EFFECT OF FSW AND MIG 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

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IN

MECHANICAL ENGINEERING

Submitted By

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CERTIFICATE

This is to certify that the Project Report entitled **"EFFECT OF FSW AND MIG WELDED PROCESSES ON MECHANICAL PROPERTIES OF AL-4.2MG-0.6MN-0.4SC-0.1ZR ALLOY WELDED JOINTS"** being submitted by KELLI HARITHA LAVANYA (317126520141), KANTA AKHIL (317126520138), PILLA JASWANTH SAI PAVAN (317126520160), KILLO UTTEJ (317126520142), 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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DECLARATION

We, the undersigned, hereby declare that this "**Thesis"** under the title of "**EFFECT OF FSW AND MIG 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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CONTENTS

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. The aim of the present work was to examine the effect of Metal inert gas welding (MIG) and friction stir welding (FSW) welding processes on mechanical properties of 0.4Sc and 0.1Zr added Al-Mg-Mn alloy plates. This research includes the preparation of plates with the aid of stir casting using three master alloys namely Al-10%Mg, Al-2%Sc and Al-5%Zr along with Al-Mg-Mn alloy. The rolled plates were carried out for tensile tests, hardness measurement, impact strength and microstructural observations. The results allowed us to identify the influence of MIG and FSW welding processes on the mechanical and topography of the investigated alloy. Inferior mechanical properties obtained for FSW and MIG welded joints compared with non-welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy. The more precipitation refinement improved the mechanical properties in FSW joints compared with MIG welded joints. These results can stand as a basis for selecting the welding process of Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy.

LIST OF FIGURES

LIST OF TABLES/CHARTS

NOMENCLATURE

H	-	Hardness
UTS	-	Ultimate tensile strength
%E	-	percentage elongation
BS	-	Bending strength
IS	-	Impact strength
MIG	-	Metal Inert Gas
FSW	-	Friction Stir 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 fulfill the requirement for such applications.

1.1.1 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 Figure 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). 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.

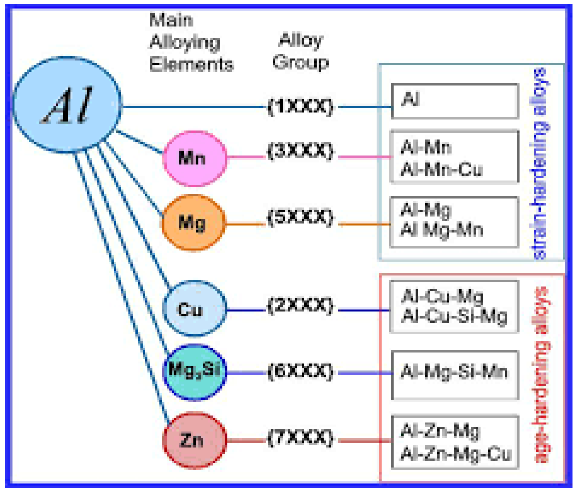

Figure 1.1 Classification of Aluminium alloys

1.1.2 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) intermetallics. These alloys are work-hardenable 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.

1.2 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 Defense 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 Figure 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).

