

**MECHANICAL AND MICROSTRUCTURAL PROPERTY
INVESTIGATION OF MAGNESIUM RARE EARTH
ELEMENT (Mg-REE) ALLOYS**

Submitted in partial fulfillment of the requirements for the award of
**Bachelor of Engineering Degree in
Mechanical Engineering**

BY

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SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **R. NAVEEN (38150068)**, and **A. KUMARA RAJA (38150055)** who carried out the project entitled **"MECHANICAL AND MICROSTRUCTURAL PROPERTY INVESTIGATION OF MAGNESIUM RARE EARTH ELEMENT (Mg-REE) ALLOYS"** under my supervision from 01.11.2021 to 10.05.2022.

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ABSTRACT

Magnesium (Mg) and its alloys are the lightest structural metal. The main reason for Mg is various industrial and clinical applications, where lightweight structures are in high demand, is its lightness. Recent developments and research on magnesium Mg alloys are discussed. Alloying changes the microstructure of the material, resulting in strengthening mechanisms that improve the ductility and mechanical properties of pure Mg. This review completely depicts the methodologies for working on the mechanical and debasement execution of mg combinations through appropriately fitting the structure of alloying components, fortifications, and handling strategies .in this research it highly points the progress and status (1) grain refinement for strengthening, (2) types of magnesium alloy system and composites. Furthermore, the magnesium composites' importance are pointed out. Describes the strategies for improving the mechanical and degradation performance of Mg alloys and the composition of alloying elements, reinforcements, and processing techniques. It also highlights the status and progress of research into (i) type of Mg alloy system and composites (iii) grain refinement for strengthening. Furthermore, it also emphasizes the importance of Mg composites. In this research work, an attempt is made to investigate Magnesium – Strontium – Gadolinium rare earth element alloy by gravity casting method, and the mechanical and microstructure properties like tensile, hardness, and optical microscope of Mg-REE alloy are investigated. The Mechanical property of tensile and hardness tests investigated and the Microstructural property of optical microscope investigation of Magnesium rare earth element (Mg-REE) alloys there by the applications of these Mg-REE alloys can be widened in various other fields.

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LIST OF ABBREVIATIONS

CCD	-	Charge-Coupled Device
CMOS	-	Complementary Metal-Oxide-Semiconductor
Gd	-	Gadolinium
HBW	-	Brinell Hardness
HREEs	-	Heavy Rare Earth Elements
LREEs	-	Light Rare Earth Elements
Mg Gd	-	Magnesium Gadolinium
Mg REE	-	Magnesium Rare Earth Elements
Mg Sr Gd	-	Magnesium Strontium Gadolinium
Mg Sr	-	Magnesium Strontium
Mg	-	Magnesium
Mg-REE	-	Magnesium Rare Earth Element
REE	-	Rare-Earth Elements
Si-C	-	Silicon Carbide
Sr	-	Strontium
UTS	-	Ultimate Tensile Strength
YS	-	Yield Strength

CHAPTER 1

INTRODUCTION

1.1 MAGNESIUM ALLOY

The annual output of magnesium alloy in China has been steadily increasing in recent years, according to reports. These are used in motorcycles, automobiles, and electric devices, among other things. The Mg-Sr and Mg-Gd system magnesium alloys have been used in industrial manufacturing as one important member of the family. Magnesium supplements give to animals at the stages of development to speed up the transition from callus to osteogenesis, as well as advance bony development and biomechanical capacities. Moreover, Mg alloys are healing bone fractures, improve bone mineral thickness, and adjusting inserts. If compared to bone, the physical properties of magnesium are superior. Magnesium has a density of 1.78–2.0 g/cm³, which is similar to 1.8–2.1 g/cm³ in human bone. Pure Magnesium (41–45 GPa) has a similar elastic modulus to natural bone (3–20 GPa), whereas titanium alloys (110–117 GPa) and cobalt-chromium alloys (230 GPa) have a much higher elastic module of the bone. Magnesium consumption has increased at a 15 percent rate over the last decade due to weight reduction for automobile fuel economy.



Fig. 1.1: Properties of Magnesium alloy
(Source: www.material-properties.org)

Die-casting is currently the most common method for producing magnesium components for automotive applications. It can be improved the properties of wrought magnesium alloy. [11] However, their mechanical properties and processing capabilities were insufficient to meet the requirements of some critical parts in vehicles and other industries. As a result, many methods for improving the mechanical properties and processing performance of Mg-Sr and Mg-Gd system alloys are being investigated around the world. The addition of Sr and Gd to Mg system alloys has been shown to refine the tensile, hardness, and microstructures. [19]

In this study, Mg-2Sr-xGd magnesium alloy specimens were prepared using a mass fraction of 2%, 4%, 6%, and 8% Gd addition in Mg-2Sr alloy, and the impact of Gd addition on the microstructure and mechanical properties at gravity casting was explored.[4]

1.2 RARE EARTH ELEMENTS (REE)

Rare-earth elements (REE), also known as rare-earth metals or rare-earth oxides, or lanthanides. A group of 17 nearly indistinguishable lustrous silvery-white soft heavy metals (typically referred to as rare earth). The periodic table includes seventeen metals known as rare earth elements. Yttrium, scandium, and 15 lanthanides are all present in this group. Lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium are some of the elements that can be found in the periodic table.



***Fig. 1.2: Photograph of rare earth elements
(Source: www.theverge.com)***

1.2.1 Classification of Rare Earth Elements

Based on their atomic weight, rare metals are divided into light rare earth elements (LREEs) and heavy rare earth elements (HREEs).

Periodic Table: Rare Earths

The periodic table displays elements with their atomic number, symbol, atomic weight, and name. The rare earth elements are highlighted in orange. The Lanthanide series (La to Lu) and Actinide series (Ac to Lr) are shown below the main table.

Fig. 1.3: Photograph of classification of rare earth elements
(Source: www.epa.gov)

Lanthanum, cerium, praseodymium, neodymium, samarium, and europium are LREEs. HREEs are classified as 'yttric,' and include elements such as terbium, ytterbium, holmium, yttrium, thulium, dysprosium, lutetium, gadolinium, and erbium. Scandium and yttrium are both classified as heavy elements in this context. Furthermore, scientists have classified Eu, Sm, and Gd as medium rare earth elements.



Fig. 1.4: Properties of strontium metal
(Source: www.material-properties.org)

Strontium and gadolinium are rare-earth elements because they are found in the same ore deposits as lanthanides and have similar chemical properties, but their electrical and magnetic properties are different.

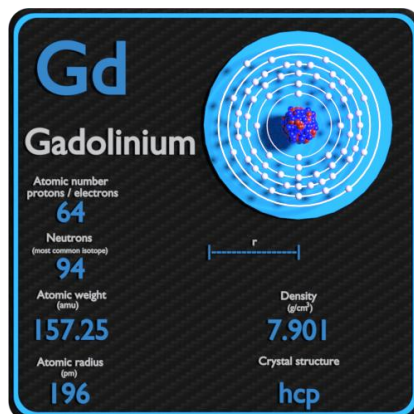


Fig. 1.5: Properties of gadolinium metal
(Source: www.material-properties.org)

Rare earth metals have similar chemical properties, another REE is expected to act similarly as effective magnesium strengthening additives. The main findings of research into strontium and gadolinium as possible additions to magnesium to improve its properties are presented in this article. The investigations of the behaviour of the alloys during casting, determinations of the mechanical properties, and their relationship with the composition and structure of the alloys are based on tensile, hardness test, and microstructure. In addition to binary Mg-Sr alloys, Mg-Gd alloys exist. Because gadolinium was thought to be a viable additive to magnesium when combined with strontium, ternary Mg-Sr-Gd alloys were studied.

1.3 MAGNESIUM ALLOY AND ITS APPLICATIONS

Magnesium alloys are the lightest structural metal and made up of magnesium, and other metals. The hexagonal lattice structure of magnesium alloys has an impact on their fundamental characteristics. Because plastic deformation of hexagonal latticed metals such as magnesium is more challenging than that of cubic latticed metals such as aluminum, copper, and steel, magnesium alloys are normally

utilised as-cast alloys, but wrought alloy research has become more widespread since 2003.

Die-cast magnesium is used for camera bodies, and lens components in modern automobiles and have been used in some high-performance vehicles. Magnesium (Mg) alloy is a wide range usage of lightest structural in many industries like Automobile, Aerospace, Electronics, and Energy sectors.

Because of its low strength pure magnesium is used for properties of mechanical and microstructure of Mg alloy is to improve reinforced with rare earth elements (REE).

Application of magnesium alloy are used in wide range, including medical and as well as chemical applications. Although the book's main focus is on structural applications of magnesium, it also covers other applications of magnesium alloys.

1.3.1 *Structural Applications of Magnesium Alloy*

The high strength to weight ratio of magnesium alloys is frequently cited as a primary reason for using them in engineering applications. Fortunately, environmental degradation can be ameliorated through good design practices and preventive measures. Automobile, industries, aerospace equipment, materials handling, and commercial are all structural applications such as automotive, aerospace, industrial, and commercial applications. The lightweight of magnesium alloy, high strength to weight ratio, high stiffness to weight ratio, castability, machinability, and great damping are the advantages of magnesium alloy



Fig. 1.6: Photograph of automobile field of magnesium alloy
(Source: www.openpr.com)

In developed countries, magnesium alloys are commonly used in engine covers, gearbox components, engine blocks, set brackets, and other components in automobile applications. It reduces the vehicle weight, fuel consumption, and exhaust emissions in the automobile industry. It improves the integration of parts and design flexibility. If Fuel efficiency is increased by 5.5 percent for every 10% reduction in vehicle weight, exhaust emissions are reduced accordingly.



Fig. 1.7: Examples of automotive components made of Mg alloys
(Source: www.exportersindia.com)

In aerospace magnesium alloys have been used in aerospace since the twentieth century. Many parts are made of magnesium alloy because it improves the aerodynamic performance of the aircraft while also reducing its structural weight. Plates and extruded profiles make up the majority of general aviation magnesium alloys, with castings accounting for a small percentage.



Fig. 1.8: Photograph of an aerospace field of magnesium alloy
(Source: www.themetalcasting.com)

Magnesium alloys are currently used in a variety of propellers, gearboxes, bracket structures, military-civil aircraft parts, and some components of rockets. The performance will continue to improve as magnesium alloy production technology advances, and the range of applications will expand.

1.3.2 *Pyrotechnics Applications of Magnesium Alloy*

Magnesium powder was first used in the production of brilliant white light as a component of fireworks, flares, and other incendiary devices. For photographic flashbulbs, fine magnesium wire was used. Magnesium is still used in survival kits as a fire starter.

1.3.3 *Electrochemical Applications of Magnesium Alloy*

Magnesium has the highest electromotive series of all the metals in saltwater, making it desirable as a sacrificial anode for cathodic protection. Batteries make use of this mechanism in a constructive way. Because of their lightweight, strength, and durability, instead of plastics magnesium alloys are being used. They also perform better in terms of heat dissipation and electromagnetic and radio frequency interference protection.

