleaning	Only 2.5% needed energy for laser weld
Good dimensional stability and repeatability	Eliminate grinding waste	Decreased fuel consumption in Air crafts
Excellent mechanical properties in grind area	Consumable material is saved	
Fine recrystallized structure	No harmful emissions	

2. STUDY ON MECHANICAL PROPERTIES

During welding process parameters have a great influence on mechanical properties. In friction stir welding, process parameters are tool rotational speed, traverse speed, tit angle, tool geometry and axial forces have a great effect on joint mechanical properties. Different methods and approaches have been used to determine excellent mechanical properties.

2.2 HARDNESS

In FSA welding upon welding parameter, the minimum hardness region will be found at various distance from the weld nugget and we'll have various depths. the HAZ hardness minimum may have the same hardness as the nugget or it may be substantially software, depending on the thermochemical processing experienced by the nugget.

2.1.1Tensile Properties: The mechanical properties of the weld considerable changes from weld centre two unaffected material unless the chemical composition is different the elastic modulus should be unaffected but other properties such as hardness yield strength ductility fatigue and creep strength main vary to a great extent this can lead to metallurgical notch formation in which stress concentration main take place even in stronger parts of the weld as these properties are used for designing criteria a review of Mechanical properties changes due to friction welding is important.

2.3 Motivation

FSW of magnesium is relatively new in the manufacturing industry. Recently requirements of weight reduction for aerospace and automotive application is increasing for this it is required to increase the strength to weight ratio of material used in aerospace and automotive industries. By reducing the weight in this application fuel consumption and its environmental impact may be reduced. For this Aluminium and magnesium alloys may be used because of the wide variety of unique property, especially low-density properties. Magnesium alloy is the most prominent material to meet the requirement of aerospace and automotive to the high strength to weight ratio and corrosion resistance. It has also high thermal and electrical conductivity so it can also be used in other application. Friction stir welding is a solid-state joining technique, and it was initially applied to aluminium alloys. However, the application of this welding process in an industry still requires accurate knowledge of the joining mechanism and the metallurgical and mechanical transformation of the materials. By using this research paper we have tried to impart knowledge in this obscure field

3. METHODOLOGY

3.1 Tolerance Design

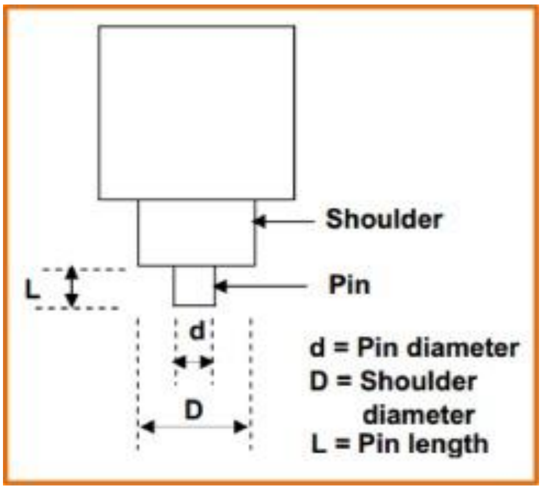
With a completed parameter design and an understanding of the effect that the various parameters have on performance, resources can be focused on reducing and controlling variation in the critical few dimensions. In our, we used mini tab to understand the how required results change with a given parameter.

3.2 Base metal characterization

In this phase, we have to decide which of the materials to be welded according to the availability in the market and thickness of the workpiece.

3.3 Design and manufacturing of FSW tool

In friction, stir welding tool places a major role, for designing a tool we mainly required to know what are the materials are going to be welded and thickness of welding so according to that we can able to determine which type of tooltip to be taken and shoulder diameter. According to the tool dimension, We can manufacture tool on CNC lathe machine.