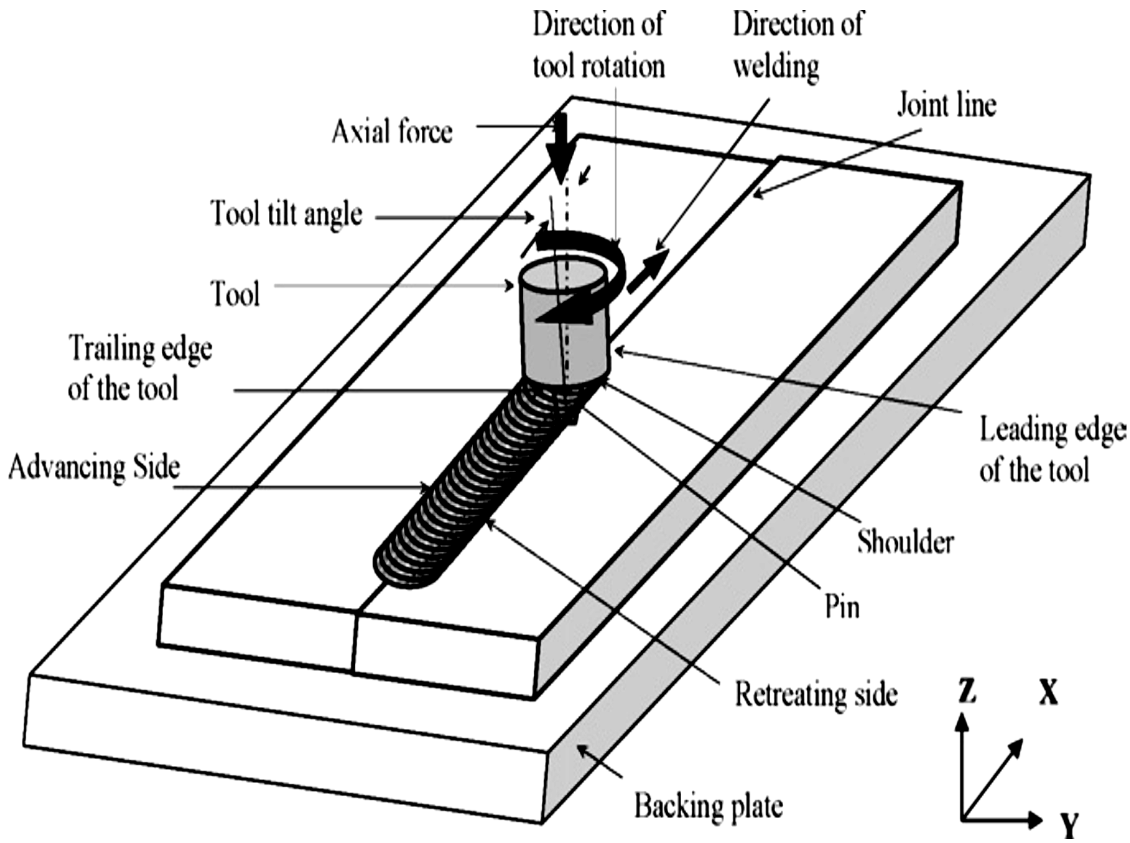

Figure 1.2 The process and terminology of FSW

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 center 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 subgrains or subgrains 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 subgrains are formed ahead of the FSW tool during the processing. The subgrains 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.

1.3 INTRODUCTION TO MIG WELDING

MIG welding (also known as GMAW) is a really popular type of welding that's frequently used for welding low-alloy steels. The schematic drawing of MIG welding is shown in Figure 1.3. The MIG process is an arc welding process which joins metals together by heating them with an electric arc formed between a wire electrode and the workpiece.

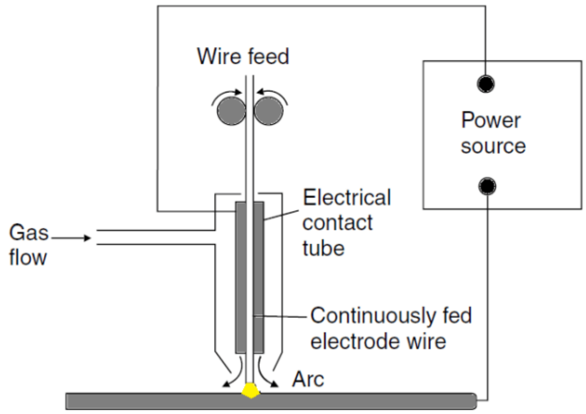

Figure 1.3 Schematic diagram of MIG Welding

The wire electrode is fed through a MIG gun which is connected to a MIG welder and is consumed into the molten weld pool. A shielding gas is also released through the MIG gun to protect the arc and weld puddle from being contaminated by the atmosphere

1.3.2. UNDERSTANDING MIG WELDING

MIG/MAG welding is a versatile technique suitable for both thin sheet and thick section components. The welding set up is shown in Figure 1.4. In this welding an arc is struck between the end of a wire electrode and the workpiece, melting both of them to form a weld pool. The wire serves as both heat source (via the arc at the wire tip) and filler metal for the welding joint. The wire is fed through a copper contact tube (contact tip) which conducts welding current into the wire. The weld pool is protected from the surrounding atmosphere by a shielding gas fed through a nozzle surrounding the wire. Shielding gas selection depends on the material being welded and the application. The wire is fed from a reel by a motor drive, and the welder moves the welding torch along the joint line. Wires may be solid (simple drawn wires), or cored (composites formed from a metal sheath with a powdered flux or metal filling). Consumables are generally competitively priced compared with those for other processes. The process offers high productivity, as the wire is continuously fed.

Manual MIG/MAG welding is often referred as a semi-automatic process, as the wire feed rate and arc length are controlled by the power source, but the travel speed and wire position are under manual control. The process can also be mechanised when all the process parameters are not directly controlled by a welder, but might still require manual adjustment during welding. When no manual intervention is needed during welding, the process can be referred to as automatic.

The process usually operates with the wire positively charged and connected to a power source delivering a constant voltage. Selection of wire diameter (usually between 0.6 and 1.6mm) and wire feed speed determine the welding current, as the burn-off rate of the wire will form an equilibrium with the feed speed.