1.3.4 *Medical Applications of Magnesium Alloy*

Magnesium compounds are utilized in compact clinical hardware where lightweight is beneficial. It is additionally utilized for wheelchairs utilized in wearing exercises. Magnesium amalgams are generally utilized in versatile clinical hardware and wheelchairs that require a light material. In light of magnesium's biocompatibility and bio absorbability, amalgams with other biocompatible components, for example, calcium are being assessed for cardiovascular stents and muscular gadgets for inside bone obsession.

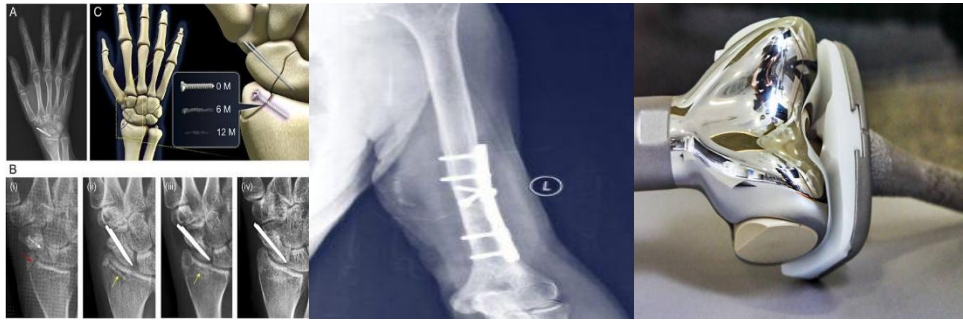


Fig. 1.9: Orthopaedic application of Magnesium Alloys
(Source: www.asianmetal.com)

Also, cardiovascular stents and orthopedics devices are potential applications of some magnesium alloys due to magnesium's biocompatibility and bio absorbability.

1.4 ADVANTAGES AND DISADVANTAGES OF MAGNESIUM ALLOYS

Following are the advantages and disadvantages of magnesium alloys are listed

1.4.1 Advantages of Magnesium Alloys

- Magnesium has the lowest density and It provides maximum acceleration due to its lower density. Its Specific strength is high and its Castability is good, making it suitable for high-pressure die casting. High-speed turning and milling are possible. Weldability is good in a controlled environment. Corrosion resistance is greatly improved when high-purity magnesium is used. [9]

1.4.2 Disadvantages of Magnesium Alloys

- At high temperatures, there is a lack of strength and creep resistance. On solidification, there is a lot of shrinkage and chemical reactivity. Elastic modulus is low. Corrosion resistance is limited in some applications. Cold workability and toughness are limited.

1.5 TYPES OF MAGNESIUM ALLOY

1.5.1 *Magnesium Rare Earth Elements (Mg REE) alloy*

Magnesium rare earth element are bio-compatibility, strength, and rate of degradation are widely used for bone implants in orthopaedic applications. When cast, pure magnesium has a low strength and a high rate of corrosion. Properties of magnesium composites can be fortified and improved by utilizing reasonable alloying components and handling conditions. Magnesium grains have high better Strength of mechanical, and microstructure properties when alloyed with components like Al, Ca, Zn, Sr, and interesting earth components REE as supporting components because of grain refinement and solid arrangement building up systems of the alloying components.

This helps to development of Mg-REE alloy, which has the potential to be a viable replacement for extremely durable bone inserts because of its biodegradability in the physiological climate, for example inside the human body. By differing the basic organization of Gadolinium (Gd) in Mg-2Sr, Mg-REE amalgam of Mg-2Sr, Mg-2Sr-2Gd, Mg-2Sr-4Gd, Mg-2Sr-8Gd, Magnesium, Strontium and Gadolinium REE combination is projected utilizing gravity projecting strategy and the mechanical and microstructure properties of Mg-REE alloy are investigated.

1.5.2 *Magnesium Strontium (Mg Sr) Alloy*

Strontium (Sr) naturally occurring antacid that is an essential component of human body to promotes the development of osteoblasts and prevents bone resorption. Strontium is a significant component in the human body that aides and has been known to underwrite the development of osteoblasts and forestall bone resorption. Some minor components intently artificially connected with calcium, for example, strontium pharmacologically affect bone when present at levels higher than those expected for typical cell physiology. Sr is found in bone and connective tissue in sums going from 320 to 400 mg in the human body. Strontium, in addition to its antiresorptive properties, has been discovered to have anabolic activity in bone, suggesting that it may have significant benefits for bone balance in both normal and osteogenic animals.

1.5.2.1 *Chemical and Mechanical properties of strontium*

Strontium has been suggested as a possible treatment for osteoporosis. Strontium has a solubility of 0.11 weight percent in Mg. It aids grain refinement and improves Mg corrosion resistance. Human body bones and teeth contain traces of the strontium (Sr) element. Strontium (Sr) builds up in human bones and helps them grow stronger. Strontium (Sr) has been shown in recent research to aid in bone reformation by promoting the osteoclast. Researchers have also discovered that adding Strontium to Magnesium as a alloy to improves mechanical & microstructure properties.

Strontium has a highly reactive chemical nature. Strontium is in group 2 of the periodic table. It has a melting point of 777 degrees Celsius, 1431 degrees Fahrenheit, or 1050 degrees Kelvin. Period five element strontium has a boiling point of 1377°C (2511°F) or 1650 K. The Sr element (where Sr is the chemical symbol for Strontium) has a density of 2.64 g cm³ and is found in the periodic table.

Strontium has an atomic number of 38 and a relative atomic mass of 87.62. ⁸⁴Sr, ⁸⁶Sr, ⁸⁷Sr, and ⁸⁸Sr are the four isotopes of the metal. The electronic configuration of strontium is Kr 5s, and the CAS number is 7440-24-6. Alloying Strontium (Sr) to Magnesium (Mg) can improve the mechanical and microstructure properties of Mg-Sr Alloy castings by refining the grain structure, decreasing shrinkage porosity, and increasing relative density.

1.5.3 *Magnesium Gadolinium (Mg Gd) alloy*

Gadolinium is a soft, bright, silvery metal with both malleable and ductile properties. It does not react in the presence of oxygen, but when exposed to moist air, it tarnishes to a form of white oxide, which protects it from further oxidation. In comparison to other normal alloying components like Strontium, Zinc, Calcium, and other interesting earth components REE, Gadolinium (Gd) with a thickness of 7.9 g/cm³ makes Magnesium REE compound denser when alloyed with Mg. Whenever Mg is alloyed with Gd, the refined grain size is superior to when some other REE is alloyed. When miniature alloyed with Magnesium, Gadolinium has a decent bio-

similarity and high solvency (Mg). This component is profoundly solvent in weak acids, and it additionally responds gradually with water to create dismal salts.

1.5.3.1 Chemical and Mechanical properties of gadolinium

At room temperature, gadolinium is paramagnetic, but when cooled or at temperatures below 20 degrees Celsius, it becomes ferromagnetic. In compound form, the element exists in its trivalent state. The metal gadolinium has a Curie point of about 17 degrees Celsius. There are approximately 27 synthetic isotopes and approximately 13 naturally occurring isotopes of gadolinium. As far as we know, the isotope ^{157}Gd has the best thermal stability of all the isotopes. Gadolinium is found in the earth's crust in about 5.2 parts per million by weight, and when mixed with nitrogen, sulphur, carbon, phosphorus, selenium, boron, silicon, and arsenic at higher temperatures, it forms binary compounds.

1.5.4 Magnesium Strontium Gadolinium (Mg Sr Gd) Alloy

Mg-Sr-Gd alloys are being created as a potential material for human bone embed applications, as per late investigations on magnesium REE combinations. Strontium advances osteogenesis by repressing the action of osteoclastic microscopic organisms. The expansion of strontium changes the construction and refines the grain size, bringing about the making of another magnesium REE compound for muscular use. At the point when Mg is alloyed with Gd, the refined grain size is superior to when some other REE is alloyed. When miniature alloyed with Magnesium, Gadolinium (Gd) has a decent biocompatibility and high dissolvability (Mg). Mg-Gd compounds are being created as a potential material for human bone embed applications, as indicated by ongoing investigations on magnesium REE amalgams.

1.6 DEFECTS IN MAGNESIUM ALLOYS

Magnesium alloys appear to have two major drawbacks when used in automotive applications are poor corrosion resistance and low high temperature (creep) strength.

1.6.1 *During Casting Defects on Magnesium Alloy*

Casting defects observed in nonferrous alloys such as aluminium during sand and permanent mould casting also apply to magnesium. However, fold formation is the most common defect during lost-foam casting of magnesium alloys. Mg alloys are more susceptible to oxidation and fold formation than Al alloys.

1.7 GRAVITY CASTING PROCESS OF MAGNESIUM RARE EARTH ELEMENTS (Mg REE) ALLOY

1.7.1 *Indufurr Preheating Oven*

A preheated oven is heated for 10-15 minutes depending upon the desired temperature without putting anything in it. The oven is preheated for some time, before actually putting the dish that you want to bake, inside it. Preheating the oven is a significant step.

1.7.2 *Die Cast Steel Mold*

In die casting, also known as high-pressure die casting, molten alloy liquid is poured into a press chamber, casting is formed by a steel mould cavity filling alloy liquid solidifying under pressure. Die casting has two main characteristics: high pressure and high speed.

1.7.3 *Electrical Resistance Furnace*

A resistance furnace is an electric furnace in which heat is generated by conductors that provide resistance to current flow. Heat treatment, heating before pressure shaping, and drying or melting materials are all common uses for resistance furnaces.

1.7.4 *Applications of Resistance Furnaces*

The resistance furnaces and ovens are used for the following applications
Heat treatment of metals such as hardening, annealing, etc.

1.7.5 *Shrinkage during the Cooling Process*

As a result of the difference in thermal expansion coefficients of plastics and metals, molded articles that tightly fit mold cavities at elevated temperatures will shrink upon cooling to room temperature.

1.7.6 *Tensile Test*

This is the mechanical testing method to determine the strength of the material and how long it can be stretched until it breaking.

1.7.7 *Hardness*

This is the most common testing method to determine by measuring the depth of indenter penetration of specially dimensioned and loaded indenter is pressed into the material's surface

1.7.8 *Optical Microscope*

It is also known as light microscope; this microscope generates that the magnified images of the small objects by using a system of lens and visible light.

1.8 PRIMARY PROCESS FOR CASTING

The processing techniques have a big impact on the properties of Mg-based materials. Solid & liquid state techniques are used to process biodegradable magnesium alloys. Powder metallurgy is a strong state combination strategy that includes mixing metal powders for the ideal creation, compaction, and sintering the material underneath its solidus temperature.