4. FABRICATION

In the present investigation, the work that has been done includes the investigation of the effect of process parameters on mechanical properties of 6mm Magnesium alloy MG AZ31 and MG AZ31 plates of friction stir welded joint, optimization of process parameters and development of a mathematical model of various mechanical properties. In this chapter, the material that has been welded and experimental setup and methodology have been discussed. Optimization technique and development of a mathematical model which are opted for investigation are also discussed in the present section.

4.1 Material selection

Magnesium alloys are used in many application in which the combination of high strength and low weight is attractive in airframe in which the low light can be significant value. Mg AZ31 is known for its lightweight and good corrosion resistance in air, water, oils and many chemicals. Alloys AZ31 is the most used series in Magnesium alloys and possesses superior weldability as compared to other heat-treatable alloys. The alloys exhibit excellent welding characteristics in all tempers when welded by any of the fusion and resistance welding procedures. The strength properties of AZ31B are not as high as the AZ31the heat treatable Magnesium alloys. However, AZ31 possess excellent corrosion resistance, good machinability, and good formability. Alloy AZ31 is the most aluminium alloy extraction.

Table 4.1 Chemical Composition

Material (%)	Mg	Al	Zn	Mn	Si	Cu	Ca	Fe	Ni
Mg AZ31	97	2.50-3.50	0.60-1.40	0.20	0.10	0.050	0.040	0.0050	0.0050

Table 4.2 Thermal properties

Properties	Metric	Imperial
Thermal expansion coefficient	26 µm/m°C	14.4 µin/in°F
Thermal conductivity	96 W/mK	666 BTU in/hr.ft².°F

Table 4.3 Mechanical Properties

Properties	Metric	Imperial
Tensile strength	260Mpa	37700psi
Yield strength	200Mpa	29000psi
Compressive yield strength	97Mpa	14100psi
Ultimate bearing strength	385Mpa	55800psi
Bearing yield strength	230Mpa	33400psi
Shear strength	130Mpa	18900psi
Shear modulus	17Gpa	2470ksi
Elastic modulus	44.8Gpa	6498ksi
Poissons ratio	0.35	0.35
Elongation at break	15%	15%
Hardness,Brinell	49	49
Charpy impact	4.30j	3.17ft-lb

