Effect of FSW and TIG welded processes on Mechanical properties of Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy welded joints

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in partial fulfillment of the requirement for the award of the degree of

BACHELOR OF ENGINEERING
IN
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CERTIFICATE

This is to certify that the Project Report entitled **"EFFECT OF FSW AND TIG WELDED PROCESSES ON MECHANICAL PROPERTIES OF AL-4.2MG-0.6MN-0.4SC-0.1ZR ALLOY WELDED JOINTS"** being submitted by TANGUDU SAISHANKAR (317126520224), PERUMALLA SRIKAR (317126520214), UPPADA BHANOJI RAO (318126520L55), YANDRA CHANDRASEKHAR (317126520231), KAMBHAMPATI KARTHIKEYAN (317126520201) in partial fulfillments for the award of degree of **BACHELOR OF TECHNOLOGY** in **MECHANICAL ENGINEERING**. It is the work of bona-fide, carried out under the guidance and supervision of **DR.M.SRINIVASA RAO**, Assistant Professor, Department Of Mechanical Engineering, ANITS during the academic year of 2017-2021.

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We, the undersigned, hereby declare that this “**Thesis”** under the title of **“Effect of FSW and TIG welded processes on Mechanical properties of Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy welded joints” s**ubmitted by me for the award of Degree of “**Bachelor of Technology**” in Mechanical Engineering at ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES (A), Visakhapatnam, is a record of original research work carried out by us. This work has not been submitted to any University or Institution in India or abroad, for the award of any degree.

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ABSTRACT

Material joining is undergoing various changes due to the unending needs of the customers for qualitative, reliable and sophisticated parts and products in the modern and technological world. In this study, friction stir welding (FSW) and Tungsten gas welding (TIG) processes were used to weld 5 mm thick Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy plates. The FSwelds and TIG welds were tested for mechanical properties (hardness, ultimate tensile strength, bending strength and impact strength) by means of vicker's hardness machine, universal testing machine and impact test machine respectively. The strength of the base material was higher, compared to the strength of the FSW and TIG welded joints. The strength of the TIG welded joint decreased, compared to the strength of the FSW welded joint. The microstructure features were also observed for base material with the aid of metallurgical microscope and compared the same with the microstructures of FSW and TIG welded joints. FSW change the material strength due to fine-grain refinement in the stir zone in Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy and therefore FS welded joint exhibited 91.6% joint efficiency followed by the TIG welded joint of 69.8%.

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NOMENCLATURE

H - *Hardness*

UTS - *Ultimate Tensile Strength*

%E - *Percentage Elongation*

BS - *Bending Strength*

IS - *Impact Strength*

FSW - *Friction Stir Welding*

TIG -*Tungsten Inert Gas Welding*

CHAPTER-I

INTRODUCTION

1.1 INTRODUCTION

The development of lightweight metals in the field of engineering and technology is due to the demand for such high strength to weight ratio materials in aerospace, automotive and marine applications. Wrought Aluminium alloys were come under this category to fulfil the requirement for such applications.

1.1.1 ALLOY

An alloy is a metal made by combining two or more metallic elements especially to give greater strength or resistance or corrosion. These are defined by the metallic bonding character. An alloy may be the solid solution of metal elements (a single phase) or a mixture of metallic phases (two or more solutions).

The metallic atoms must dominate in its chemical composition and the metallic bond in its crystalline structure. Commonly, all alloys have different properties from those of the component. Making of the alloy gives the material to attain desirable properties such as increase in the values of hardness and lowering of the melting points. Some of the physical properties such as density and conductivity of an alloy element may not differ greatly from those of its component elements but engineering properties such as tensile strength and shear strength may be considerably different from those of constituent materials.

1.1.2 CLASSIFICATION OF WROUGHT ALUMINIUM ALLOYS

Wrought Aluminium alloys are generally classified as strain-hardening alloys and age-hardening alloys and the detailed classification is shown in Fig. 1.1. In Wrought Aluminium alloy designation system, the first digit refers to the main alloying elements, the second digit gives the modification in that alloy, the third and fourth digits give the individual alloy variations and identification of the alloy in that group. The strain-hardening alloys (1xxx, 3xxx, 4xxx and 5xxx alloy series are non-heat treatable).

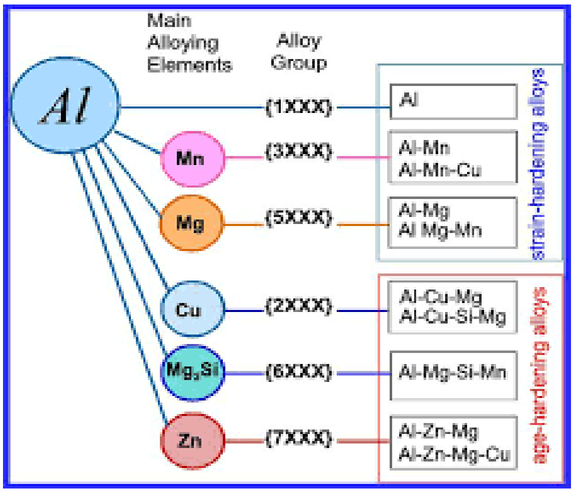


Fig. 1.1 Classification of Aluminium alloys

The strength of these alloys may be improved by strain hardening technique. The age-hardening alloys (2xxx, 6xxx and 7xxx alloy series). These alloys improved their properties by heat treatment and quenching followed by natural or artificial aging.

1.1.3 DESIGNATION AND APPLICATIONCS OF ALUMINIUM ALLOYS

The international alloy designation system accepted the naming scheme for the wrought alloys in which each alloy is given a four digit number, where the first digit indicates the major alloying elements, the second digit if different from zero indicates a variation of the alloy. and the third and fourth digit indicates the specific alloy in the series.

Table 1.1 Designation and Applications of Aluminium Alloys

Alloy	Main alloying Element	Applications
1xxx	Mostly 99%pure Aluminium	Electrical and Chemical industries
2xxx	Copper	Aerospace applications
3xxx	Manganese	Architecture
4xxx	Silicon	Welding rods and Automobile parts
5xxx	Magnesium	Marine applications
6xxx	Magnesium & silicon	Architectural extrusions
7xxx	Zinc	Aircraft components
8xxx	Some other elements like nickle, iron, lithium	Electrical wires

1.1.4 THE MAJOR ADVANTAGES OF USING ALUMINUM

- Aluminium has a density around one third that of steel and is used advantageously in applications where high strength and low weight is required.
- When the surface of aluminium is exposed to air, a protective oxide coating is formed which is resistant to corrosion.
- Aluminium is an excellent conductor of both heat and electricity, its conductivity is around twice to that of copper.