The most cost-effective method of processing magnesium-based materials is casting, which involves superheating the metal above 750°C in an inert gas atmosphere to prevent oxidation, then transferring it to a mould and allowing it to solidify. As shown schematically, the processing sequences of biodegradable magnesium and its alloys from raw materials to finished medical devices are critical. The working process of the casting to obtain the desired form like rods, plates, wires,

and tubes are subjected to process in hot or cold. In implants, secondary processing such as joining, packaging, machining, and sterilization are used.

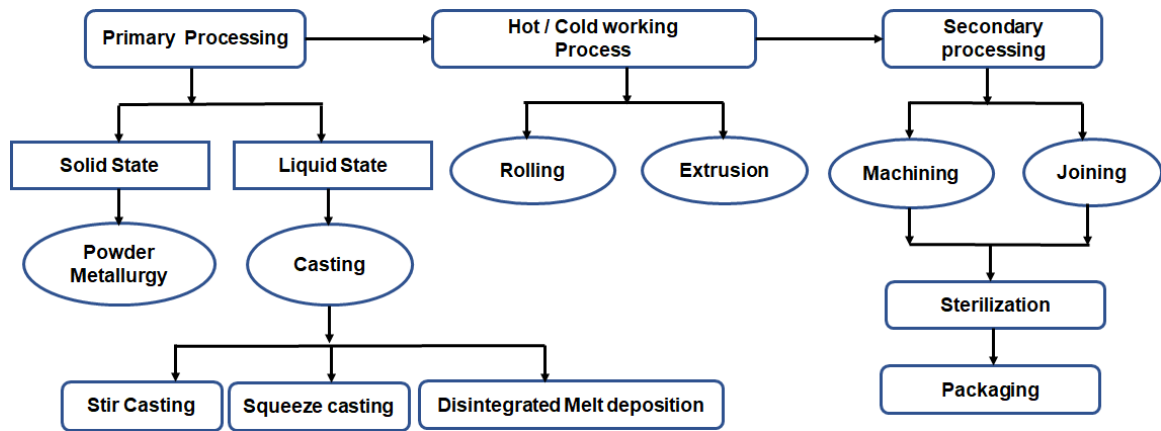


Fig. 1.10: Primary Process of Casting

1.8.1 Stir Casting

Stir casting is one of the most popular and widely used methods of material formation, primarily for Metal Alloys and Metal Matrix Composites, in which metals are melted and cast into appropriate shapes and sizes by pouring them into cavities. Liquid metallurgy is another name for it. Metals such as magnesium, aluminium, copper, and zinc were melted in this furnace for casting, resulting in Metal Alloys and Metal Matrix Composites. Ceramics with Oxide Metals For research institutes, we manufacture small scale machines with a high accuracy limit.

CHAPTER 2

LITERATURE SURVEY

Following are the categories which have been studied for this research, it has been categorized into three sections

- i. Literature survey on Tensile properties of Mg REE alloys
- ii. Literature survey on Hardness properties of Mg REE alloys
- iii. Literature survey on Microstructure properties of Mg REE alloys

2.1 LITERATURE SURVEY ON TENSILE PROPERTIES OF Mg REE ALLOYS

- Fan Jinping et al. (2011) in his research paper Effects of Sr addition on mechanical properties and microstructure of Mg-6Al magnesium alloy found that the effects of Sr on tensile strength were discovered. When the addition of Sr in magnesium alloy temperature and content levels are varying the TS, YS, and ductility. At room temperature, the tensile strength is increased by 2 percent, and Sr content is added to magnesium alloy increased by 2 percent. Due to the addition of Sr content in magnesium alloy of tensile strength is decreased. [4]
- Yang Miao et al. (2014) in his research paper Corrosion and mechanical properties of AM50 magnesium alloy after being modified by 1 wt.% rare earth element gadolinium investigated a result that is possible to conclude that Gd increases tensile strength while decreasing deformation capacity in AM50 magnesium alloy. Magnesium alloy of AM50 of TS is increased with the addition of gadolinium content due to second phase strengthening, grain boundary strengthening, and grain refinement.[16]

- Sankaranarayanan Seetharaman et al. (2014) in his research paper on microstructure, and mechanical properties of new magnesium-zinc-gadolinium alloys, investigated the results and also show that increasing the amount of Zn and Gd in the Mg-3.4Zn-0.8Gd alloy improves the YS and UTS. The tensile failure strain, on the other hand, was negatively affected.[11]
- Saravanan Annamalai et al. (2019) in his research paper magnesium alloys: a review of applications magnezijeve zlitine pregled uporabe in his research paper they investigated the pure magnesium alloy should be alloyed with other elements to improve mechanical properties due to its low mechanical strength. Many commercial wrought Mg alloy systems, such as the AZ, ZK, and WE systems, have been developed to improve mechanical properties.[10]
- Sravya Tekumalla et al. (2004) in their research paper magnesium-rare earth alloy of mechanical properties system are investigated the tensile properties of Mg-Gd binary alloys after secondary processing were investigated. The rare earth elements have a significant impact on the properties of magnesium alloys, but due to their scarcity, the cost of most rare earth elements is higher than that of conventional alloying elements.[12]
- Wu, et al (2007) in his research paper study of the microstructure and mechanical properties of Mg-rare earth alloys they investigated the various test temperatures, the tensile strength was investigated. The results revealed that as the temperature rises, the tensile strength of these alloys decreases. The tensile strength of the investigated alloys rapidly decreases when tested at 300 degrees Celsius. [13]

2.2 LITERATURE SURVEY ON HARDNESS PROPERTIES OF Mg REE ALLOYS

- Ali Pasa Hekimoglu et al. (2019) in his research Effect of Strontium and Magnesium Additions on the Microstructure and Mechanical

Properties of Al–12Si Alloys found that the ternary Al–12Si–Sr alloys' hardness, yield, and tensile strengths increased to 0.1 percent strontium content. Hardness and tensile strength decreased when strontium was added in excess of 0.1 percent, while yield strength remained unchanged. In the microstructures of the amalgams, the breakdown and more homogeneous conveyance of the eutectic silicon particles can cause a hardness expansion. [1]

- Ifeanyi Anthony Anyanwu et al. (2001) in their research paper Aging characteristics and High-Temperature Tensile Properties of Mg-Gd-Y-Zr Alloys found that the ageing temperatures of 225 and 250 °C, specimens with low gadolinium content, such as GY56K and Y10K alloys, do not show the same degree of age-hardening as GY17K and GY122K alloys. [6]
- Lavish Kumar Singh et al. (2017) in their research paper Effects of gadolinium expansion on the microstructure and mechanical properties of Mg-9Al alloy is investigated the impact of Gd on solid-solution strengthening is much more grounded than Al and Zn's. Mg–9Al alloy mechanical properties in this study, the amount of Gd in the body is measured and correlated with the microstructure. When Mg–9Al is alloyed with Gd, the grain size of the alloy is reduced. Crystal growth is slowed when Gd is added. Gd addition causes sluggish solute atom diffusion because the diffusion layer ahead of the advancing solid/liquid interface is constitutionally undercooled. The addition of Gd results in higher hardness values when compared to the alloy without Gd. [7]

2.3 LITERATURE SURVEY ON MICROSTRUCTURE PROPERTIES OF Mg REE ALLOYS

- Ali Pasa Hekimoglu et al. (2019) in his research Effect of Strontium and Magnesium Additions on the Microstructure and Mechanical Properties of Al–12Si Alloys they investigated that the ternary Al–12Si–Sr alloys' hardness, yield, and tensile strengths increase up to 0.8 percent

gadolinium content. When gadolinium is added in excess of 0.8 percent, hardness, tensile strength, and yield strength do not change significantly and experimental alloys containing strontium and magnesium, respectively, in terms of hardness, yield strength, tensile strength, and elongation to fracture. [1]

- Xiaoqin Zeng et al. (2006) in his research Effect of Strontium on the Microstructure, Mechanical Properties, and Fracture Behaviour of AZ31 Magnesium Alloy for Sr-containing alloys found that the cooling rate sensitivity of alloys with a higher Sr content (0.1 pct) is steeper due to grain size. At a given cooling rate, the grain size decreases with Sr additions up to 0.1 pct, then increases when Sr is increased to 0.5 pct, and finally decreases with increasing Sr additions. [15]
- Guoqin Wuthe et al. (2020) in their research paper Microstructure and Texture Evolution of Mg-Gd-Y-Zr Alloy during Reciprocating Upsetting-Extrusion they investigated that the element Gd was advantageous in the formation of a precipitation phase with high thermal stability.[5]
- Sankaranarayanan Seetharaman et al. (2014) in their research paper microstructure and mechanical properties of new magnesium-zinc-gadolinium alloys, found the grain characteristics of the magnesium alloys Mg-2.0Zn-0.5Gd and Mg-3.4Zn0.8Gd are nearly equiaxed grains in both alloys, indicating complete recrystallization of the Mg-matrix during extrusion.[11]
- Wu Lu et al. (2010) in their research paper on As-projected microstructure and Sr-containing periods of AZ31 magnesium compounds with high Sr contents observed that the optical images of the AZ31 with various Sr contents (0, 0.3 percent, 2.5 percent, and 5.0 percent). The essential -Mg and -Mg₁₇Al₁₂ stages that accelerate along interdendritic; the dendritic arm separating and grain size of the AZ31 composite without Sr are greater than those of the other compounds, according to the findings.[14]

- Ren-guo Guan et al. (2013) in his research paper Development and assessment of magnesium-zinc-strontium composite for biomedical applications Alloy handling, microstructure, mechanical properties, and biodegradation examined on the grounds that both Zn and Sr are normally present in the human body, they are probably going to biocompatibility necessities, and their debasement items can be utilized and let out of the body, they were picked as alloying components. [8]
- Aria Afsharnaderi et al. (2018) in their research paper on microstructure evolution and mechanical properties of the AZ91 investigated these Magnesium Alloy with Sr and Ti Additions in As-Cast and As-Aged Conditions, these dark zones have a lamellar structure that can be related to the β -Mg₁₇Al₁₂ (DP) intermetallic. As Sr and Ti were added, the β -Mg₁₇Al₁₂ intermetallic became smaller and more uniformly dispersed along grain boundaries.[2]
- Lavish Kumar Singh et al. (2017) in his research paper Impacts of gadolinium expansion on the microstructure and mechanical properties of Mg-9Al combination they explored the impact of Gd on strong arrangement reinforcing is a lot more grounded than the impacts of Al and Zn, as per research. In this study, the mechanical properties of Mg-9Al combinations with various Gd contents were evaluated and correlated with the microstructure. When Mg-9Al is alloyed with Gd, the grain size of the alloy is reduced. Crystal growth is slowed when Gd is added. Gd addition causes sluggish solute atom diffusion because the diffusion layer ahead of the advancing solid/liquid interface is constitutionally undercooled. The addition of Gd results in higher hardness values when compared to the alloy without Gd. [7]
- Fan Jinping et al. (2011) in their research paper Effects of Sr addition on mechanical properties and microstructure of Mg-6Al magnesium alloy they investigated the amount of free-state Sr in the magnesium alloy melt was increased, the grain size of the magnesium alloy got smaller. However, because strontium was so active that adding more Sr

aggravated burnout, the refining effect of the 6 percent addition was not significant when compared to the 4 percent addition. [4]