Table 4.4 Physical Properties

Properties	Metric	Imperial
Density	1.77 g/cm3	0.0639 lb/in³

4.2 Tool Design

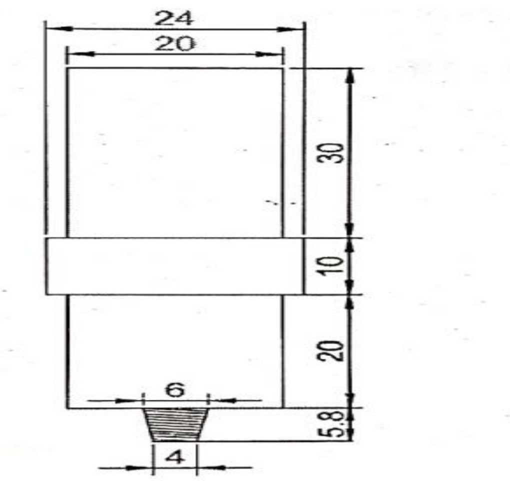


Fig. 5: Design of Tool Using AUTOCAD Software

4.3 Selection of process parameters and Design of Experiments

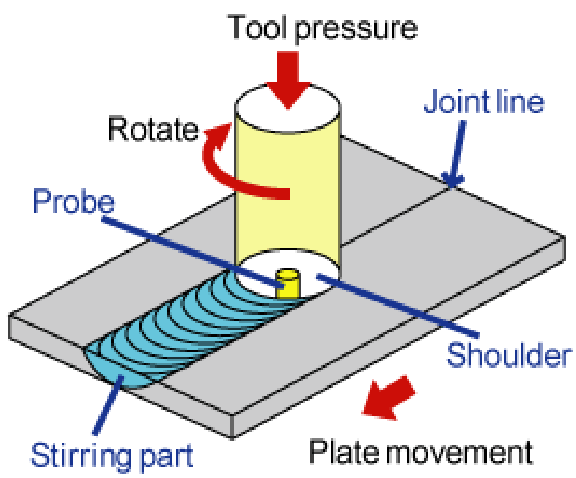
From literature, it is well known that the input welding parameters play a major role in determining the weld quality. As the process facts have not been disclosed so far, the selection of input parameters to join aluminium alloy is very difficult. Response Surface Methodology (RSM) is a collection of mathematical and statistical techniques useful for the modelling and analysis of problems in which to optimize this response. The RSM is important in designing, formulating, developing and analysing new scientific studies and products. It is also efficient in the improvement of existing studies and products. In this investigation, RSM will be used to reduce the number of experiments, in additional to build a numerical relation between the quality of welding and the welding parameters.

FSW process parameters such as tool rotational speed, traverse speed, tool tilt angle and tool shoulder diameter influence the mechanical properties of the joint. To increase the efficiency of the FSW process, the mechanical properties of joints must be optimized. Therefore, it is important to determine the welding parameters at which the mechanical properties reach their optimum.

After a large number of trails, experiments have been conducted to determine the working range of the above factors by varying one the process parameters and keeping the rest of them at a constant value. The selected process parameters and their working range are shown in the table.

Table 4.5 Selected process parameters

Parameters	Level 1	Level 2	Level 3
Tool-rotation speed(rpm)	1400	1400	1400
Feed rate (mm/sec)	100	100	100
Tool tilt angle(degree)	0	0	0



4.3 Machine Used For Welding

Fig. 6: Friction stir welding

4.4 Welding

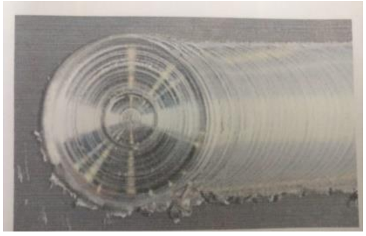


Fig. 7: Friction stir welding

We have taken Magnesium AZ31 of the size of 100*50*6mm on advancing side which supports the weld in the direction of tool travel and Magnesium AZ31 of the size of 100*50*6mm on retrieving side which opposes the weld in the opposite direction of the tool travel.

Two metal plates are fixed on the workbench of friction stir welding machine with adjusted screw and backing plates to support metal. Then two metal plates are welded at different values of speed, feed rate and same tilt angle with different types of tools.

Table 4.6: Parameters used during the experiment

Workpiece no	RPM	Feed rate	Tilt angle	Tools
1	1400	100	0	Tapered cylindrical pin
2	1400	100	0	Cylindrical pin
3	1400	100	0	Square taper pin
4	1400	100	0	Hexagonal pin

5. EXPERIMENTATION

It is evident from the literature survey that the selection of parameters and suitable methodology during welding plays a vital role in the improvement of mechanical properties and sound welding 0f Magnesium plates with friction stir welding. Variation of process parameters affects the weld appearance, mechanical properties and hardness of weld zone.

5.1 Tensile Test

The uniaxial tensile test was carried out to achieve the joint strength and percentage elongation. Percentage elongation represents ductility of the welded joints. Tensile strength and percentage elongation of welded joints.

5.1.1. Universal Testing Machine: Tensile stress is defined as when a body is subjected to two equal and opposite axial pull, as a result of which body tends to extend its length and stress is induced is known as tensile stress. The tensile strength of a material is the maximum amount of tensile stress that it can take before failure. The most common type of test used to measure the mechanical properties of the material is the tension test. Tension test is widely used to provide basic design information on the strength of the materials and is an acceptance test for the specification of materials. The major parameters that describe the stress-strain curve obtained during the tension test are the tensile strength, welding efficiency. In this test, specimens were prepared suitable for gripping into the jaws of the testing machine type that would be used. The specimen used was approximately uniform over a gauge length. Tensile specimens are machined from the material to be tested in the desired orientation and according to the standards. The cross-section of the specimen is usually round, square or rectangular. For sheet and plate stock, a flat specimen is usually employed.