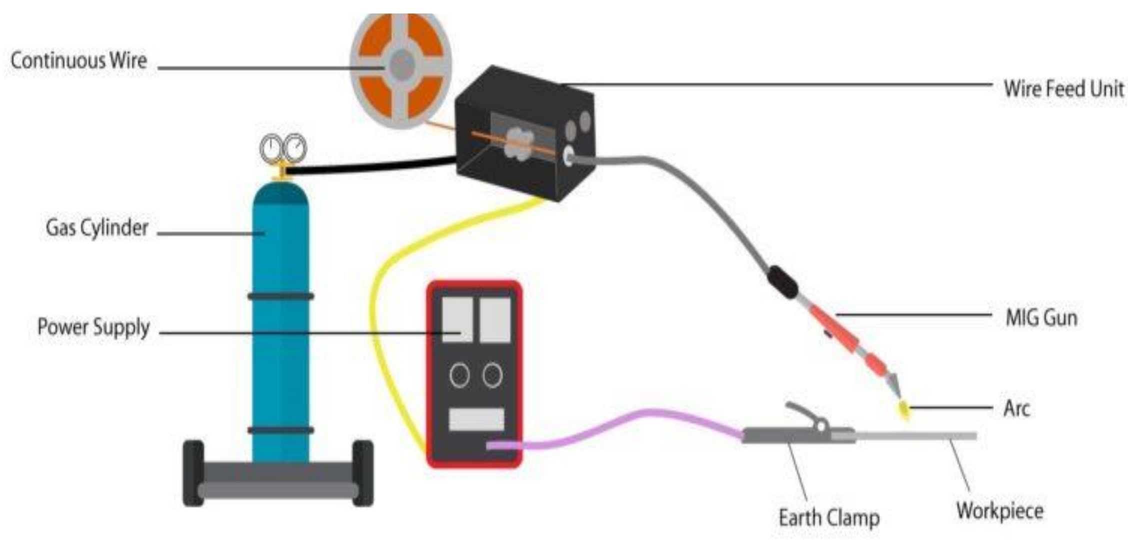

Figure 1.4 MIG Welding Setup

1.3.3. PRINCIPLE OF MIG WELDING

In a MIG 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.

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CHAPTER-II

LITERATURE REIVEW

Roder et. al. (1996), Aiura et al. (2000) investigated on the Al–Mg–Mn alloys with the additions of scandium.

Svensson et. al., (2000) evaluated mechanical properties of Aluminium alloys AA5083 subjected to friction stir welds where AA5083 alloy got fractured near center of the weld and hardness was constant across the weld. The grain size in AA5083 alloy is nearly 10 micro meter. Sound welds are obtained with FSW process for a range of plate thickness with different welding parameters. Welding process affected the particles in material such as larger particles will get little fractured compared to smaller particles.

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.

Røyset and Ryum (2005) observed that Zr was another transition element could be used for refining the structure and for fast precipitation of intermetallics with combination of Sc in aluminium alloys and it could reduce the level of Sc addition.

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.

Okuyucu et. al., (2007) developed a model using ANN for the analysis and simulation of the correlation between friction stir welding (FSW) parameters of aluminium plates and mechanical properties of the welded joint. The process parameters consist of weld speed and tool rotation speed verses the output mechanical properties of weld joint, namely: tensile strength, yield strength, elongation, hardness of WZ and hardness of HAZ. Good performance of the ANN model was achieved and the model can be used to calculate mechanical properties of the welded plates as a function of process parameters.

Balasubramanian et al., (2008) studied the high strength aluminium alloy joints produced by gas metal arc welding and gas tungsten arc welding under the effect of continuous current and pulsed current technique. Pure argon used as a shielding gas. The pulsed current gas metal arc weld joints produced high strength values and high joint efficiency than other welded joints. Due to that International Journal of Engineering Research & Technology Conference Proceedings Volume 5, Issue 13 Special Issue - 2017 1of fine grains the Base metal and heat affected zone regions produced high hardness values than weld metal. Pulsed current gas tungsten arc weld joints produced high highness values and continuous current gas metal arc weldjoints produced low hardness values. A very fine grain in the welded region was produced by the pulsated current gas metal arc welding

Lakshminarayanan et al., **(2009)** investigated the AA6061 Aluminium alloy joints mechanical properties welded by gas metal arc welding, gas tungsten arc welding and friction stir welding. Single V joint configuration, pure argon shielding gas and AA4043 filler wire were used for the gas metal arc welding and gas tungsten arc welding. Non consumable high carbon steel tool was used for the friction stir welding. Diamond compound was used for a final polishing. The friction stir weld joints produced the high strength values than GMAW and GTAW. The strength value 34% higher than the GMAW and 15% higher than the GTAW. The base metal and heat affected zone produced the high hardness values than the weld metal. FSW produced the high hardness value and GMAW produced low hardness value. Equiaxed uniformly distributed fine grains increased the high tensile properties in the weld region for FSW joints.

Ghazvinloo et al., **(2010)** analyzed robotic MIG welding AA6061 fatigue life, impact and bead penetration properties under the effect of welding speed, voltage and current. 2.35 mm and 10mm thickness 60 degree V groove plates were welded by using 1mm diameter ER5356 filler material. The welding parameters welding speed, voltage and current were varied during the process. The increased voltage and current reduced the fatigue life but the welding speed increased the fatigue life. Decreased welding speed and increased current voltage improved the impact energy. Bead penetration mainly influenced and depends on the welding current.