- Bettles et al. (2009) in their research paper Microstructure and mechanical behavior of an elevated temperature Mg-rare earth-based alloy Materials Science and Engineering they investigated the connection among microstructure and mechanical properties was investigated. After heat treatment, the microstructure of the full grain refined alloy has many features, including several phases, which operate in vastly different dimensions to influence mechanical properties.[3]
- Yang et al. (2008) in their research paper review on the research and development of magnesium alloys investigated that the microstructure and mechanical properties of the Mg-Nd-Zr alloy were studied in relation to the rare earth elements gadolinium and dysprosium. Differences in precipitation kinetics and precipitate compositions have been discovered, with these differences having a significant impact on mechanical properties. Gd additions have been found to increase YS when compared to yttrium or dysprosium.[17]
- Zhang et al. (2013) in their research paper Effect of strontium content on porosity and tensile properties of squeeze cast Mg-Al–Sr alloy found that the microstructural analysis of the amount of Sr in squeeze cast alloys influenced several phases. Furthermore, the grain size of the alloys shrank as the strontium content in the alloys increased. The decrease in tensile properties is thought to be due to an increase in porosity following the addition of Sr, which appears to offset its grain refinement effect. It shows that increasing Sr causes grain size to decrease significantly. According to this experimental observation, the grain refinement effect of Sr on Mg-Al alloys causes an increase in Sr content to result in a decrease in grain size for the squeeze cast Mg-Al–Sr alloy. [18]

CHAPTER 3

AIM AND SCOPE OF THE PROJECT

3.1 AIM OF THE PROJECT

To collect experimental tensile test, hardness test, and microstructure data of magnesium, alloys of strontium, and gadolinium in various bio-medical implants from the existing literature.

To develop the Material of Magnesium Alloy using a gravity casting process and produce as cast binary and ternary alloys of Mg Sr Gd depending upon Bio-Medical applications.

To perform and investigate the strength of magnesium alloys using a micro tensile testing setup.

To find and investigate the hardness values of casted binary Alloy and ternary alloy by using a microhardness testing machine.

Identifying and investigating the microscope images of binary and ternary magnesium alloy using an optical microscope.

3.2 SCOPE OF THE PROJECT

The outcome of the project will be a detailed report, presented in a journal with the characteristic properties of magnesium alloy (Mg Sr Gd) of casted material.

This report consists of the values of the hardness test, tensile test, and optical microscope image.

This hardness and tensile strength values predicts that how strength the mechanical properties behaves and how the grain structure improves under physical properties. And will be helpful in suitability for biomedical applications like in orthopedic.

3.3 METHODOLOGY OF RESEARCH

After analyzing and reviewing the numerous works of literature with the information and facts learned, the transparent process of the methodology recommended for the research work is illuminated as follows.

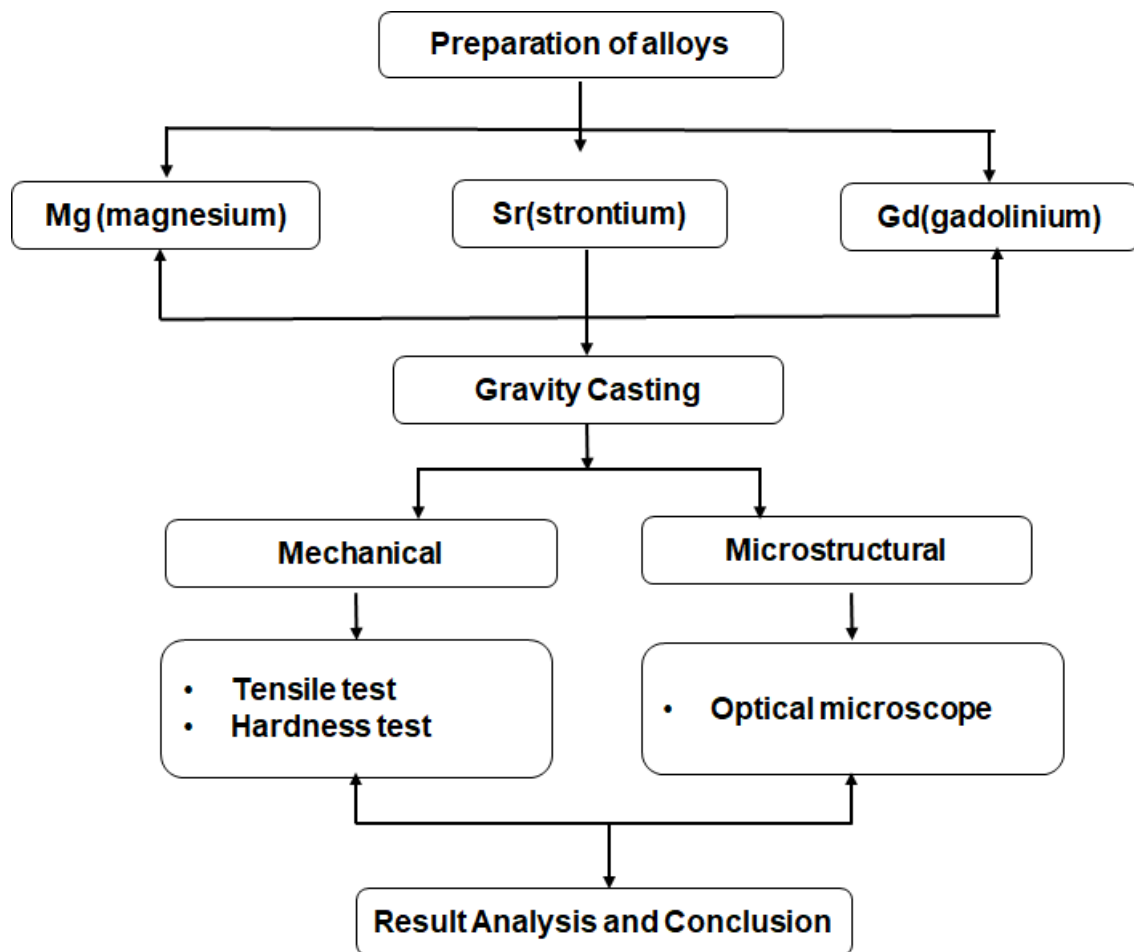


Fig. 3.1: Stages of preparation of alloys

3.4 WORK FLOW PROCESS

The First step in the workflow process collects the materials required for investigation, Binary alloy and ternary alloy of the material are Magnesium-

Strontium-Gadolinium. After the preparation of amalgams, the amalgams were further machined to test the tensile test, hardness test and optical microstructure, based on these tests the analysis is being carried out between the two amalgams

3.4.1 *During Casting defects on Magnesium Alloy*

Casting defects observed in nonferrous alloys such as aluminum during sand and permanent mold casting are applicable to magnesium; however, fold formation is the most common defect during lost-foam casting of magnesium alloys. Mg alloys are more susceptible to oxidation and fold formation compared to aluminum alloys.

CHAPTER 4

MATERIALS AND METHODS

4.1 PREPARATION OF ALLOYS

The prerequisites for this test study are unadulterated magnesium, strontium acetate compound and Gd. In this cycle, silicon carbide (Si-C) crushing paper is utilized to set up a microstructure test with a molecule size of up to 4000, and afterward it is cleaned to $0.3\mu\text{m}$ with silica gel. In pure Mg has 650°C liquifying point the time being to liquify the magnesium material will take up to 35-40 minutes, and has density of 1.73g/cm^3 since the density of magnesium material is less and has better advantage to biomedical applications and has the composition of 99.9%. Whereas in Sr master amalgam has the liquifying point of 777°C and it takes more time to liquify depending on the composition of the material, but as of now during the experimental investigation in preparation of amalgam, strontium has the composition of 2% and therefore it takes 10-15 minutes to melt the material, and has the density of 2.64 g/cm^3 . Whereas in Gd it has the liquifying point of 1313°C , being the highest liquifying temperature in comparison to Mg and Sr master amalgam takes more time to liquify the gadolinium depending on composition being taken during the preparation of amalgam. As per our experimental study, Gd material is taken as the composition of 2% by weight, and being the maximum density in the material of 7.9g/cm^3 . The materials of pure magnesium, strontium master alloy and gadolinium.



Fig. 4.1: Photograph of (a) Magnesium, (b) Strontium, and (c) Gadolinium

The following magnesium-based alloys were used in this study: The base alloy is a Magnesium- 2 Strontium (Mg-2Sr) alloy with an elemental composition of 98 weight percent pure Mg and 2 weight percent Sr. Similarly, the Magnesium-Strontium-Gadolinium Mg-2Sr-2Gd amalgam, which contains 96 wt% unadulterated Mg, 2 wt% Sr, and 2 wt% Gd, has a natural piece of 96 wt% unadulterated Mg, 2 wt% Sr, and 2 wt% Gd. Mg-2Sr-4Gd alloy with 94 weight percent pure Mg, 2 weight percent Sr, and 4 weight percent Gd, Mg-2Sr-6Gd alloy has an essential organization of 92 wt% unadulterated Mg, 2 wt% Sr, and 6 wt% Gd. Mg-2Sr-8Gd combination is a magnesium REE Mg-2Sr-xGd compound with a basic synthesis of 90% unadulterated Mg, 2% Sr, and 8% Gd.

Similarly, the weight percent of Gadolinium (Gd) is varied between 2 wt percent, 4 wt percent, 6 wt percent, and 8 wt percent while keeping the 2 wt percent of Sr constant. These things are disseminated in matrix technological solutions, Kalpadi, Tamil Nadu.

The capacity of the warming heater is to utilize the pre-INDFURR warming heater to warm the metal form, as demonstrated in Figure Lasting metal molds can create countless top-notch parts. The quick and ordinary cooling that happens here influences the sub-segments of the item.



Fig. 4.2: INDFURR Preheating oven

Then, as demonstrated in Figure, preheat the die cast steel to 450°C to advance stream and diminish warm-harm to the dispersion. At that point apply building materials or shape cleaner on the form openings to forestall the spread of parasitic grip and expand the existence of the shape. Die cast steel is under the category of non-ferrous metals and are mainly used for the manufacturing of

components like Mg alloy ingots. Being the material of mould as die cast steel possesses several advantages during the preparation alloy like having high resistance to erosion and having greater hardness and strength, also processes high conduction of electricity etc.