A study has been carried out for the evaluation of the mechanical properties like tensile strength and percentage elongation with the help of computer-controlled universal testing machine. The universal testing machine serves for conducting tests in tension, compression, bending and shearing for metals and other materials. The testing machine is operated hydraulically and driving is performed by the help of an electrical motor.

Fig. 8: Universal Testing Machine

5.1.2 TENSILE TEST SPECIMEN PREPARATION

After welding all the 4 joints as per the taken parameters. Cut the joints for a tensile specimen as per the dimensions given below, cutting is done on a milling machine with a multi-point cutting tool. After cutting all the specimens fix the tension specimen on a universal tensile test machine. Universal tensile test machine consists of various parts in our work we fix the specimen in the upper and lower jaw then we apply load gradually so that specimen elongates.

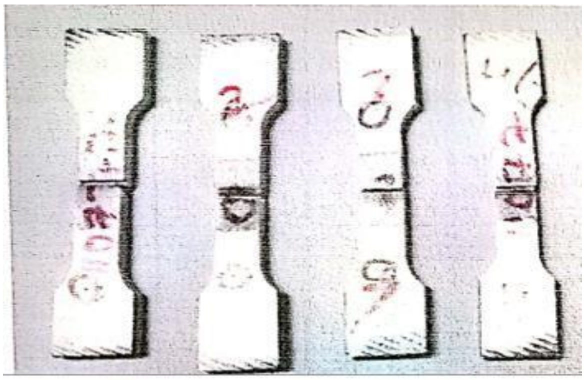


Fig. 9: Before Tensile Test

Table 5.1:Tensile Test results

Specimen no	Ultimate tensile load	Ultimate tensile stress	Elongation	Yield stress	Tools used
1	5.6	118	0.6	55.229	Taper Cylindrical pin
2	6.12	135	1.2	70.238	Cylindrical pin
3	6.640	109	0.5	77.423	Square pin
4	7.720	87	0.7	91.046	Hexagon pin

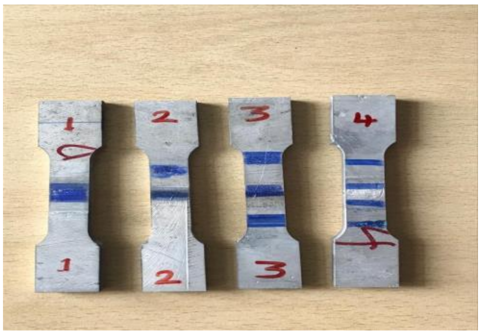


Fig. 10: After Tensile Test

5.2 Surface Roughness

Surface roughness often shortened to roughness, is a component of surface texture. It is quantified by the deviations in the direction of the normal vector of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small, the surface is smooth. In surface meteorology, roughness is typically considered to be the high-frequency, short-wavelength component of a measured surface. However, in practice, it is often necessary to know both the amplitude and frequency to ensure that a surface is fit for a purpose.

Roughness plays an important role in determining how a real object will interact with its environment. In tribology, rough surfaces usually wear more quickly and have higher friction coefficients than smooth surfaces. Roughness is often a good predictor of the performance of a mechanical component, since irregularities on the surface may form nucleation sites for cracks or corrosion.

There are many different roughness parameters in use, but Ra is by far the most common, though this is often for historical reasons and not for particular merit, as the early roughness meters could only measure Ra Other common parameters include Ra, Rz. Please note that Ra is a dimensional unit that can be micrometre.