Kaiser and Banerjee and Srinivasa Rao et al., (2010) tested Al–Mg–Mn alloys with Sc additions, who concluded that the effect of Sc addition was well-defined on yield stress than tensile strength. Al–Mg–Mn alloys with additions of Sc–Zr.

Dileep et. al., (2010) analyzed AA2219-T87 was friction stir welded to Al-Mg alloy AA5083-H321. Weld microstructures, hardness, and tensile properties were evaluated. Friction stir welding can produce satisfactory butt welds between AA2219-T87 and AA5083-H321 sheets with a joint efficiency of around 90% (based on alloy 5083). For this specific material combination failures occur in the lowest hardness in the weldment heat-affected zone of alloy 5083 side, where tensile failure observed to take place.

Srinivasa Rao et al., (2011) 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.

Wang et al. (2012) studied the effect of Er addition on Al– 6Mg–0.7Mn–0.1Cr–0.15Ti alloy. Their results showed that the strength did not increase with Er addition and also observed that the uniform elongation decreased, because Er first reacted with Ti and Cr to form Al20Ti2Er, Al8Cr4Er phases. This precipitation strengthening weakened the grain refinement.

Suresh Kumar et. al., (2012) discussed the austenitic stainless steel 304 mechanical properties with dye penetrate testing welded by TIG and MIG. In this study the TIG welding produced the less hardness value than the MIG welding. The TIG welds of stainless steel withstand the high load and produced high ultimate strength than MIG welds. Austenitic grains were presented in the microstructure and no remarkable indication from the Dye Penetrate Testing. The HAZ was increased by increased the welding current.

Patel et al., (2013) evaluated the parameters; welding current, wire diameter and wire feed rate to investigate their influence on weld bead hardness for MIG welding and TIG welding by Taguchi's method and Grey Relational Analysis (GRA). From the study it was concluded that the welding current was most significant parameter for MIG and TIG welding. By use of GRA optimization technique the optimal parameter combination was found to be welding current, 100 Amp; wire diameter 1.2 mm and wire feed rate, 3 m/min for MIG welding.

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.

Duan et al. (2016) and Malopheyev et al. (2017) discussed the super plastic ductilities of Al–Mg–Mn alloys with Zr additions. Their results showed that the super plastic ductilities of Al–Mg–Mn alloys with Zr additions was higher than Al–Mg–Mn alloys with Er additions.

Sravanakumar et. al., (2018) investigated friction stir welding joints between armour grade aluminum alloy AA5083 by changing parameters such as tool profile, rotational speed, feed rate, translational speed, thermal properties and study influences of FSW on the micro hardness and tensile strength and also analyzed how Al alloy AA5083 exhibits its tremendous performance in extreme environments. Here parameters ranging from 700 to 1400 rpm where best spindle speed is 1220 rpm , welding speed is 40 mm per minute, feed rates from 20 to 40 mm/min and maximum hardness of 86.7VHN produced good tensile and hardness.

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 of FSW process for Al-Mg-Mn-Sc-Zr alloys

Sravana Kumar et. al., (2020) carried out optimization of FSW aluminum alloy having dimensions of 100*75*6.35 mm and analyzed mechanical behavior of welded joints such as hardness, tensile strength and material properties of Al alloys which were checked by ANOVA analysis. Parameters such as welding speed tilt angle, tool profile, and spindle speed influences strength of joints. Tensile strength and hardness increased with increasing tool rotational speed 1000rpm to 1400 rpm, speed from 30 mm/min to 40mm/min and tool tilt angle 2 degree.

CHAPTER-III

OBJECTIVE AND METHODOLOGY

3.1 OBJECTIVE

The main objective of the present work is to study the effect of FSW and MIG welding processes on the mechanical properties of Al-Mg-Mn-Sc-Zr.

3.2 METHODOLOGY

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

CHAPTER IV

EXPERIMENTATION

4.1 INTRODUCTION

In the present study, the aluminum alloys Al–4.2Mg– 0.6Mn alloy was produced by melting in an electrical resistance furnace (Figure. 3a). 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 mold. The casting process is as shown in Figure 3(a–d).

Figure 4.1 (a-d) shows the Electrical Resistance Furnace (b)Pouring molten mixture into the preheated permanent mold (c)Al-Mg-Mn-Sc-Zr as cast plate (d) Cold rolling of plate

The final temperature of the melt was always maintained at 1000 ± 15 C with the help of the electronic controller. Then, the melt was homogenized under stirring at 900^{o}C.

Casting was done in mild steel metal mold with graphite paste (die coat) as mold releasing agent preheated to 200°C. 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 plates.