1.1.5 ALUMINIUM ALLOY CHOSEN FOR THE PRESENT STUDY

In this project work, a 5xxx series alloy is chosen for the investigation. This alloy usually contains aluminium (Al), magnesium (Mg), manganese (Mn) as principal alloying constituents and traces of other metals. This alloy attains medium strength and high corrosion resistance among all the non-heat treatable alloys, derives their strength primarily from solid solution strengthening by Mg and Mn. Increase in the Mg content in this series of alloys leads to increase in tensile strength, Mn increases corrosion resistant due to the presence of Al_3Mg_2, Mg_2Si, Al_6(Fe, Mn) intermetallic. These alloys are work-hard enable and can be easily drawn into any shape due to high formability, and exhibits high ductility, good weldability, durability, good finishing characteristics. Thus, these alloys were used in many chemical industries, ship buildings, naval and marine applications. Medium strength is the limitation for these alloys. Al-Mg-Mn alloys are often strengthened by work hardening/stain hardening strengthening, solid solution strengthening, grain refinement strengthening and precipitate strengthening mechanisms. Amongst different strengthening mechanisms for Al-Mg-Mn alloys, Minor-alloying strengthening is an alternative way, which involves the addition of alloying elements such as Ti, Fe, Er, Cr, Mn, Cu, Zn, Ni, Hf, Zr, and Sc as an alloying element. In the present study, Al-Mg-Mn alloy containing the traces of Sc and Zirconium is considered.

1.1.6 APPLICATIONS OF ALLOY 5083

- Shipbuilding
- Rail cars
- Vehicle bodies
- Tip truck bodies
- Mine skips and cages

1.2 INTRODUCTION TO FRICTION STIR WELDING

With the development of technology, more and more challenging problems are faced by the scientists and technologies in the field of metal joining in the research organizations and industries like Defence Research and Development Organization laboratories (DRDO's), aeronautics, automobiles, nuclear reactors, etc. The difficulty in adopting the traditional welding processes can be attributed mainly, new materials with low weld strength. To make efficient use of modern welding processes, it is necessary to know the exact nature of the welding problem. It is to be understood that (i) the methods cannot replace the traditional welding processes and (ii) a particular welding method found suitable under the given conditions may not be equally efficient under other conditions. A careful selection of the process for a given metal joining problem is, therefore, essential. Before selecting the welding process to be employed the following aspects must be studied: (i) Physical parameters (ii) Properties of the work material and the type of weld (iii) Process capability (iv) Economic considerations. Hence, Researchers in the area of material science are developing materials having a high strength, hardness, toughness and other diverse properties. The welding of metals in such materials by traditional methods is still more difficult. So to meet such demands a different class of welding process has been developed.

In the recent years, a new solid-state joining technique popularly known as Friction stir welding (FSW) was invented and patented by The Welding Institute (TWI), United Kingdom in the year 1991 [Thomas et al., (1991)]. The need of FSW was brought-out in the first paragraph for the reason that FSW was eco-friendly [Mishra et al., (2005)] and applicable for high strength to weight ratio materials and does not exhibit welding defects like porosity and hot cracks [Knipstrom et al., (1997)].

1.2.1 UNDERSTANDING FSW

In solid-state welding, the accepted principle of weld formation is stated that the bonding occurs, when a pair of contamination-free surfaces is brought together in the range of inter-atomic-distances and the force utilized for bonding is the inter-atomic force. In most of the solid-state welding process, like forge welding, diffusion welding, friction welding, explosive welding, ultrasonic welding, roll bonding, etc., the bonding is established by generating fresh metal-to-metal contact by eliminating oxide layers and impurities from the interface under required pressure and temperature. These process conditions modify the base material interface to satisfy the solid-state welding condition and do not generate any additional surfaces in the material. In contrast, due to the third body (the FSW tool) interaction in FSW, additional interfaces are generated during the process. Finally, all the surfaces are coalesced with each other by the applied pressure and temperature, and thus, the sound solid-state weld is produced. Therefore, the mechanism of weld formation in FSW will be clearly known only when the role of the tool is understood. The material flow is an important tool to understand the role of the FSW tool on the of weld formation.

Friction stir welding (FSW) is a relatively new process to join metals such as Aluminium, magnesium and steel alloys in the solid state. The process consists of a rotating tool which is plunged into two sheet or plates tightly abutted along a weld line, which line is then traversed by the rotating tool. (In fact, for most FSW processes the sheets are moved and the rotating tool is held stationary, but the distinction is insignificant.) During the process, heat is generated by plastic deformation as well as by the friction between the tool and the work-pieces. The work-pieces are ultimately joined by the stirring action of the softened (but always solid) material. The advantages of FSW include low residual stress, low energy input, and fine grain size compared to the conventional liquid-solid welding method.

1.2.2 PROCESS AND TERMINOLOGY OF FSW MACHINE

The process and terminology of FSW are schematically explained in Fig. 1.2. The advancing side is the side where the velocity vectors of tool rotation and traverse direction are similar and the side where the velocity vectors are opposite is referred to as the retreating side. The process parameters are tool material, tool geometry, axial force, tool rotation speed, traverse speed and tool tilt angle. The tool tilt angle is the angle between the tool axis and the normal to the surface of the sheets being welded. Normally, the microstructural investigation reveals that the friction stir weldment has four different regions based on the microstructural features, namely weld nugget zone (NZ), thermo-mechanically affected zone (TMAZ), heat-affected zone (HAZ) and base or parent material (BZ).