Fig. 4.3: Die cast steel mold about to be kept in the oven

In the pot, the iron metal in some cases liquefies with sand, glass, remains and different fluids. Since coal can't be singed to a sufficiently high temperature, steel would not soften in old occasions. Then again, stainless steel crucible can be softened on the grounds that it has a high carbon content, so it has a low dissolving point, and can decrease the carbon substance of pork by adding iron metal or fluid pork for quite a while with time it spreads the metal gradually. Stainless steel crucibles are also preferred during the casting process because of their high temperature resistance and corrosion resistance, as well as their ability to resist themselves by casting different materials. As demonstrated in Figure, unadulterated magnesium is added to the tempered steel cauldron.



Fig. 4.4: Casting of Mg REE alloys (a) Placing pure magnesium in Stainless Steel Crucible and (b) Placing of stainless-steel crucible in the Electrical resistance furnace

Then, less treatment in the defensive climate of metal filtration innovation. Eliminate any gliding material or particles on the top. Numerous impurities buy to top of the water and are skimmed off or removed. Skimming of impurities is removed by the help of cup rod and were the impurities found to be less than 10%. Most of the times in every material the impurities are always present in it and has to be skimmed off to avoid dislocations or imperfections in the cast material. Also, during the casting ternary alloy system, the same process has been carried out for skimming under protective atmosphere.



Fig. 4.5: Skimming under protective atmosphere

The main disadvantage is that if skimming is not done during the casting processes, then after the as cast alloy produced, after the casting and solidification may leads to several problems like crack on the as cast ingots and cannot be easily machined.

Next, after the impurities taken out from the pure Mg, then Sr master amalgam is being added in the stainless-steel crucible containing pure magnesium molten. If only strontium is added to the stainless-steel crucible, then strontium oxide reaction takes place which in turn effects the atmosphere. In the similar way the Gd is added instead of Sr master amalgam in stainless steel crucible with the pure Mg hot molten metal. The Sr master alloy is added to the pure Mg molten metal as shown in figure. Next, die cast steel mold is taken out from the furnace which is preheated at 450°C.



Fig. 4.6: Addition of Mg-Sr master alloy (or) gadolinium

During the preheating of mold, it may take several hours depending on the size of the mold, resulting in significant production losses during routine refits and even more so during spontaneous refits. After that, hand stirring is done in the stainless steel crucible that was removed from the electrical resistance furnace. During the hand stirring process the molten metal is being stirred to give the homogenized mixture and then the impurities were settled to the top when addition of strontium master alloy in pure magnesium molten metal. Thereby the skimming process is done to remove the impurities settled at top in the stainless-steel crucible. Hand stirring and skimming are used in the same way that gadolinium is added to pure magnesium molten metal in an electrical resistance furnace.



Fig. 4.7: Removal of preheated die cast steel mold from preheated oven

After the hand stirring and skimming process, the molten metal is in pure form and is then poured into the preheated die cast steel mold through the runner where the molten metal starts entering into the mold from bottom to top and also few impurities settled at the top of the mold while pouring the molten metal.



Fig. 4.8: (a) Hand stirring process and (b) Skimming process

After the pouring of molten metal, solidification is being carried out for 15-20 minutes were to cool the as cast magnesium alloy from 750°C to room temperature and also during the solidification process the shrinkage which they themselves reduces the dimensions during cooling when compared to actual dimensions of the die cast steel mold. And finally, the as cast Magnesium-strontium alloy being taken out from the die cast steel mold after solidification and also in the similar way the as cast Magnesium- strontium- gadolinium alloy is being done and carried out. Mg-2Sr is forever delivered by the attractive field. Subsequent to liquefying the unadulterated Mg, keep it at 750 ° C for 45 minutes, add the Mg-Sr (% wt.) ace compound under consistent mixing for 10 minutes, at that point reheat at 750°C. Using extraction specialist to implant dissolving into effectively hot metal form (400 ° C). A hardened steel pot is warmed to 500 ° C ~ 550 ° C in a 2kW obstruction heater under argon (Ar) insurance 99.98% magnesium is an unadulterated fixing in a non-rough, non-grating texture for warmth and softening.



Fig. 4.9: (a) Pouring the alloy molten metal into the preheated die cast steel mold, (b) Shrinkage during the cooling process and (c) As cast Mg Sr Gd alloy

Argon (2% wt.) and SF₆ (98%) emerge from the pot to forestall oxidation during warming and dissolving. At that point the temperature ascends to 720°C, and afterward the mechanical dry composite expert (Gd) and Mg-Sr (2% wt. Sr) and Mg-2Sr-xGd (x=2%, 4%, 6% and 8% wt) ace combination the metal. The magnesium combination is blended to guarantee that the blending components are completely receptive to one another and equally circulated. After the magnesium combination has been kept in a dissolved state for 30 minutes, it is squashed and tossed into a dead shape to frame an ingot. The flowchart of the casting of an alloy as shown in figure.

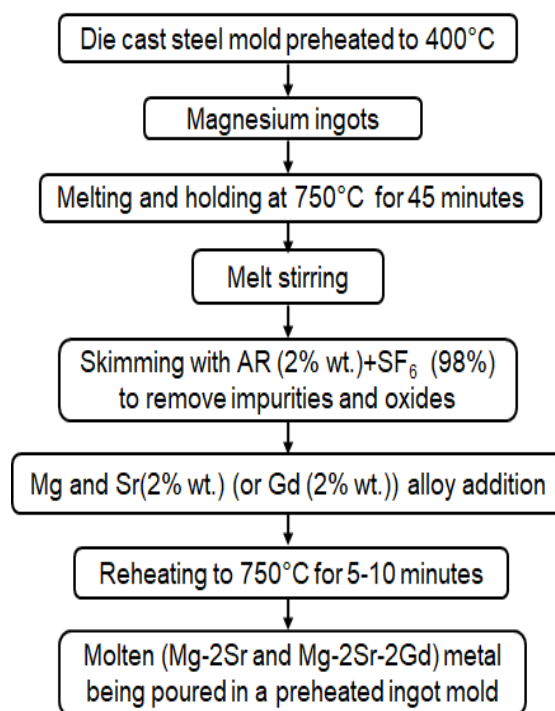


Fig. 4.10: Stages on research

4.2 SHEAR CUTTING AND CLEANING PROCESS

Metals are cut using a simple process called shearing. It's essentially a metal fabrication process that's used in rolling mills all over the world for both hot and cold cutting of steel. The shear stress in the material exceeds the ultimate shear strength when a large shearing force is applied, and the material fails and separates at the cut location.

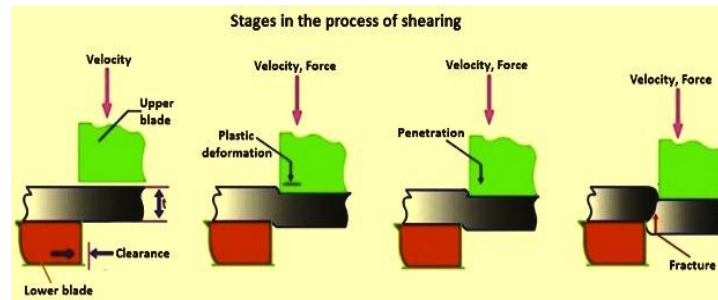


Fig. 4.11: Stages in Shear Cutting
(Source: www.ispatguru.com)

4.2.1 Cleaning with Acetone before Testing

After shear cutting, the samples are cleaned with an acetone solution to remove dust and other particles before the testing process begins.

4.3 WIRE CUT EDM

To achieve a specific gap, a CNC wire-cutting EDM machine used by a servo system to apply impulse voltage to the electrode wire and workpiece, and the impulses are then discharged in the working liquid between the electrode wires and workpiece.

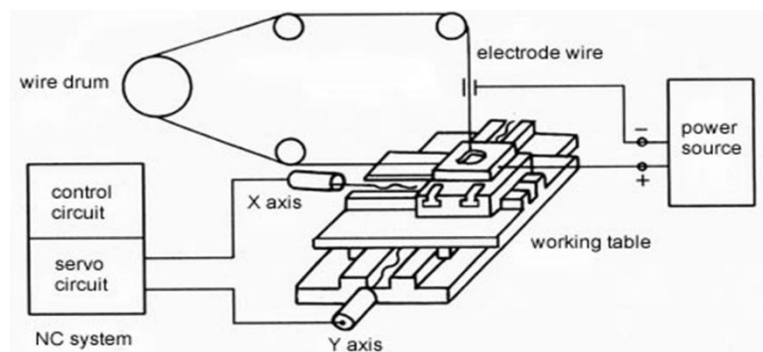


Fig. 4.12: Wire cut EDM

Numerous tiny holes appear as a result of the impulse discharging erosion before the required shape of the workpiece is achieved, as shown in the figure.

When a workpiece comes close to an electrode wire in an insulating liquid and the gap between them narrows to a certain value, the insulating liquid is quickly broken through a discharging channel, and electrical discharging occurs. The eroded workpiece cools quickly in the working liquid and is flushed away after releasing a massive high temperature of up to more than 10000 degrees Celsius.

4.4 TENSILE TEST

By Tensile testing, compound samples were resolved. The planning of tests relies upon the exploration targets and material testing systems or details. The tensile test is generally a cross segment of the suspended sample. It shows up the two shoulders and the measure (cross area) are in the center. The shoulders are expansive and can be effortlessly held, and the cross segment of the check part is little and can be fixed.



Fig. 4.13: Photograph of Micro tensile testing setup

There are numerous approaches to make a sample shoulder to coordinate with various grasps on an estimating machine. Every gadget has its benefits and impediments for instance, a serrated grasp handle is simple and cheap to create, however test arrangement relies upon the ability of the subject matter expert. Then again, the fixed handle guarantees the right arrangement. Sharp shoulders and ties can likewise give great arrangement however, the specialist ought to make sure to envelop each shoulder in any event by a similar width on both

sides, in any case, the strands will extend until the sample breaks. It is known to add extra apparatuses to the standard and to the majority, which are planned to be removed from the transmission and used to make test models. As the grain structure in the workpiece may change, these samples may not completely address the whole work. For more modest workpieces or where there is a need to test key appropriation parts, an apparatus can be accommodated examining. A sample of the workpiece prepared by the stock bar can be made in similar parts as the stock.