4.2 FRICTION STIR WELDING MACHINE

The plate size of 120 mm x 120mm x 5 mm was cut from the sheet by water jet machine for FSW from the fabricated Al-Mg-Mn-Sc-Zr alloys in rolled sheets of size 150 mm x 150 mm x 5 mm thick.

The FS Welding was done on FSW-3T-NC machine The FSW Machine and its control panel are used in the experimental work with its specifications are shown in Figure 4.2.

Figure 4.2. FSW Machine

Table 4.1 Specifications of FSW machine

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

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. The loading of plates for FSW is shown in Figure 4.3

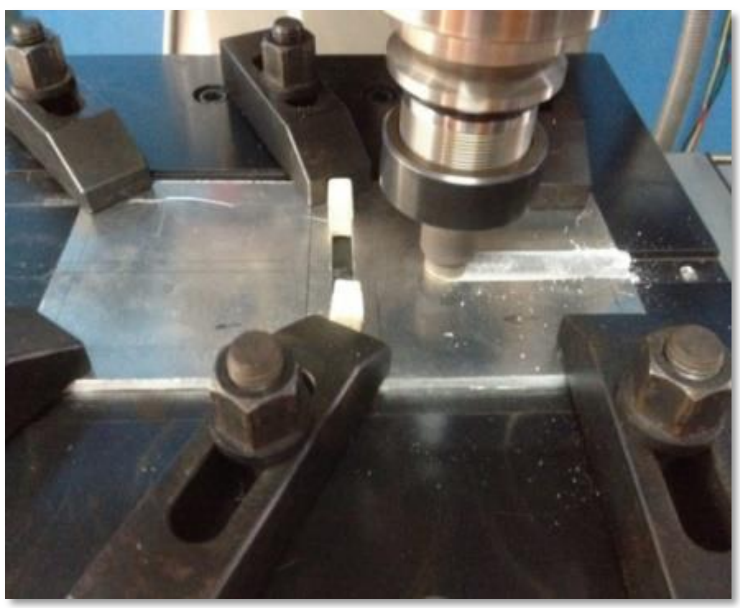

Figure 4.3 Fixing of plate on FSW machine

The welding was done perpendicular to the rolling direction of the plate. The standard specimens for hardness measurement, ultimate tensile strength, bending strength and impact strength were machined from the Friction stir welded plate. In FSW experimentation, the most influenced FSW process parameters (applied load (AL), tool rotational speed (RS), and tool traverse speed (TS)) in improving the mechanical and metallurgical properties of the friction stir welds were considered to evaluate the hardness, ultimate tensile strength, %elongation, bending strength, and impact strength. The FSW process parameters and their corresponding value considered for this work is shown in Table 4.2

Table 4.2 FSW Process parameters and corresponding values

S. No	**Process parameters**	**Notation**	**Unit**	
1	Applied load	AL	kN	10
2	Tool rotational speed	RS	Rpm	1200
3	Tool traverse speed	TS	mm/min	25
4	Tool material	T	_	H13

4.2.1 FS WELDED 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 according American Society for Testing of Material (ASTM E8M - Standard Test Methods for Tension Testing of Metallic Materials) guidelines were followed to preparing the test specimens as shown in Figure 4.4.

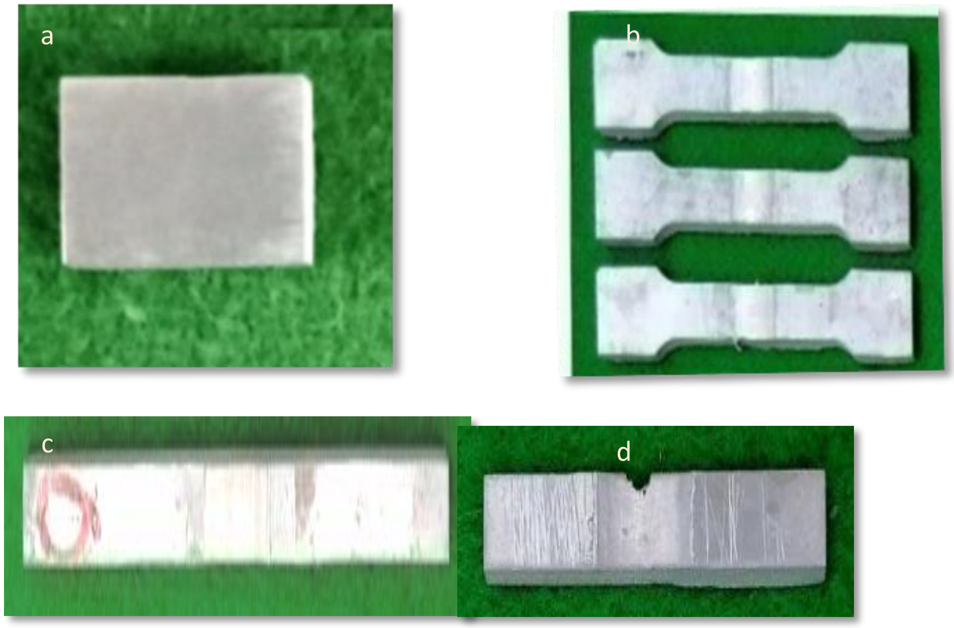

Figure 4.4 FS welded test specimens
(a) Hardness (b) Tensile (c) bending (d) impact test