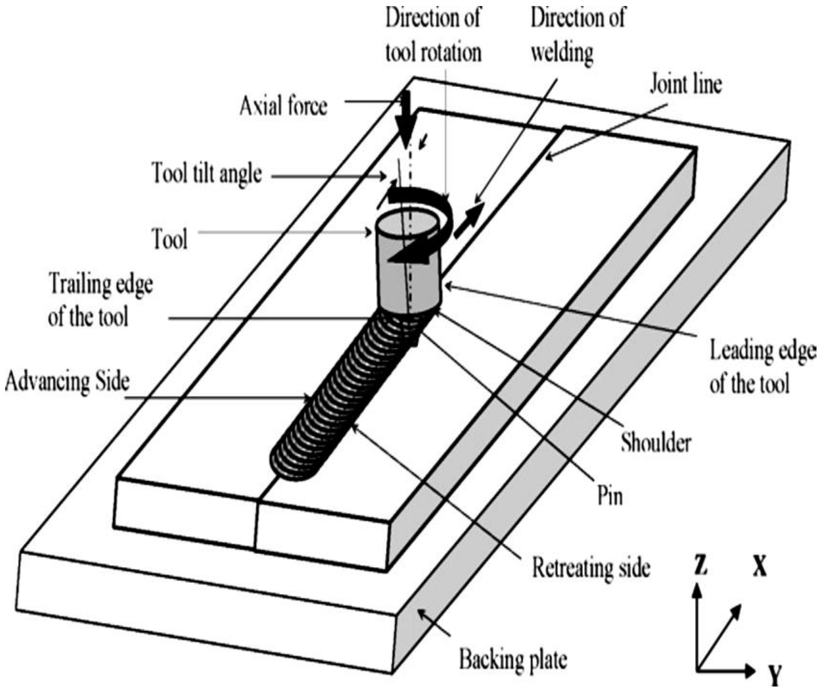


Fig. 1.2 The process and terminology of FSW

1.2.3 PRINCIPLE OF FSW

In FSW, the material that flows around the tool undergoes intense plastic deformation at elevated temperature, normally leading to a very fine (1–10µm) grain structure in the centre of the weld region. This region of the weld volume is commonly referred to as the “nugget”. Because the production of a fine-grained structure significantly affects mechanical properties, understanding the evolution of the FSW microstructure is of significant technological and scientific interest. Although the exact mechanisms are not well understood, the fine grain structure observed in the nugget has been usually attributed to dynamic re-crystallization. Several researchers have proposed that dynamic re-crystallization may occur continuously by rotation of existing sub grains or sub grains developed during processing within the parent microstructure. However, it is worth mentioning that all the proposed mechanisms regarding microstructure evolution during FSW have been based on observation of the final structure in the welded materials. The grain structures surrounding FSW tool were also studied using electron backscattered diffraction (EBSD) scans to reveal the development of grain structure during FSW. It was suggested that sub grains are formed ahead of the FSW tool during the processing. The sub grains gradually develop greater misorientations as they near the tool, while maintaining the same size, producing the final refined grain structure. However, the grain structure in the region very close to the pin tool was not characterized. In fact, it is very difficult to get clear EBSD patterns very close to the pin tool. Unfortunately, it is in this area that material undergoes the most severe plastic deformation at the highest temperature, which may have a significant effect on the resulting microstructure during FSW. It is logical that the final refined grain structures should be an evolution of the microstructures formed around the pin tool.

1.2.4 IMPORTANT PARAMATERS OF FWS TOOL

- Tool Design
- Tool tilt and plunge depth

1.2.5 APPLICATIONS OF FSW

- Shipbuilding and offshore
- Aerospace
- Automotive
- Railways
- Fabrication
- Robotics
- Personal computers
- Joining of aluminum 3D printing Material

1.2.6 ADVANTAGES OF FWS WELDING

- Good mechanical properties in the as-welded condition.
- Improved safety due to the absence of toxic fumes or the spatter of molten material.
- No consumables -A threaded pin made of conventional tool steel, e.g., hardened H13, can weld over 1 km (0.62 mi) of aluminium and no filler or gas shield is required for aluminium.
- Easily automated on simple milling machines -lower setup costs and less training.
- Can operate in all positions (horizontal, vertical, etc.), as there is no weld pool.
- Generally good weld appearance and minimal thickness under/over-matching, thus reducing the need for expensive machining after welding.
- Can use thinner materials with same joint strength.
- Low environmental impact.
- General performance and cost benefits from switching from fusion to friction.

1.2.7 DISADVANTAGES OF FWS WELDING

- Exit hole left when tool is withdrawn.
- Large down forces required with heavy-duty clamping necessary to hold the plates together.
- Less flexible than manual and arc processes (difficulties with thickness variations and non-linear welds).
- Often slower traverse rate than some fusion welding techniques, although this may be offset if fewer welding passes are required.

1.3 INTRODUCTION TO TIG WELDING

TIG stands for tungsten inert gas welding or sometimes this welding is known as gas tungsten arc welding. In this welding process, the heat required to form weld is provided by a very intense electric arc which is form between tungsten electrode and work piece. In this welding a non-consumable electrode is used which does not melt. Mostly no filler material is required in this type of welding but if it required, a welding rod fed into the weld zone directly and melted with base metal. This welding is mostly used for welding aluminum alloy.

1.3.1. UNDERSTANDING TIG WELDING

TIG welding is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmosphere by an inert shielding gas (argon or helium), and a filler metal is normally used. The power is supplied from the power source (rectifier), through a hand-piece or welding torch and is delivered to a tungsten electrode which is fitted into the hand piece. An electric arc is then created between the tungsten electrode and the work piece using a constant-current welding power supply that produces energy and conducted across the arc through a column of highly ionized gas and metal vapours. The tungsten electrode and the welding zone are protected from the surrounding air by inert gas. The electric arc can produce temperatures of up to 20,000°C and this heat can be focused to melt and join two different parts of material. The weld pool can be used to join the base metal with or without filler material. Schematic diagram of TIG welding and mechanism of TIG welding are shown in fig. 1.3 respectively.