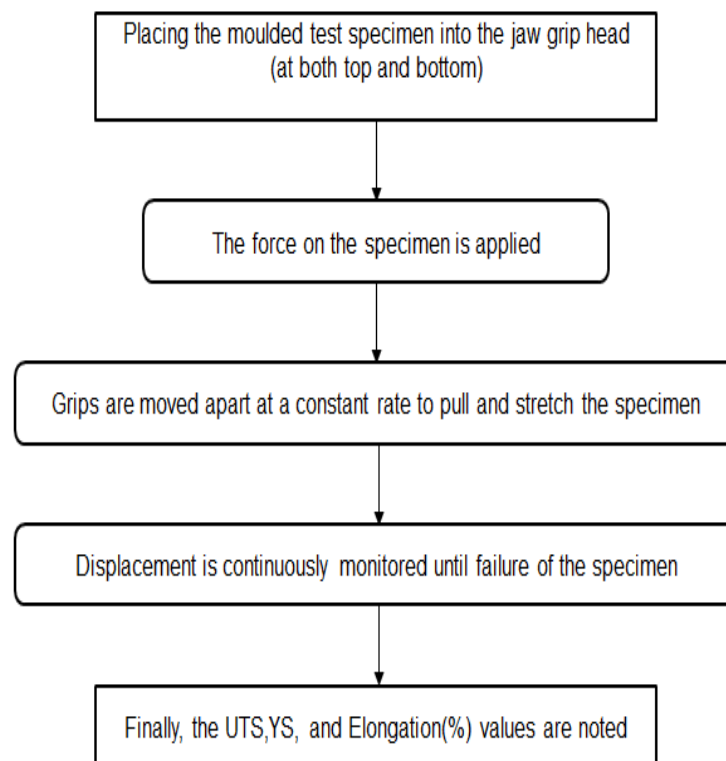


Fig. 4.14: Flow chart of tensile testing method

The following steps takes place during the tensile testing for finding out the UTS, YS and EL (%) as shown in the figure. The first step in this testing is to place the mould test specimen into the jaw grip head at both top and bottom up-to jaw length, the jaw grip plays an important role for successful mechanical tests as if the specimen slippage between the jaws occurs or if the specimen breaks or tears in the jaw area testing may need to be discarded, then the force on the specimen is applied in tensile nature, when the force is applied to the specimen then the grips or shoulders moved apart at a constant rate to pull and stretch the specimen after the

shoulders or grips moved at a constant rate then the displacement is continuously monitored until the failure of the specimen and the displacement is shown from the system and then the values of UTS, YS, and Elongation are shown in the system and the values has been noted.

4.5 HARDNESS TEST

Brinell hardness testing was utilized to quantify the heaviness of the Mg-2Sr parallel compound and the ternary Mg-2Sr-xGd ($x = 2, 4, 6$, and 8) combination. The test was performed for 15 seconds under a combination heap of 300 gf with an ASTM E92. Preceding testing, all cleaned tests were disintegrated by $0.3\mu\text{m}$ to lessen the effect of additional mistakes on the investigation.



Fig. 4.15: Photograph of Brinell hardness testing setup

Instructions to by implication decide the particular properties of combinations that are clinically significant. Microhardness testing is performed on a diamond molded sample. Utilize the Brinell hardness testing system to test. During this interaction, tension on the sample surface of is a pyramidal jewel indenter with a surface point of 136° . Set rating connects to cover the whole sample region and match all samples. The combination was cut into round shapes, partitioned into 5

samples as per the size of every blend, and 5 tests were performed on each amalgam. An assortment of strengths of the amalgams combined with a normal length of 25mm and a diameter of 5mm. The figure shows the flowchart with the following steps for hardness testing method. The first step to place the sample on the microhardness machine stage and click and drag to move the sample and next step is to scroll to focus it means that the sample is to present near to the diamond indenter which consist of 136° on each side of plane.

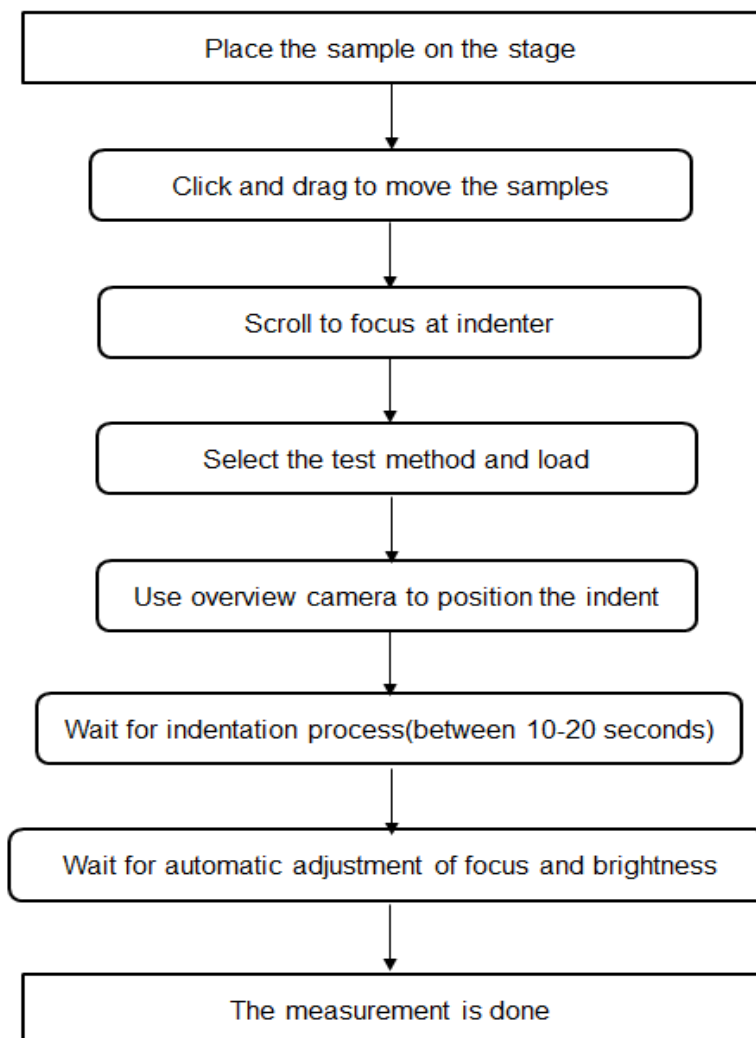


Fig. 4.16: Flow chart of hardness testing method

Next to select the load of 300gf and use the overview camera to position the indent and has to wait for the indentation process for about 10-20 seconds and then wait for the automatic adjustment of focus and brightness, then the measurement is being done and noted.

4.6 OPTICAL MICROSTRUCTURE

It is also known as the light optical microscope and it's a type of microscope using visible lights and a lens device to view the small samples. It has several advanced designs to improve sample contrast, basic optical microscopes and resolution is very simple. These microscopes have visible light to view through the naked eye.

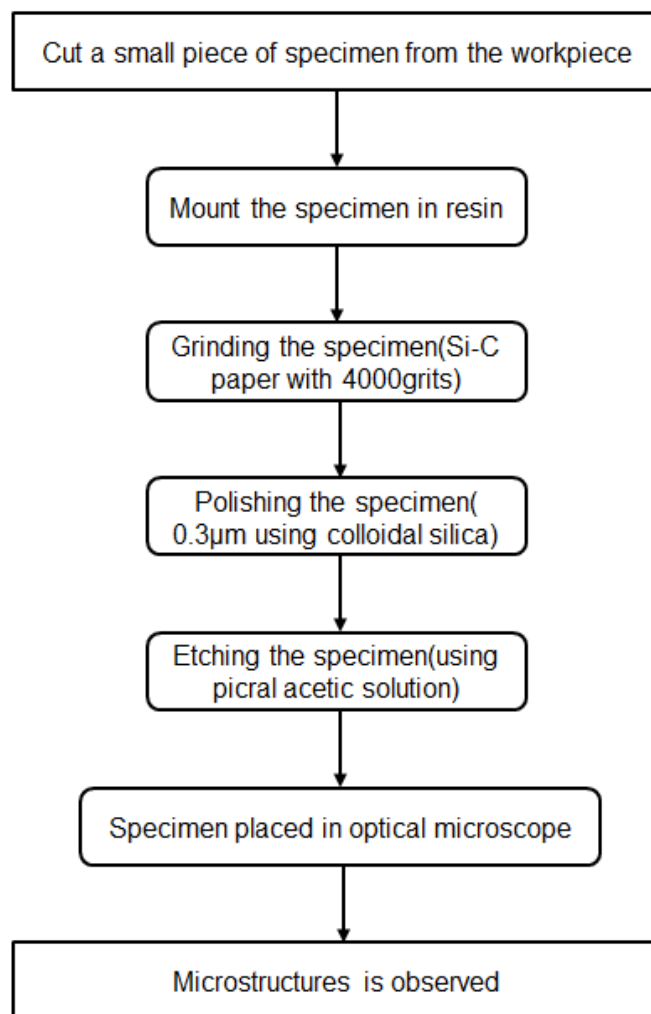


Fig. 4.17: Flowchart for finding the optical microstructure

An optical microscope image can be captured with ordinary light-sensitive cameras to create a micrograph. Images were once captured on photographic film, but advances in complementary metal-oxide-semiconductor (CMOS) and charge-coupled device (CCD) cameras have allowed digital images to be captured. Purely

optical microscopes, which examine a sample with a CCD camera and display the image on a computer screen without using eyepieces.

Samples for microstructural characterization were prepared with silicon carbide (Si-C) grinding papers up to 4000 grits, where it removes saw marks and levels and cleans the specimen surface and to make the specimens flat and then polishing up to 0.3 μm using colloidal silica to remove the artifacts of grinding but very little stock.

The specimens were then etched with a picral acetic solution, which increases surface contrast and allows for microstructure visualisation. Etching in metallography alters the surface profile or optical properties of grain boundaries, phases, or grain surfaces, allowing microscopic inspection and the use of optical fibres in the microscope. An optical microscope was used to examine the microstructure of the prepared samples.

The figure shows the following steps which have been done during the characterization of optical microstructure. The first step is to cut a small piece of specimen of binary Mg-2Sr alloy and ternary Mg-2Sr-4Gd And Mg-2Sr-8Gd alloy of any shape and size from the workpiece and then mounting the specimen in the resin after that we have grinded the specimen with the silicon carbide grinding paper containing 4000grits which removes saw marks and levels and cleans the specimen surfaces and then polishing the specimen up to 0.3 μm using colloidal silica, where it removes the artifacts of grinding but very little stock, and then etching the specimen with the help of picral acetic solution and finally the specimen of binary Mg-2Sr alloy and ternary, Mg-2Sr-4Gd And Mg-2Sr-8Gd alloy is placed in optical microscope to obtain the microstructure.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 TENSILE TEST

The tensile test property variations like UTS, YS, and elongation (%) of the samples of both binary and ternary alloy are listed in table. The effect of Sr content in binary alloy had a nominal effect on the strength of the alloy.



Fig. 5.1: Tensile specimen (a) Before testing (b) After testing

Table 5.1: Tensile test values containing UTS, YS, and Elongation of magnesium rare earth alloy

S.NO	Magnesium alloy	UTS Mpa	YS Mpa	% Elongation
1	Mg-2Sr	69.553	28.759	9.4
2	Mg-2Sr-2Gd	83.488	17.403	8.9
3	Mg-2Sr-4Gd	81.992	48.435	6.9
4	Mg-2Sr-6Gd	89.065	39.556	5.5
5	Mg-2Sr-8Gd	115.027	40.884	8.3

The graph of Fig. 5.2 shows tensile strength plotted on vertical axis and their respective five trials in the horizontal axis for both the binary and ternary alloy of magnesium.