Precautions required for FSW

- Material preparation – Work piece material should be clean and the surfaces to be welded should be milled flat and deburred in order for a positive mating surface. Before welding a weld channel must be milled in order to provide a consistently flat surface for the friction stir tool shoulder.
- Work holder – Ensure the work pieces are seated flat against the anvil surface and that the setscrews and clamps are tight.
- Temperature – Between welds the tool must be cooled with compressed air until it is warm to the touch (approx. 115^{o} F). It is not about temperature but consistency. It is also possible to start each weld equal time apart.

- Tool geometry – Critical tool dimensions (shoulder/pin diameter, pin length) should be within +/-0.0005” for repeatability when replacing a broken tool.
- Dwell time – It is necessary for the tool to build heat before traversing and to ensure consistent heat is delivered each time. A dwell can be used in the welding program for consistency. A dwell time sensitivity analysis may be performed by varying dwell time from 0-5 seconds, but typically 0 to 3 seconds is sufficient

4.3 MIG WELDING MACHINE

MIG i.e., metal inert gas welding is generally used for large and thick materials. It employs a consumable wire that acts as both the electrode and the filler material. Compared to TIG welding, it is much faster, resulting in shorter lead times and lower production costs.

The plate size of 120 mm x 120mm x 5 mm was cut from the sheet by water jet machine for MIG welding from the fabricated Al-Mg-Mn-Sc-Zr alloys in rolled sheets of size 150 mm x 150 mm x 5 mm thick.

This work piece is clamped to the work bench by work piece holder. Measurements are made required to place welding. A weld channel is run as bead on plate. The Welding was done by using continuous solid aluminum wire of MTL 5183 grade as electrode manually with input parameters of Current (117 A), Voltage (18V), and High purity (98%) argon gas was the shielding gas which protects the workpiece from contamination due to outer atmosphere. The experimental setup is shown in the Figure 4.5.

Each welding process was carried out based on the standard Welding Procedure Specification (WPS). The welding was done perpendicular to the rolling direction of the plate. The standard specimens for hardness measurement, ultimate tensile strength, bending strength and impact strength were machined from the Metal Inert Gas Welded plate.

Figure 4.5 MIG Welding experimental setup

4.3.1 MIG WELDED SPECIMEN PREPERATION

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 MIG welded plate as shown in Figure 4.6.