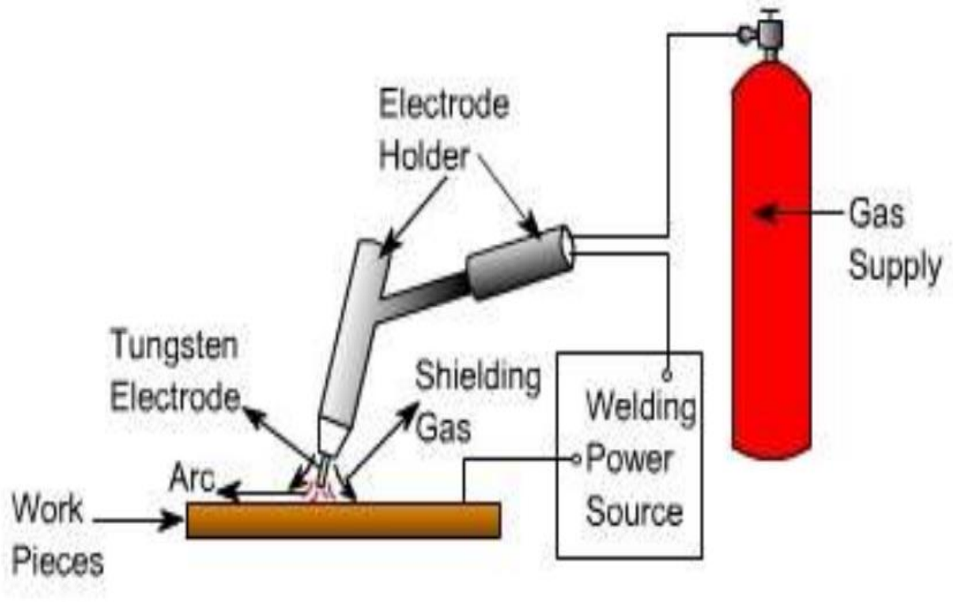


Fig. 1.3 Schematic Diagram of TIG Welding

1.3.2. PRINCIPLE OF TIG WELDING

In a TIG welding process, a high intense arc is produced between tungsten electrode and work piece. In this welding mostly work piece is connected to the positive terminal and electrode is connected to negative terminal. This arc produces heat energy which is further used to join metal plate by fusion welding. A shielding gas is also used which protect the weld surface from oxidization.

1.3.3 THE WORKING OF TIG WELDING

In the process, the low voltage high current supplied by a power source to welding or tungsten electrode. The electrode is connected to a negative terminal and the workpiece is connected to a positive terminal.The supplied current form a spark between the tungsten electrode and the workpiece. Tungsten is a non-consumable electrode that gives a highly intense arc. This arc produces intense heat and it melts base metal which forms a welding joint. Shielded gases like argon, helium is supplied via pressure valve and regulating valve to the welding torch. The shielded gases form a shield around the weld and do not allow to enter oxygen and other reactive gases. Also, these shielded gases create a plasma that increases the heating capability of arc for better welding. While welding thin material there is no filler is required but to make thick joints require some filler material in the form of the rod to fed manually by a welder into welding.

1.3.4 PARTS OF TIG WELDING

- **POWER SOURCE**

  The main part of welding is a power source. There is a high current power source is needed for TIG welding. This welding uses both AC and DC power sources. The DC current is used for stainless steel, Mild Steel, Copper, Titanium, Nickel alloy, etc. AC current is used for aluminum, aluminum alloy, and magnesium. In the power source, there is a transformer, a rectifier, and electronic controls. The 10-35 V and 5-300 A current required for arc generation.

- **THE TORCH**

  Tig torch is most important in TIG Welding. The torch has three main parts tungsten electrode, collets, and nozzle. The torch has either water-cooled or air-cooled. The collet holds the tungsten electrode. They are available in various diameters according to a diameter of the tungsten electrode. The arc and shielded gases are flowing into the welding zone via a nozzle. The cross-section of the nozzle is small which gives high intense arc.

- **SHELDING GAS**

  Generally, argon and other inert gases are used as shielding gas. The importance of shielding gas is it protects the weld from oxidization. The shielded gas protects the welding area from oxygen and other gases from the atmosphere. There is different inert gases are used according to metal. The shielded gases are regulated by the system into welding.

- **FILLER MATERIAL**

  For welding of thin sheets, no filler is used but thick weld filler material is used. A filler material is used in the form of rods and feeds directly during welding manually.

1.3.5 APPLICATIONS OF TIG WELDING

- TIG Welding is widely used to weld aluminum and aluminum alloys.
- It is also used to weld stainless steel, carbon base alloy, copper base alloy, nickel base alloy, etc.
- It is also used to weld dissimilar metals.
- TIG welding is widely used in aerospace industries.

1.3.6 ADVANTAGES OF TIG WELDING

- TIG Welding provides a stronger joint com14pared to shield arc welding.
- The joint made with tig welding is corrosion resistant and ductile.
- With this welding, a wide verity of joint designs can form.
- This welding type doesn’t require a flux.
- The process is automated.
- This is suitable for thin sheets.

- It provides excellent surface finish as there is almost no metal splatter.
- The flawless joint can create due to a non-consumable electrode.
- A welder has more control over welding than other welding types.
- It works on both AC and DC current as a power supply.

1.3.7 DISADVANTAGES OF TIG WELDING

- It can weld up to a thickness of about 5 mm.
- Require high skill labor.
- It has a high initial or setup cost compare to arc welding.
- This is a slow welding process.

CHAPTER-2

LITERATURE REVIEW

Norman et al. (2003) investigated that small addition of scandium (Sc) in Al aerospace alloys (AA2024 and AA7475). They studied the weldability and mechanical properties of MIG/TIG welded joint of these alloys.

Mandal (2005) documented about Aluminium welding, and he reported that the friction stir welding technique is derived from the conventional friction welding. This welding process is mainly suited for Aluminium and its alloys.

Polmear (2006) Al-Mg-Mn alloys are widely used for their good weldability and formability. In the annealed state, these alloys exhibit low-to-moderate strengths ranging from 90 to 160 MPa for different Mg contents.

Belov et al. (2007) studied the Al-Mg-Mn alloys with additions of Sc-Zr. They observed that the Al-Mg-Mn-Sc-Zr was a promising light-weight material in the class of Aluminium alloys can be used in low-density systems which exhibit high strength, good weldability and corrosion resistance.

HE Zhen-bo et al. (2011) compared friction stir welding (FSW) and tungsten inert gas (TIG) for properties of Al-Mg-Mn-Sc-Zr alloy with hot rolled plate and cold rolled conditions. Their results showed that compared with the base metal, the strength of FSW and TIG welded joints decreased, and the FSW welding coefficients were higher than the TIG welding coefficients. They concluded that for each condition of Al-Mg-Mn-Sc-Zr alloy, the tensile strength, elongation and welding coefficient of FSW welded joints are higher than those of TIG welded joints.

Jau-WenLin et al. (2014) observed that the notch tensile strength and the notch strength ratio for FSW (212 MPa, 1.10) are significantly higher than those (190 MPa, 1.02) of TIG welding. For the impact tests, the weld zone and heat-affected zone energy absorption values for FSW (2.87 J, 2.25 J) are higher than those (1.32 J, 0 J) of TIG welding. XRD tests are performed to determine components of copper before and after welding process for TIG and FSW.

Ranjit Bauri et al. (2015) observed that no defect obtained at tool rotational speed of 1200 rpm and traverse speed of 24 mm/min and vertical load 8kN for in 5083 Al+Ni particles metal matrix composite.