Table 5.2: Surface roughness sample 1 results

Sample.no	Tool used	Ra (µm)	Rq (µm)	Rz (µm)
1	Taper cylindrical	4.61	5.97	29.9

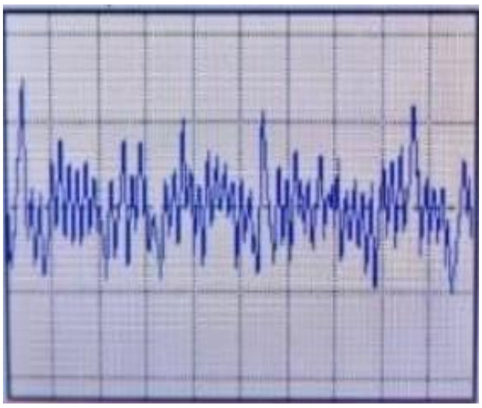


Fig. 11: Surface roughness sample 1 graph

Table 5.3: surface roughness sample 2 results

Sample.no	Tool used	Ra (µm)	Rq (µm)	Rz (µm)
2	Cylindrical pin	3.08	3.89	19.3

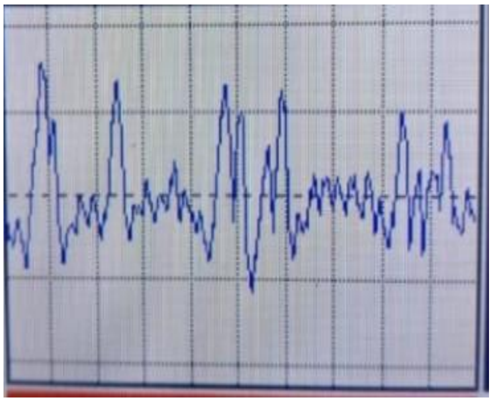


Fig. 12: Surface roughness sample 1 graph

Table 5.4: surface roughness sample 3 results

Sample.no	Tool used	Ra (µm)	Rq (µm)	Rz (µm)
3	Square pin	4.85	5.88	25.4

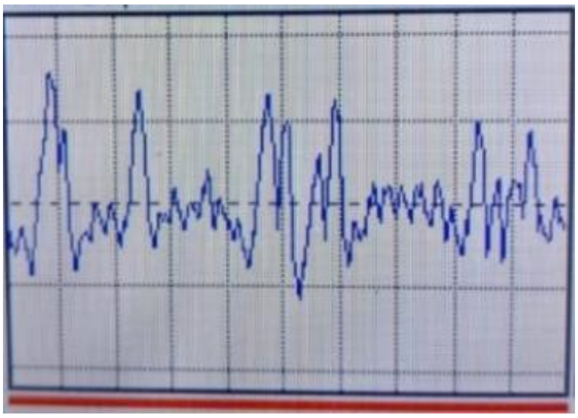


Fig. 13: Surface roughness sample 3 graph

Fig. 14: Surface roughness sample 4 graph

Table 5.5: surface roughness sample 4 results

Sample.no	Tool used	Ra (µm)	Rq (µm)	Rz (µm)
4	Hexagonal pin	9.8	12.2	50.4

5.3 Hardness

Vickers microhardness measurements were carried out on the specimens along the centerline across the joint using a load of 100 g for the loading time of 10 s. Figure 26 shows the hardness profiles obtained from the welded joints.As seen from the figure, hardness increases in the weld regions of all the joints. The increase in the hardness is very similar in all the joints produced at different transverse speeds. On the other hand, even if just a bit a hardness loss occurred in the stir and heat-affected zones. The lowest hardness value in the stir zone was displayed on the transverse speed of 100 mm/min. When the transverse speed of 80 mm/min was used, the hardness affected zone is close to that of base metal for all the joints. Vickers hardness value of the base metal is about 70 HV.