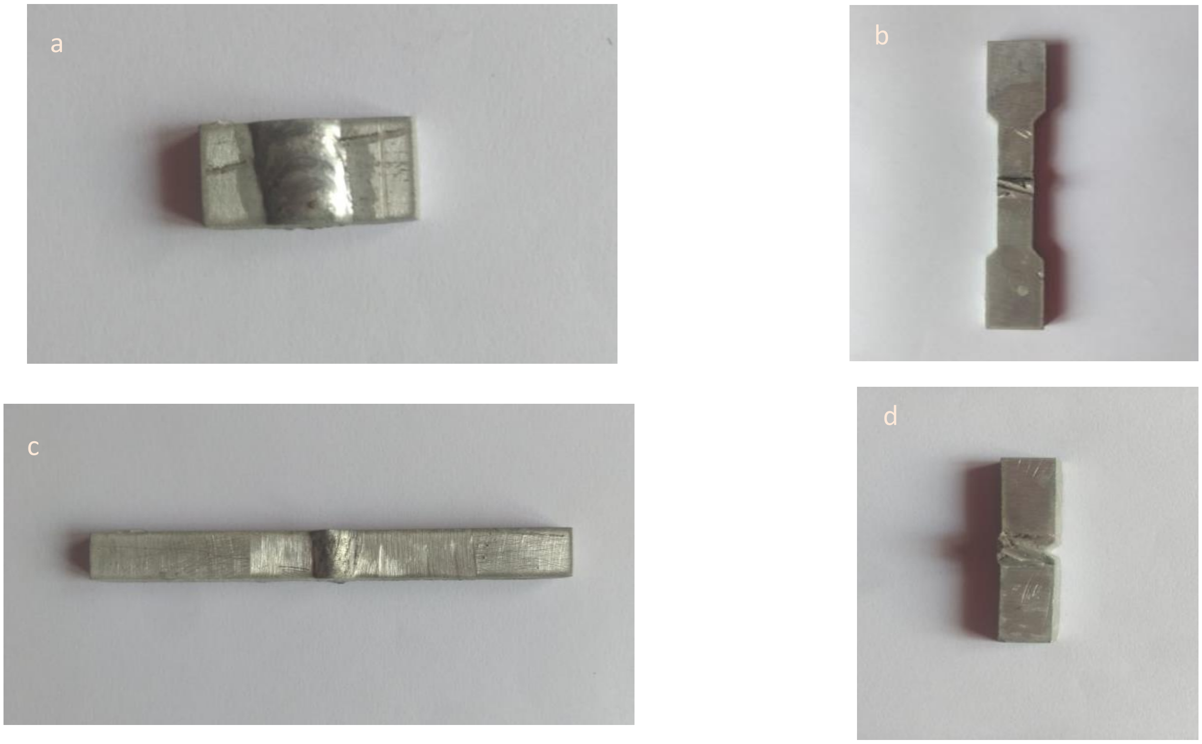

Figure 4.6 MIG welded test specimens
(a) Hardness (b) Tensile (c) bending (d) impact test

4.4 MECHANICAL PROPERTIES:

4.4.1 VICKERS MICRO HARDNESS MEASUREMENT OF THE FS WELDS/MIG WELDS

The Vickers microhardness of the welded joints was measured on a 401MVD Vickers microhardness tester (Figure 4.7) 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.

Figure 4.7 Vickers micro hardness tester

4.4.2 TENSILE TEST FOR FS WELDS AND MIG 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 is shown in Figure 4.8, 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 10 mm^2 cross-sectional area. Ultimate strength, yield strength, and % elongation were recorded after averaging of three data points.

Figure 4.8 Universal testing Machine

4.4.3 BENDING TEST OF FS WELDS AND MIG 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. The size of the specimen was 100 X 10 X 5 mm^3 as shown in Figure 4.9. Two specimens for each alloy were tested and averaged.

Figure 4.9 UTM for Bending test

4.4.4 IMPACT TEST FOR FS WELDS AND MIG WELDS:

The Charpy V-notch impact tests were performed using Krystal Elmec, model KI 300, range-168 J 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^oV-notch, 2 mm deep with a 0.25 mm root radius. Three specimens for each composition were tested and averaged. Figure 4.10, shows the specimen of impact test.

Figure 4.10 Impact test equipment

CHAPTER V

RESULTS AND DISCUSSIONS

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 stir welded and MIG welded components to show better welding technique. The results of unwelded components are obtained for literatures by many research workers and results of FS welds and MIG welds were studied in this work.

5.2 CHEMICAL COMPOSTION OF FABRICATED ALLOY:

The aluminum alloys Al–4.2Mg– 0.6Mn alloy was produced by melting in an electrical resistance furnace. 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) and cold rolling the material. The obtained alloy consists of composition as shown in Table 5.1

Table 5.1. The Chemical composition of the fabricated alloy. (wt.%)

Mg	Mn	Si	Cr	Zn	Ni	Li	Sc	Zr	Bal.
$4.2^{+0.7}_{-0.2}$	$0.6^{+0.4}_{-0.2}$	$0.17^{+0.23}_{-0.17}$	$0.10^{+0.30}_{-0.10}$	$0.06^{+0.19}_{-0.06}$	$0.006^{+0.044}_{-0.006}$	$0.001^{+0.049}_{-0.001}$	$0.4^{+0.05}_{-0.05}$	$0.1^{+0.05}_{-0.05}$	Al

The mechanical properties of fabricated alloy Al-Mg-Mn-Sc-Zr, 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. These are obtained from the literatures mentioned.

Basing on the investigations on metallographic specimen of the fabricated Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy in optical microscope revealed that the presences of fragmented intermetallics due to addition of Sc and Zr with formation of some spherical particles shown in Figure 5.1, revealing a hardness of 139 VHN.

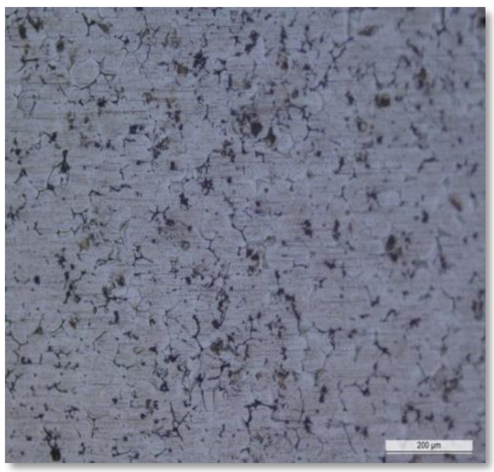

Figure 5.1 Optical Micrograph of Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr

The mechanical properties of the fabricated alloy is shown in Table 5.2

Table 5.2 Mechanical Properties of the Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy

Alloy Type	**Hardness**	**Tensile strength**	**Yield stress**	**Elongation**	**Bending strength**	**Impact strength**
	(VHN)	**(MPa)**	**(MPa)**	**(%)**	**(MPa)**	**(KJ/m^2)**
Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr	139	260.40	208	7.4	3480	2.5

5.3 COMPARISON OF MECHANICAL PROPERTIES:

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

The Figure 5.2 shows the structure of the friction stir welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy, from the center of the nugget zone, it has shown the new grains formations which are fine and measures less than 2 microns uniformly. In case of FS welding the hardness exhibited is about 111 VHN, which is 79.8 percent of the non-welded alloy. This may be due to the fine black particles which are the eutectic constituents of Al_3(Sc, Zr) in primary aluminium solid solution.