Guofu_Xu et al. (2016) observed that Al-5.8%Mg-0.4%Mn-0.25%Sc-0.10%Zr(wt.%) alloy was successfully welded by tungsten inert gas (TIG) and friction stir welding (FSW) techniques, respectively, The TIG welded joint fails in the heat-affected zone and the fracture of FSW joint is located in stirred zone. Al-Mg-Mn-Sc-Zr alloy is characterized by lots of dislocation tangles and secondary coherent Al3(Sc, Zr) particles.

Srinivasa Rao et al. (2018) studied the effect of minor additions of scandium and zirconium to Al-Mg-Mn alloys. They observed that Scandium (0.2 – 0.6 wt. %) and zirconium (0.1wt. %) addition introduce an appreciable improvement in the mechanical properties to mechanical properties of Al-Mg-Mn alloys.

Srinivasa Rao et al. (2018) observed that the better mechanical properties are obtained at tool rotational speed of 1132 rpm and traverse speed of 26.26 mm/min and vertical load 9.6 kN for Al-Mg-Mn-Sc-Zr alloys.

Pian Xu et al. (2018) observed that Al-Mg-Sc-Zr alloy plates were welded by variable polarity plasma arc welding (VPPAW) with Sc-containing filler wire, show that the weld zone and heat-affected zone (HAZ) are narrow due to the high concentrated heat input of VPPAW.

Husain Mehdi et al. (2019) observed that the experimental result of TIG, FSW and (TIG + FSP) welded joint. Coarse grain structure was observed in TIG welding and fine grain structure was observed in FSP process. In addition, very fine grain structure we observed in stir zone due to the effect of intense plastic deformation and temperature during TIG + FSP.

Jiqiang Chen et al. (2019) observed that the microstructure and property exhibited significant difference between the two frictions stirs weld joints. The weld efficiency of the FSW joint developed using base metal in HR condition is over 90%, while that of the FSW joint developed using base metal in T6 condition is only 70%. The hardness of the weld nugget of HR joint is obviously higher than that of the weld nugget of T6 joint, due to the different changes in the original precipitates during the friction stir welding process.

CHAPTER-3

OBJECTIVE AND METHODOLOGY

3.1 OBJECTIVE

The main objective of the present work is to study the effect of FSW and TIG welding processes on the mechanical properties (Ultimate tensile strength, Hardness, Bending strength, Impact strength) of Al-Mg-Mn-Sc-Zr Alloy.

3.2 METHODOLOGY

- Preparation of Al-Mg-Mn-Sc-Zr alloy plates using stir casting.
- Bead on plate welding using FSW and TIG welding processes.
- Preparation of specimens for tensile test, hardness test, 3-point bend test and impact test.
- FSW and TIG Welded joints specimens is tested for measurement of hardness, ultimate tensile strength, %elongation, bending strength, and impact strength.

CHAPTER-4

EXPERIMENTATION

4.1 INTRODUCTION

In the present study, the aluminium alloys Al–4.2Mg– 0.6Mn alloy was produced by melting in an electrical resistance furnace (Fig. 4.1a). This alloy was prepared by stir casting, using Al–4.2Mg–0.6Mn alloy and three master alloys (Al–10wt% Mg, Al–2wt%Sc and Al–5wt% Zr), that was melted in alumina crucible and then poured into a metal mould. The casting process is as shown in (Fig. 4.1a–d).

(a) Electrical Resistance Furnace (b)Pouring molten mixture into the preheated permanent mould (c)Al-Mg-Mn-Sc-Zr as cast plate (d)Cold rolling of plate
Fig..4.1 Fabrication process of Al-Mg-Mn alloy

The final temperature of the melt was always maintained at 1000 ± 15ºC with the help of the electronic controller. Then, the melt was homogenized under stirring at 900ºC. Casting was done in mild steel metal mould with graphite paste (die coat) as mould releasing agent preheated to 200ºC. After casting, the plates were machined into 150 X 150 X 6 mm^3 using wire-cut electric discharge machine, then cold-rolled to 5 mm-thick sheets. Al-Mg-Mn-Sc-Zr alloys were fabricated by melting in an electrical resistance furnace (stir casting) as shown in Fig. 4.1

4.2 FRICTION STIR WELDING MACHINE

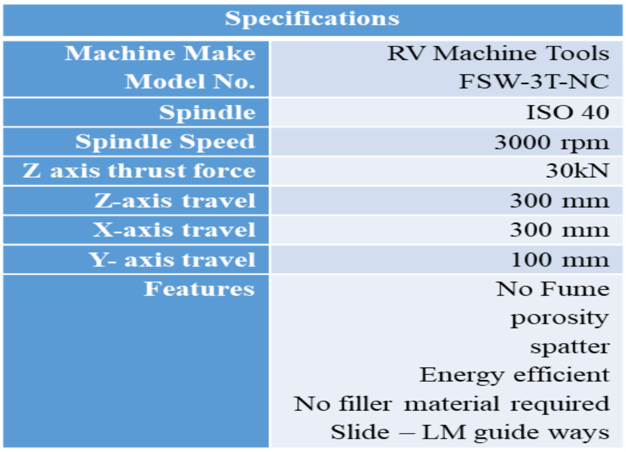
The machine is a computer numerical controlled Friction Stir welding and attached with the necessary instruments and accessories. The FSW Machine and its control panel are used in the experimental work with its specifications are shown in Fig. 4.2.

Fig 4.2 FSW Machine machine

Fig 4.3 FSW Experimental setup

FSW machine was used to make the Al-Mg-Mn-Sc-Zr alloy bead on plate weld joint using a H13 tool steel cylindrical pin profile tool. Fig. 4.3 shows the fixing of plate on FSW machine. The FSW Process parameters and corresponding values is shown in Table 4.3