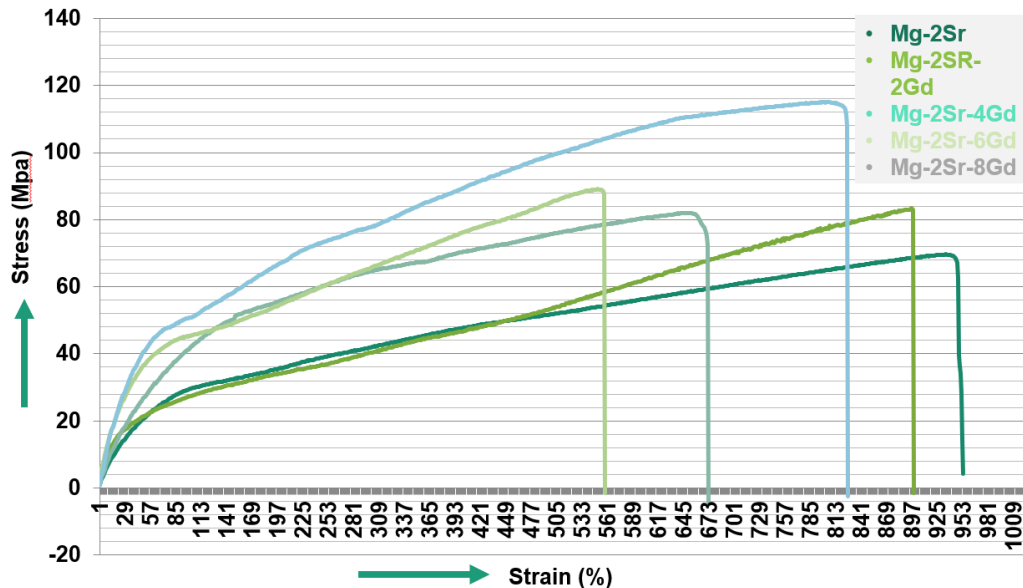


Fig. 5.2: Tensile graph of Mg-2Sr, Mg-2Sr-2Gd, Mg-2Sr-4Gd, Mg-2Sr-6Gd. And Mg-2Sr-8Gd alloy

The line graph represents yield strength (YS) and the ultimate tensile strength (UTS). Both UTS and YS have represented by a unit Mpa. In binary Mg-2Sr, ultimate tensile strength shows in trial-1 with the value of 69.553Mpa. whereas in ternary Mg-2Sr-2Gd alloy, the ultimate tensile strength shows in trial-1 show the value of 83.821Mpa, whereas in ternary Mg-2Sr-4Gd alloy, the ultimate tensile strength shows in trial-1 shows the value of 83.992Mpa, whereas in ternary Mg-2Sr-6Gd alloy, ultimate tensile strength shows in trial-1 shows the value of 89.065Mpa, whereas in ternary Mg-2Sr-8Gd alloy, ultimate tensile strength shows in trial-1 shows the value of 115.027 Mpa.

The tensile strength variations of the sample alloys with magnesium, strontium, and gadolinium respectively the ternary Mg-2Sr-2Gd alloys' tensile strengths increased up to 0.2 percent gadolinium content. Tensile strength increased when gadolinium was added in excess of 0.2 percent. The ternary Mg-2Sr-4Gd alloys' tensile strengths increased up to 0.4 percent gadolinium content. Tensile strength was reduced when gadolinium was added in excess of 0.4 percent.

The ternary Mg-2Sr-6Gd alloys' tensile strengths increased up to 0.6 percent gadolinium content. Tensile strength was reduced when gadolinium was added in excess of 0.6 percent. The ternary Mg-2Sr-8Gd alloys' tensile strengths increased up to 0.8 percent gadolinium content. Tensile strength increased when gadolinium was added in excess of 0.8 percent. [1]. strain-stress curves of as-cast magnesium alloy and Gd-modified magnesium alloy (2 wt%) [5]. The tensile strengths of as-cast magnesium alloy and Gd modified magnesium are 69.553 MPa and 83.488 MPa, respectively (Gd=0.2 wt percent). As can be seen, the curves are similar in shape and number. The strain-stress curves of a magnesium alloy as-cast and a magnesium alloy modified with Gd are shown. By acting as grain refinement and grain boundary strengthening, Gd, a rare earth element, improve the tensile properties of magnesium alloy [4]. Tensile strength increased with increasing Gd addition, peaking at 0.8 percent Gd, when compared to Mg REE alloys. The addition of Gd increased the tensile strength of magnesium alloy due to grain refinement, grain boundary strengthening, and second phase strengthening.

In binary Mg-2Sr, yield strength shows in trial-1 with the value of 28.759Mpa, whereas in ternary Mg-2Sr-2Gd alloy, yield strength shows in trial-1 shows the value of 17.403Mpa, whereas in ternary Mg-2Sr-4Gd alloy, yield strength shows in trial-1 shows the value of 48.435Mpa, whereas in ternary Mg-2Sr-6Gd alloy, yield strength shows in trial-1 shows the value of 39.556Mpa, whereas in ternary Mg-2Sr-8Gd alloy, yield strength shows in trial-1 shows the value of 40.884Mpa.

The yield strength of the experimental alloys of strontium, gadolinium, and magnesium content. The ternary Mg-2sr-2Gd alloys' yield strengths increased up to 0.2 percent gadolinium content. Yield strength was reduced when gadolinium was added in excess of 0.2 percent. The ternary Mg-2sr-4Gd alloys' yield strengths increased up to 0.4 percent gadolinium content. Yield strength increased when gadolinium was added in excess of 0.4 percent. The ternary Mg-2sr-6Gd alloys' yield strengths increased up to 0.6 percent gadolinium content. Yield strength was reduced when gadolinium was added in excess of 0.6 percent. The ternary Mg-2sr-8Gd alloys' yield strengths increased up to 0.8 percent gadolinium content. Yield strength increased when gadolinium was added in excess of 0.8 percent. The yield

strength decreased at (0.2 percent Gd), then increased, then decreased at (0.6 percent Gd), and finally reached its maximum at (0.8 percent Gd) (0.8 percent Gd). However, when compared to binary alloys, the ternary alloy of Mg-2Sr-xGd reached its maximum at (0.8 percent Gd). When strontium was added in excess of 0.1 percent, strength decreased while yield strength remained unchanged. The microstructure of the amalgams are more homogeneous and the breakdown conveyance of eutectic silicon particles in the expansion of hardness.

For elongation (%) in binary Mg-2Sr alloy shows a value of 9.45% whereas in ternary Mg-2Sr-2Gd alloy shows a value of 8.98%, whereas in ternary Mg-2Sr-4Gd alloy shows a value of 6.9%. whereas in ternary Mg-2Sr-6Gd alloy shows a value of 5.57%. whereas in ternary Mg-2Sr-8Gd alloy shows a value of 8.38%. Based on the above five values of magnesium alloy.

The elongation of the experimental alloys of strontium, gadolinium, and magnesium content. The ternary Mg-2sr-2Gd alloys' elongation increased to 0.2 percent gadolinium content. Elongation was reduced when gadolinium was added in excess of 0.2 percent. The ternary Mg-2sr-4Gd alloys' elongation increased to 0.4 percent gadolinium content. Elongation was reduced when gadolinium was added in excess of 0.4 percent. The ternary Mg-2sr-6Gd alloys' elongation increased to 0.6 percent gadolinium content. Elongation was reduced when gadolinium was added in excess of 0.6 percent. The ternary Mg-2sr-8Gd alloys' elongation increased to 0.8 percent gadolinium content. If the gadolinium concentration is greater than 0.8 percent, Addition of Gd has an effect. When gadolinium content was zero, binary alloy Mg-2Sr had a 9.4 percent gadolinium content. When the gadolinium content was increased to 2%, 4%, 6%, and 8%). Elongation suddenly decreased. [6] As a result, when gadolinium concentrations exceed 0.8 percent, there is no significant change in the addition of Gd.

Mg-2Sr-4Gd exhibits the highest yield strength (YS), Mg-2Sr-8Gd exhibits the highest ultimate tensile strength (UTS), and Mg-2Sr exhibits the highest elongation of 48MPa, 115 MPa, and 9.4%, respectively, among the investigated samples [13].

5.2 HARDNESS TEST

The table of Figure shows Hardness of five trials of the binary and ternary alloy of magnesium. The table shows variation of hardness values in different. Hardness has represented by a unit HV.

Table 5.2: Hardness number values of binary and ternary magnesium alloy

S.NO	Sample	Ball diameter(mm)	Load (kgf)	Brinell hardness values	Average Brinell hardness (HBW)
1	A81	2.5	60	111.146	111.03
				111.328	
				110.633	
2	A84	2.5	60	107.961	108.71
				109.737	
				108.461	
3	A85	2.5	60	116.555	115.66
				114.778	
4	A86	2.5	60	115.130	115.07
				115.027	
5	A87	2.5	60	113.617	113.28
				112.962	

The table shows the Brinell hardness (HBW) values for homogenized binary Mg–2Sr alloy and ternary Mg-Sr-Gd alloy of five trials in alloy. In binary Mg-2Sr amalgam, Hardness shows in trial-1 with the value of 111.146HBW, and in trial-2 shows the value of 111.328HBW, and in trial-3 shows the value of 110.633HBW, and based on the above three trials in binary Mg-2Sr alloy shows an average value of 111.03HBW. whereas in ternary Mg-2Sr-2Gd alloy, Hardness shows in trial-1 shows the value of 107.961HBW, trial-2 shows the value of 109.737HBW, and in trial-3 shows the value of 108.461HBW Based on the above three trials in ternary Mg-2Sr-2Gd amalgam shows an average value of 108.71HBW. In ternary Mg-2Sr-4Gd alloy, Hardness shows in trial-1 shows the value of 116.555HBW, in trial-2, shows the value of 114.778HBW. Based on the above two trials in ternary Mg-2Sr-4Gd amalgam shows an average value of 115.66HBW. In ternary Mg-2Sr-6Gd alloy,

Hardness shows in trial-1 shows the value of 115.130HBW, in trial-2 shows the value of 114.027HBW. Based on the above two trials in ternary Mg-2Sr-6Gd amalgam shows an average value of 115.07HBW. In ternary Mg-2Sr-8Gd alloy, Hardness shows in trial-1 shows the value of 113.617HBW, in trial-2 shows the value of 112.962HBW. Based on the above two trials in ternary Mg-2Sr-8Gd amalgam shows an average value of 113.28HBW. Therefore, the addition of Gd does not change when addition of gadolinium exceeds to 0.8%. Hardness strength decreased when strontium was added in excess of 0.1 percent, while yield strength remained unchanged. The breakdown and more homogeneous conveyance of the eutectic silicon particles in the microstructures of the amalgams can cause an expansion in hardness. The grain size of the Mg–Sr alloy is reduced when it is alloyed with Gd. The addition of Gd slows the growth of crystals. As the diffusion layer ahead of the advancing solid/liquid interface undergoes constitutional undercooling, Gd addition causes sluggish solute atom diffusion. When compared to the alloy without Gd, the addition of Gd results in higher hardness values

5.3 OPTICAL MICROSTRUCTURE

The optical microstructure of the binary Mg–2 (wt.%) Sr alloy, as well as the ternary Mg–2(wt.%) Sr–4(wt.%) Gd, and Mg–2(wt.%) Sr–8(wt.%) Gd alloys. When compared to binary Mg-2Sr alloys, Mg–2(wt. percent) Sr–4(wt. percent) Gd and Mg–2(wt. percent) Sr–8(wt. percent) Gd alloys have the largest grains.