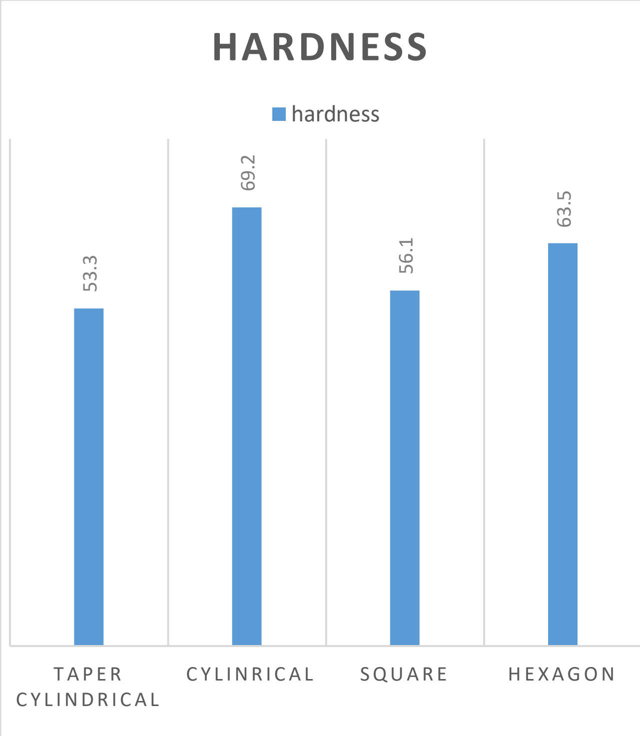


Fig. 15: Hardness Results

5.4 Microstructural Aspects

When the welded joints were investigated macrographs by microscopy, some weld defects were observed. As it is well known, welding of magnesium alloys is hard to other structural materials so it was come up some typical problem such as porosity because of hydrogen dissolves completely in the healing process and is separated while temperature decreases. The generated heat and plastic deformation rate are very important during welding. It was revealed that the dimension of the weld defect decreases as the transverse speed decreases. These weld defects affected the welding performance inherently.

Metallography specimens were extracted from joints for microstructural examinations. It is explained that metallurgical changes of friction stir welded magnesium alloys and the effect of welding parameters to the evolution of microstructure. For this purpose, after grinding and polishing, the specimens were etched using 20 ml acetic acid, 20 ml distilled water, 3 gr picric acid and 50 ml ethanol for 3-5 s.

The micrographs of base metal and welded joints are given respectively. When the welded joints were investigated by a microscopy, grain size structure of base metal are changed into the grain refinement in the stirring zone due to dynamic recrystallization. The joints performed with a rotational speed of 1400 rev/min, transverse speed of 100mm/min, contain finer grains in the stirring zone compared to other joints. But stirring zone in other joints shows similar grain structure, the size of grain structure changed slightly. One of the reasons for emerged this formation was generated heat during the welding. Because transverse speed effect the generated heat end plastic deformation. If the transverse speed is increase the grain structure is change slight. Especially, the joints performed with transverse speed of 140 mm/min was threw this situation into sharp relief.

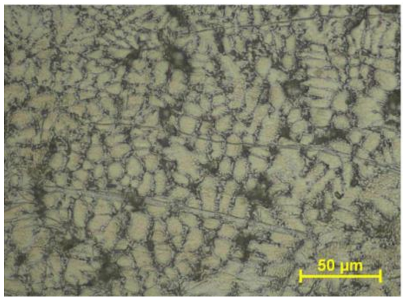


Fig. 16: Microstructural view of the base material.

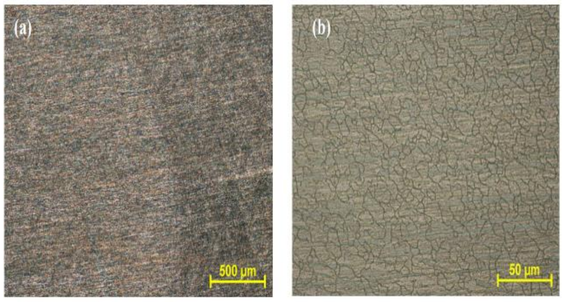


Fig. 17 : Microstructural view of the welded specimen produced at 1400 rev/min - 100 mm/min by using Taper cylindrical pin a) transition zone b) stir zone.