Table 4.1 Specifications of FSW



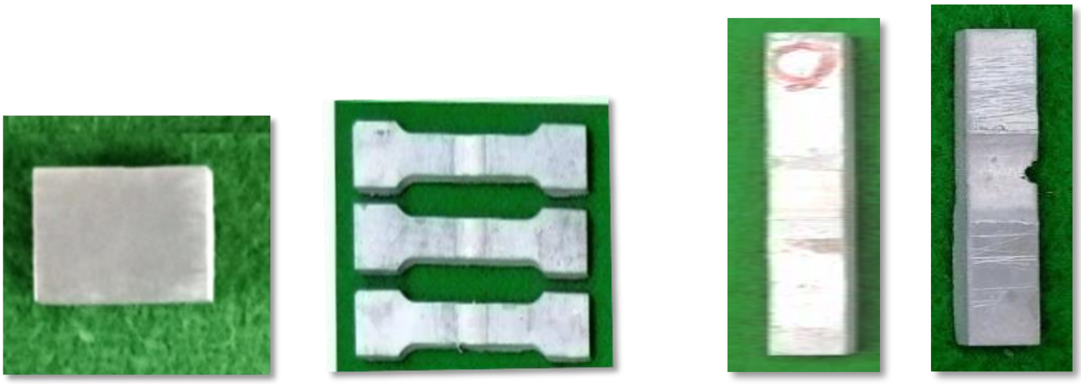
Specifications	
Machine Make Model No.	RV Machine Tools FSW-3T-NC
Spindle	ISO 40
Spindle Speed	3000 rpm
Z axis thrust force	30kN
Z-axis travel	300 mm
X-axis travel	300 mm
Y- axis travel	100 mm
Features	No Fume porosity spatter Energy efficient No filler material required Slide – LM guide ways

Table 4.3 FSW process parameters

Applied Load	Tool Rotational Speed	Tool traverse speed
kN	rpm	mm/min
10	1200	25

4.2.1 FSW SPECIMEN PREPARATION

The cold rolled Al-Mg-Mn-Sc-Zr plate was welded by FSW machine and this was cut in standard specimen shapes and dimensions the standard specimens for hardness measurement, ultimate tensile strength, bending strength and impact strength were machined from the Friction stir welded plate as shown in Fig. 4.4



(a) Hardness (b) Tensile (c) Bending (d) Impact test

Fig 4.4 FSW Specimens

4.3 TIG WELDING MACHINE

Gas tungsten arc welding (GTAW), also known as Tungsten Inert Gas (TIG) welding. Using an inert gas shield instead of a slag to protect the weld pool, the process was a highly attractive replacement for gas and manual metal arc welding. TIG has played a major role in the acceptance of aluminium for high quality welding and structural applications. In the TIG process the arc is formed between a pointed tungsten electrode and the workpiece in an inert atmosphere of argon or helium. The small intense arc provided by the pointed electrode is ideal for high quality and precision welding and input parameters were Current (160 A), Voltage (14 V), Travelling speed (55 mm/min) and Gas flow rate (16 lpm). The experimental setup is shown in the Fig. 4.5

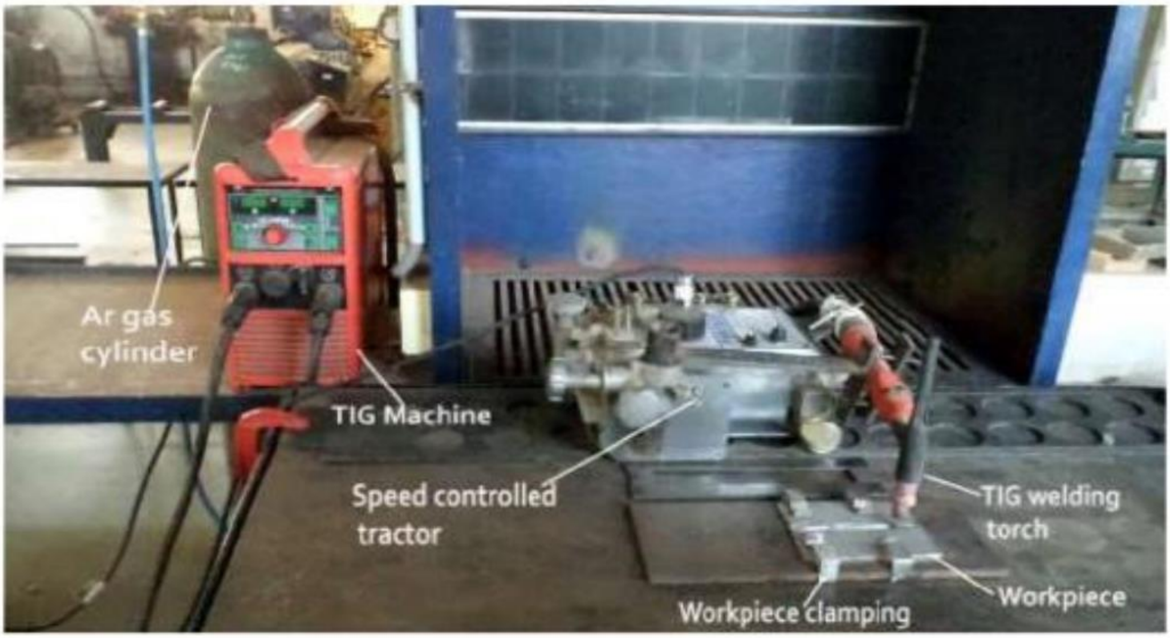
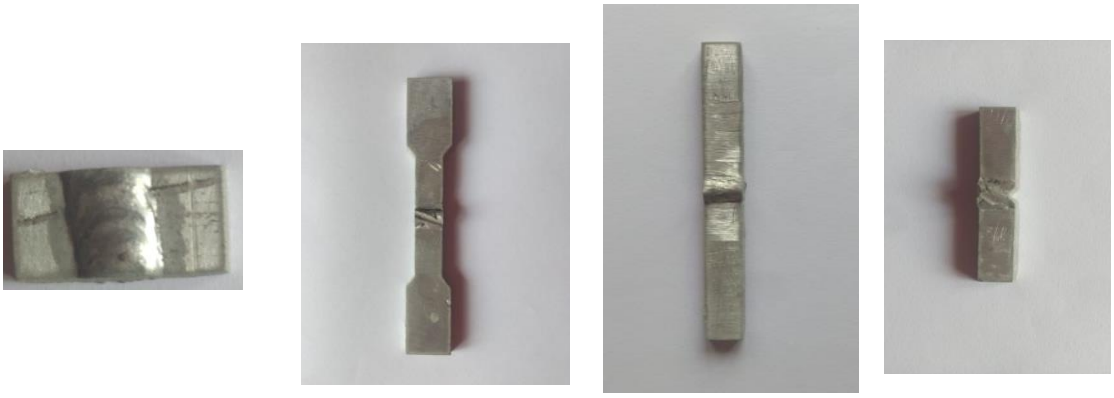


Fig 4.5 TIG Welding Experimental Setup

4.3.1 TIG SPECIMEN PREPARATION

The cold rolled Al-Mg-Mn-Sc-Zr plate was welded by MIG machine and this was cut in standard specimen shapes and dimensions**.** The standard specimens for hardness measurement, ultimate tensile strength, bending strength and impact strength were machined from the TIG welded plate as shown in Fig. 4.6



Hardness test specimen

Tensile test specimen

3-point bend test specimen

Impact test specimen

Fig 4.6 TIG Welded Specimens

4.4 MECHANICAL PROPERTIES

4.4.1 Vickers Micro Hardness Measurement of the FS Welds and TIG Welds

The Vickers microhardness of the welded joints were measured on a 401MVD Vickers microhardness tester on the transverse section of the welded joints. Vickers microhardness tester by applying 200g load for 10 seconds. The hardness specimen was cut to standard sub dimensions as 30 mm X 15mm X 5 mm.