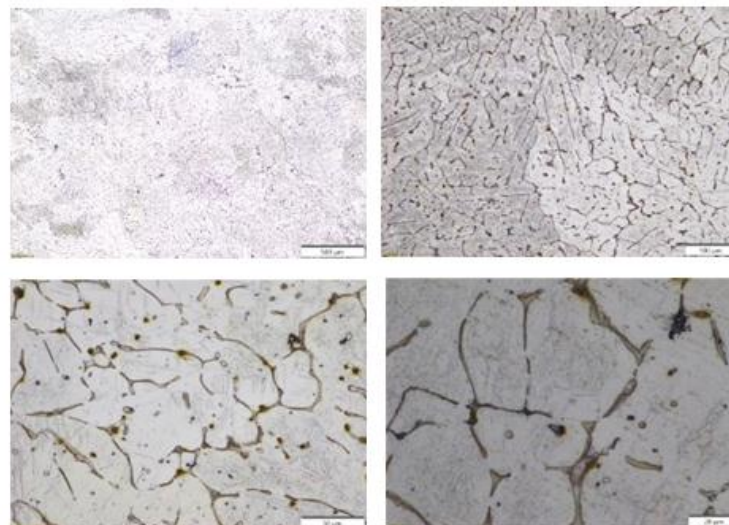


Fig. 5.3: Microstructure of Mg-2Sr Magnesium REE alloy

Due to the grain refinement in ternary Mg-2Sr-4Gd And Mg-2Sr-8Gd alloy brings better enhancement with the skin during implantation and also during ageing stages. The more refinement in alloy microstructure the better will be the advantage during implantation and also reduces stress shielding. So, Gd plays a major role in grain refinement in ternary Mg-2Sr-4Gd, And Mg-2Sr-8Gd alloy.

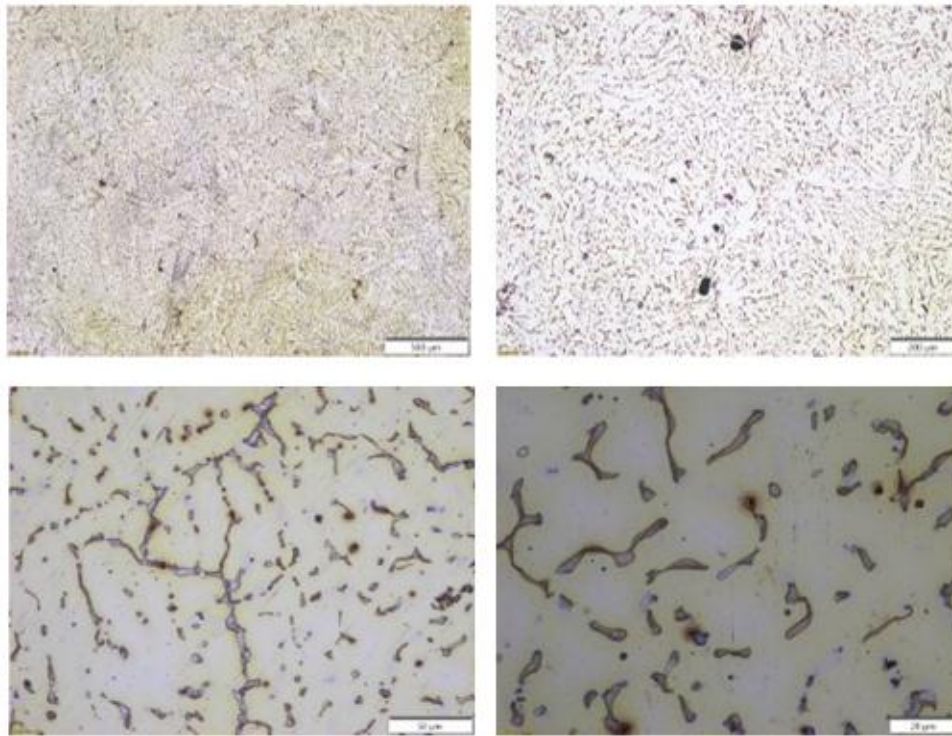


Fig. 5.4: Microstructure of Mg-2Sr-4Gd Magnesium REE alloy

The optical microstructure of the binary and ternary alloy is shown in figure. The optical images of the Mg-2Sr-xGd alloy with different Gd contents (0.4% and 0.8%). The grain characteristics of Mg-2Sr-4Gd, and Mg-2Sr-8Gd alloys are shown in figures. It reveals nearly equiaxed grains in the alloys, thus indicating complete recrystallization of Mg-matrix during extrusion [8].

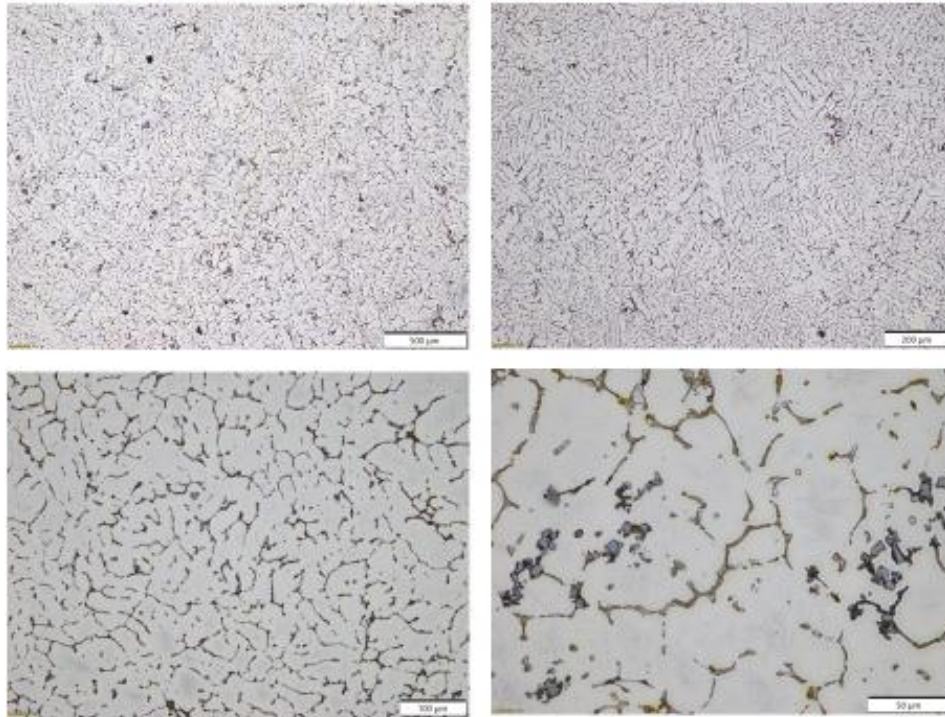


Fig. 5.5: Microstructure of Mg-2Sr-8Gd Magnesium REE alloy

The dendritic matrix was clearly refined as the gadolinium content increased to 4% and 8%, and the dendrite arm spacing became larger. [6]. The addition of Sr and Gd alloying elements to Mg has resulted in a fine equiaxed microstructure, according to the microstructural analysis. As a result, increasing Gd addition improves tensile and compressive strength properties, which can be attributed to the following strengthening mechanisms. Strengthening from grain size reduction and formation of refined and equiaxed grains, which impede stress transfer across grain boundaries. Strengthening from grain size reduction and formation of refined and equiaxed grains, which impede stress transfer across grain boundaries. [5]. Gd, on the other hand, improves plastic deformation properties while lowering toughness. The fracture mode of the magnesium alloy is also quasi-cleavage fracture, based on the shape of strain-stress curves. [4] As a result, it's possible to conclude that Gd improves tensile strength while lowering deformation capacity in magnesium alloy. The tensile strength of increased with Gd addition due to grain refinement, grain boundary strengthening, and second phase strengthening.

As shown in the optical images in the figures the as-homogenized samples 0Gd, 0.6Gd, and 0.8Gd evolve to grain sizes of 20 μ m, 20 μ m, and 50 μ m, respectively. Grain interiors and grain boundaries are precipitated by a high density of the second phase due to annealing treatment. Those samples have a distinct microstructure. the figures show that numerous long rod shape and dotty phases are found in grain interior.[14]

CHAPTER 6

SUMMARY AND CONCLUSION

- The material chosen in this present investigation is Mg, Sr, and Gd. The gravity casting process is being carried out to prepare the ingots of blends like Mg-2(% wt.) Sr, Mg-2(%wt.) Sr-2(% wt.) Gd, Mg-2(%wt.) Sr-4(% wt.) Gd, Mg-2(%wt.) Sr-6(% wt.) and Mg-2(%wt.) Sr-8(% wt.) Gd. Gravity casting generally prepared because of their better dimensional accuracy, better as cast surface finish etc., After the preparation of alloy three testing has been carried out consisting of Tensile test, Hardness test, and Optical microstructure of both the amalgam.
- A tensile test is performed using a micro tensile testing machine, demonstrating that the cast alloys have good tensile properties. Among the investigated samples, Mg-2Sr-4Gd has the highest yield strength (YS), Mg-2Sr-8Gd has the highest ultimate tensile strength (UTS), and Mg-2Sr has the highest elongation of 48MPa, 115 MPa, and 9.4 percent, respectively.
- The hardness value of the addition of Gd does not show any significant change when gadolinium addition exceeds 0.8 percent when tested using a micro hardness testing machine.
- Using Optical Microscope, the microstructure of both the amalgams is being found out and shows that the binary Mg-2(%wt.) amalgam has larger particle size and also larger grain boundary, were as in Mg-2(%wt.) Sr-4(%wt.) Gd amalgam shows that larger refine grain boundaries and smaller refine particle sizes.

- For the first time in this study, Mg-2Sr-xGd alloys were developed, and their tensile test, Brinell hardness, and optical microstructure were systematically investigated for bone implant applications, among other things.
- Gd has the potential to improve the optical microstructure, ultimate tensile strength, yield strength, elongation, and hardness of ternary Mg-2Sr-xGd-based Mg alloys as an alloying element, according to the observations.
- Tensile strength and hardness are good mechanical properties and finer crystal size makes the suitability in ternary Mg-Sr-Gd alloy for biomedical applications.

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