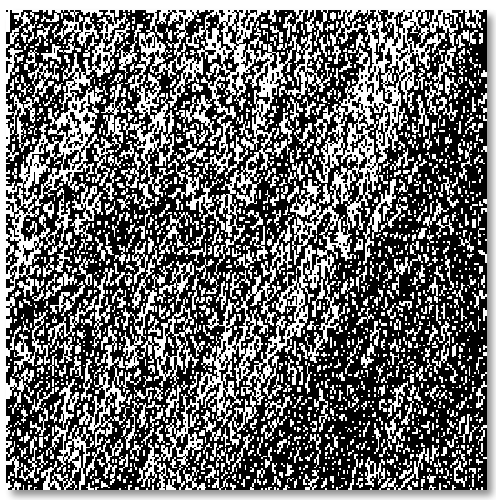

Figure 5.2 Optical micro graph of FS welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr

Table 5. 3 Mechanical properties of the FS weldedAl-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy

Alloy Type	**H**	**UTS**	**IS**	**BS**
	VHN	**(MPa)**	**KJ/m2**	**(MPa)**
FS welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr	111	238.54	11.25	3325

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. 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 exhibited 91.6% of joint efficiency.

5.3.2 Effect of MIG Welding process on Mechanical Properties of Al-Mg-Mn-Sc-Zr alloy

The microstructure investigation from Figure 5.3 allowed assessing the hardness of 87 VHN which is 62.5 percent of the hardness value of non-welded alloy. The structure consists of a coarse interdendritic network with intermetallic particles of Al, Mg, Mn precipitated within a dendritic network of aluminium solid solution

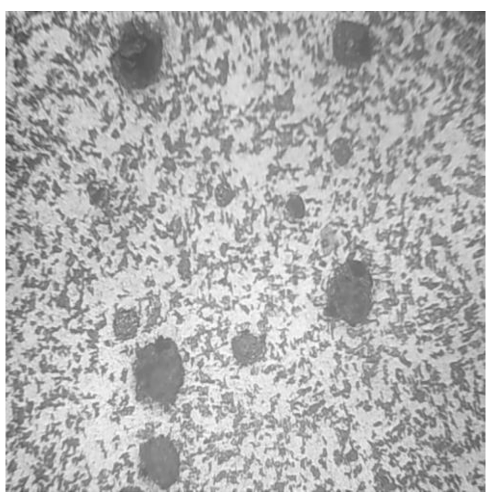

Figure 5.3 Optical micro graph of MIG welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr

Table 5.4 Mechanical properties of the MIG welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy

Alloy Type	**H**	**UTS**	**IS**	**BS**
	VHN	**(MPa)**	**KJ/m^2**	**(MPa)**
MIG welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr	87	166.20	3.8	3264

The mechanical properties of the Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy is shown in Table 5.2 and the mechanical properties after FSW and MIG welding processes are shown in Table 5.3 and Table 5.4. After FSW, the strength of the joint is 238.34 MPa which is 91.6% of non-welded alloy. The strength property of MIG welded joint is 166.20 MPa which is 63.82% of non-welded alloy, which is less effective than the FSW process.

Similar trend was observed for bend strength, which implies as strength increases the bend strength also increases. The impact strength of the FS welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr alloy is significantly greater than non-welded alloy and MIG welded alloy as the strain hardening and precipitate strengthening is more owing to finer grains in the stir zone compared to welded seam of MIG welded joint and non-welded alloy.

CHAPTER VI

CONCLUSION & FUTURE SCOPE

6.1 CONCLUSION

- Al-Mg-Mn-Sc-Zr alloys were successfully fabricated by stir casting technique.
- FSW and MIG 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,

301.7% Impact strength and % elongation is 66.2% was obtained when compared to that of non-welded Al-Mg-Mn-Sc-Zr alloy .

- Hardness (87 VHN), Ultimate tensile strength (166.20 MPa), Bending strength (3264 MPa), Impact strength (3.8 KJ/m2) and % elongation is 4.8 was exhibited in MIG welded joint.

- Hardness 62.5 %, Ultimate tensile strength 63.8%, Bending strength 93.7 %, Impact strength 135.7 % and elongation percent is 64.86% was achieved in MIG welded joint to that of non-welded Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr 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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