Fig. 4.7 Vickers micro hardness tester

4.4.2 Tensile Test of the FS welds and TIG welds

Three testing samples were prepared from each joint and put under tensile testing on universal testing machine. Tensile tests were done according to the standards of ASTM E8 with constant cross head speed by using TUE-C-600 model universal testing machine to achieve material’s parameters such as ultimate strength, yield strength, and % elongation. Tensile specimens were machined to standard sub-specimens of 50-mm gauge length and 12.5 X 5 mm^2 cross-sectional area. Ultimate strength, yield strength, and % elongation was recorded after averaging of three data points.

Fig 4.8 UTM and Tensile test specimen

4.4.3 Bending Test of the FS Welds and TIG Welds

The three-point bend tests were performed to evaluate the bending strength of the test specimens with mandrel size 4t (t is thickness of the specimen) shown in fig 4.9. The size of the specimen was 100 X10 X 5 mm^3. Two specimens for each alloy were tested and averaged.

Fig 4.9 UTM and Bending test specimen

4.4.4 Impact Test of the FS welds and TIG Welds

The Charpy V-notch impact tests were performed using Krystal Elmec, model KI 300, range-168 J shown in Fig. 4.10 to know the actual energy observed by the specimens. The standard specimen size for Charpy impact testing was 10 X 10 X 55 mm^3 containing 45^o V-notch, 2 mm deep with a 0.25 mm root radius. Three specimens for each composition were tested and averaged.

Fig 4.10 Impact test equipment and impact test specimen

CHAPTER-5

RESULTS AND DISCUSSION

5.1 INTRODUCTION

Aluminum alloys are widely used in marine, aerospace, automobile industries, railway vehicles, bridges, offshore structure topsides and high-speed ships due to its lightweight, corrosion resistance and higher strength to weight ratio. In all cases, welding is the primary joining method which has always, represents great challenge for designers and technologies. This present study focuses on comparison of mechanical properties of un welded, Friction stirs welded and TIG welded components to show better welding technique. The results of un welded components are obtained for literatures by many research workers and results of FS welds and TIG welds were studied in this work.

5.2 Chemical Composition of fabricated alloy

The chemical composition of the Al-Mg-Mn-Sc-Zr alloy is shown in table 5.1 and mechanical properties are tabulated in Table 5.2.

Table 5.1 Chemical composition of the Al-Mg-Mn-Sc-Zr alloy

Alloy type	Mg	Mn	Si	Cr	Zn	Ni	Li	Sc	Zr	Bal.
Al-Mg-Mn-Sc-Zr alloy	4.20	0.60	0.17	0.10	0.06	0.006	0.001	0.41	0.11	Al

Table 5.2 Mechanical Properties of the Al-Mg-Mn-Sc-Zr alloy

Alloy type	H (VHN)	UTS (MPa)	%E	BS (MPa)	IS (KJ/m^2)
Al-Mg-Mn-Sc-Zr alloy	139	260.4	7.4	3480	2.8

5.3 Comparison of Mechanical Properties

5.3.1 Effect of FSW welding process on Mechanical Properties of Al-Mg-Mn-Sc-Zr alloy

It can be seen that the hardness, ultimate tensile strength (UTS), %elongation, bending strength and impact strength of Al-Mg-Mn-Sc-Zr alloy are higher than those of FS welded Al-Mg-Mn-Sc-Zr alloy.

Table 5.3 Mechanical Properties of fabricated Alloys

Alloy type	H (VHN)	UTS (MPa)	%E	BS (MPa)	IS (KJ/m^2)
Friction stir welded Al-Mg-Mn-Sc-Zr alloy	111	238.54	4.9	3325	11.25

FSW change the material strength due to fine-grain refinement in the stir zone in Al-Mg-Mn-Sc-Zr alloy and therefore FS welded Al-Mg-Mn-Sc-Zr alloy exhibited 91.6% of joint efficiency.

5.3.2 Effect of TIG welding process on Mechanical Properties of Al-Mg-Mn-Sc-Zr alloy

Table 5.4 Mechanical Properties of fabricated Alloys

Alloy type	H (VHN)	UTS (MPa)	%E	BS (MPa)	IS (KJ/m^2)
TIG welded Al-Mg-Mn-Sc-Zr alloy	94	157.86	4.6	3215	3.8

5.3.3 Effect of welding processes on Hardness

At the weld center the micro hardness values of FSW and TIG welded joints are the lowest compared to non-welded alloy which is caused due to softening of the material at the central part of the welded specimens. The micro hardness of the TIG welded joint is lower than the FSW welded joint.

5.3.4 Effect of welding processes on Tensile strength

It can be seen that the improvement in the mechanical properties of the FSW welded joint compared to TIG welded joint. The obtained tensile strength of FSW joint is 238.54 MPa and TIG welded joint is 157.86 MPa, where as non-welded alloy’s strength is 260.40 MPa. FSW change the material strength due to fine-grain refinement in the stir zone in Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr and therefore FS welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr exhibited 91.6% of joint efficiency and 69.8% of joint efficiency in TIG welded alloy.

5.3.5 Effect of welding processes on Impact strength

The highest impact strength (11.25KJ/m^2) obtained for FS welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy due to fine grains in the stir zone produces tiny dimples, which leaded to improved strength. This strength is obtained by calculating the ratio of actual energy observed to its cross-sectional area.

5.3.6 Effect of welding processes on bending strength

The lowest bending strength observed in TIG welded alloy and high bending strength achieved in non-welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy. It is also observed that the bending strength increased with the increase of tensile strength.