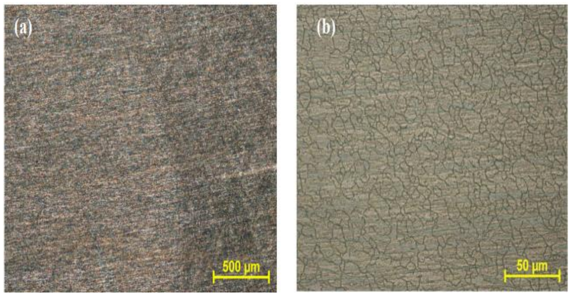


Fig. 18: Microstructural view of the welded specimen produced at 1400 rev/min - 100 mm/min by using cylindrical pin a) transition zone b) stir zone.

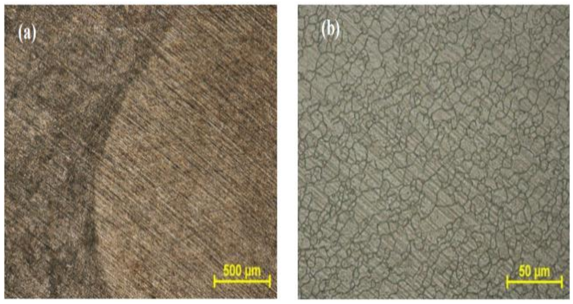


Fig. 19: Microstructural view of the welded specimen produced at 1400rev/min - 100mm/min by using Square pin a) transition zone b) stir zone.

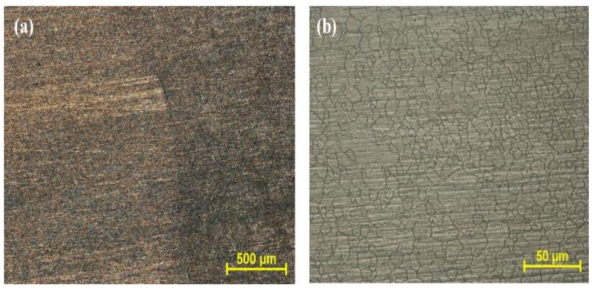


Fig. 20: Microstructural view of the welded specimen produced at 1400 rev/min - 100 mm/min by using Hexagonal pin a) transition zone b) stir zone.

6. CONCLUSION

In present work for fulfilling the objective, an experimental model has been developed to study the mechanical properties of a Magnesium AZ31 welded joints by friction stir welding a design of experiments was selected to identify the effect of parameters like rotational speed welding speed till angle on responses ultimate tensile strength percentage elongation and toughness of the joint to validate the output results have correlated with published results a mathematical model has been developed using regression analysis to delete the selected input parameters with the response variables the main parameters affecting the mechanical properties rotational speed welding speed and tilt angle in this work the following conclusions word derived from selected process parameters on mechanical properties changes in the joint.

- Elongation of welded joint increases with increase in tool rotational speed, same with feed rate.
- Toughness welded joints decreases slightly with increasing tool rotational speed and then increases with increase in speed team with feed rate and tilt angle first decreases suddenly and then increases rapidly.
- Good tensile test, surface roughness, micro structure, hardness is obtained by using a cylindrical pin.
- Optimized parameters from our experience are

Table 6.1:optimized parameters

Response	Spindle speed (RPM)	Tilt angle (DEGREE)	Feed rate (MM/MIN)
UTS	1400	0	100
Surface Roughness	1400	0	100
Hardness	1400	0	100
Micro Structure	1400	0	100

7. FUTURE SCOPE

- In future thermal modelling may be applied to study how the cooling rate affects the microstructure and other mechanical properties of welded joint of similar and dissimilar material.
- 2.taguchi is single objective optimization technique in future we will use multiple objective optimization techniques like the recreational analysis.
- Microstructure analysis of weld zone can be done.
- Further research can be conducted by using different tool shapes than the one's mentioned above

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