5.3.7 Effect of welding processes on Microstructure

The optical micrograph of Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy is shown in Fig. 5.1(a). The fragmentation of Al3Mg2 and Al3Sc1−xZrx intermetallic and the average grain size vary from 15 to 25µm with the distribution of dentric structure and spherical particles. Fig. 5.1(b) represent the microstructure of the FS welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr consists of fine grains in the stirred zone with an average grain size less than 2µm. This reduction in grain size depends on FSW parameters.

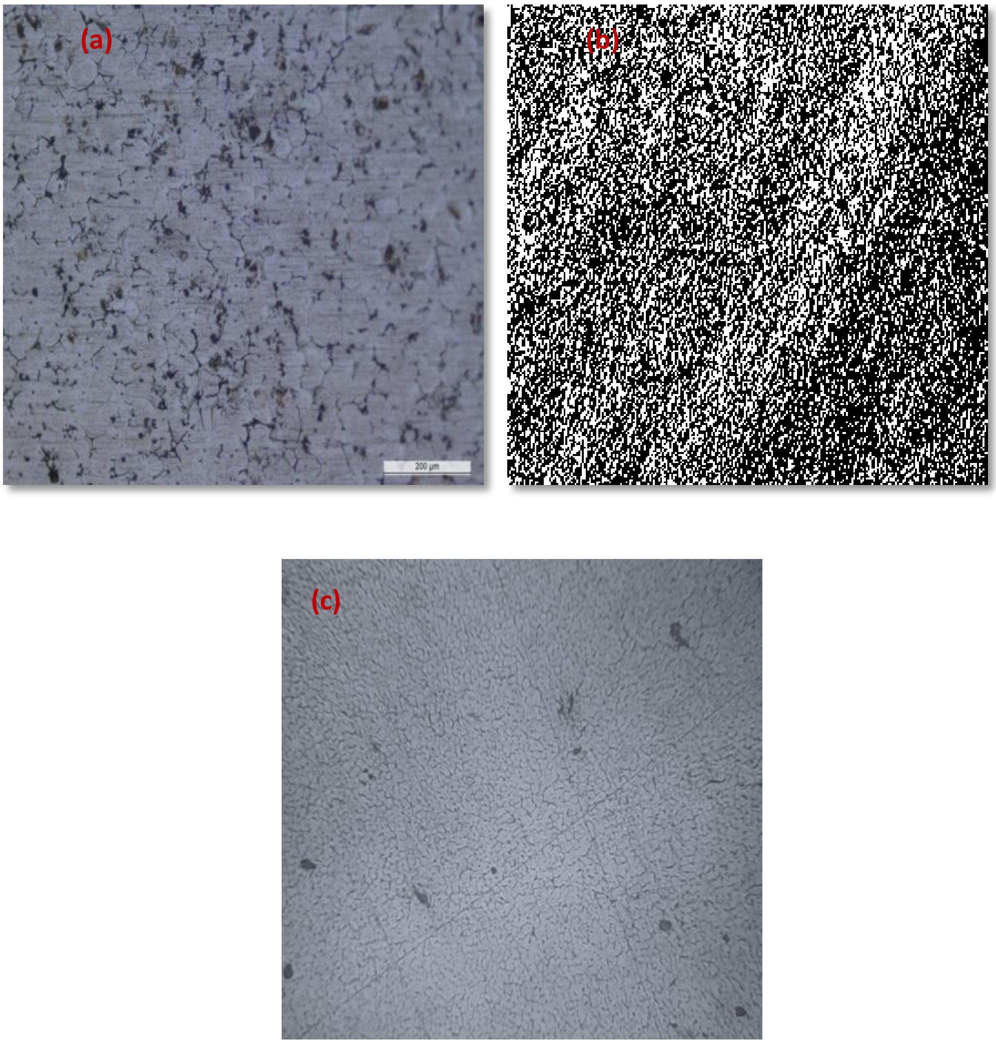


Fig. 5.1 Optical Micrograph (a) Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr
(b) FS welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr (c) TIG welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr

Fig. 5.1(c) shows the microstructure of TIG welded alloy which consists of very fine interdendritic network with finely dispersed intermetallic particles in the matrix of aluminium solid solution. The microstructural change in TIG welded joint and FSW welded joint is occurred due to the high and low temperatures in the weld centers respectively.

CHAPTER-6

CONCLUSION AND FUTURE SCOPE

6.1 CONCLUSION

- Al-Mg-Mn-Sc-Zr alloys were successfully fabricated by stir casting technique.
- FSW and TIG welding processes were successfully applied to Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy plates.
- Considerable amount of refinement of grains along with the precipitate formations was observed in FSW welded joint of the investigated alloy compared to MIG welding and non-welded alloy
- Al-Mg-Mn-Sc-Zr alloy achieved the mechanical properties, i.e., Hardness (139 VHN), Ultimate tensile strength (260.4 MPa), Bending strength (3480 MPa), Impact strength (2.8KJ/m2) and % elongation is 7.4.
- Friction Stir Welded Al-Mg-Mn-Sc-Zr alloy achieved the mechanical properties, i.e., Hardness (118.98 VHN), Ultimate tensile strength (238.54 MPa), Bending strength (3325 MPa), Impact strength (11.25 KJ/m2) and % elongation is 4.9 was obtained.
- Friction Stir Welded Al-Mg-Mn-Sc-Zr alloy achieved the mechanical properties, i.e., 85.5 % Hardness, 91.6% Ultimate tensile strength, 95.5 % Bending strength, 401.78 % Impact strength and % elongation is 66.2% was obtained when compared to that of non-welded Al-Mg-Mn-Sc-Zr alloy.

- TIG Welded Al-Mg-Mn-Sc-Zr alloy achieved the mechanical properties, i.e., Hardness (94 VHN), Ultimate tensile strength (157.86 MPa), Bending strength (3215 MPa), Impact strength (3.8 KJ/m2) and % elongation 4.6 was obtained.
- TIG Welded Al-Mg-Mn-Sc-Zr alloy achieved the mechanical properties, i.e., 67.62 % Hardness, 60.62 % Ultimate tensile strength, 92.385 % Bending strength, 135.71% Impact strength and % elongation is 66.1% was obtained when compared to that of non-welded Al-Mg-Mn-Sc-Zr alloy.

6.2 FUTURE SCOPE

- The present work further extended to validate in FEA softwares.
- Fatigue studies can be done on the fabricated alloy
- Tensile tests of the fabricated alloy can be conducted at wide range of temperature
- Effect of other welding processes also can be studied on the fabricated alloy.

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