

DEVELOPMENT OF MAGNESIUM (Mg Sr Gd) ALLOYS FOR BIOMEDICAL APPLICATIONS

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

By

IMAM BASHA. K (37150075)

G. BHAVANI KIRAN (37150068)



DEPARTMENT OF MECHANICAL ENGINEERING

SCHOOL OF MECHANICAL ENGINEERING

SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)

Accredited with Grade "A" by NAAC | 12B Status by UGC | Approved by AICTE
JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI - 600 119

April - 2021



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by AICTE

Jeppiaar Nagar, Rajiv Gandhi Salai, Chennai – 600 119

www.sathyabama.ac.in

DEPARTMENT OF MECHANICAL ENGINEERING

BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of Imam Basha. K (37050075), G. Bhavani Kiran (37150068) who carried out the project entitled “Development of Magnesium (Mg Sr Gd) Alloys for biomedical applications” under our supervision from October 2020 to April 2021.

Internal Guide

Mr. J.R. DEEPAK M. E., (Ph.D.,)

Head of the Department

Dr. G. ARUNKUMAR, M.E., Ph.D.,

Submitted for Viva voce Examination held on _____

Internal Examiner

External Examiner

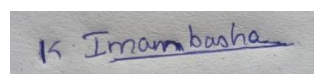
DECLARATION

I IMAM BASHA.K and G. BHAVANI KIRAN.K hereby declare that the Project Report entitled “**DEVELOPMENT OF MAGNESIUM (Mg Sr Gd) ALLOYS FOR BIOMEDICAL APPLICATIONS**” done by me under the guidance of **Mr. J R. DEEPAK M.E., (Ph.D.)** at **SATHYABAMA INSTITUTE OF SCIENCE AND TECHNOLOGY, CHENNAI** is submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering / Technology degree in MECHANICAL DEPARTMENT.

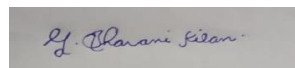
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PLACE: SATHYABAMA UNIVERSITY, CHENNAI

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2.

Handwritten signature of G. Bhavani Kiran in blue ink on a light gray background.

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ABSTRACT

Magnesium is a metal material that ages and can be utilized as a perpetual and transitory substitution material in bone applications. Lasting information gadgets incorporate elbows, wrists, shoulders, lower legs, and so forth, very much like brief information gadgets, which incorporate screens, pins, links, and so on. In any case, their low optical presentation and their-by large unacceptable appearance under the mechanical climate have ruined their far-reaching use.

The best compound as far as mechanical conduct and microstructure is Mg-2Sr-2Gd. At last, the connection between the optical microstructure and mechanical properties was assessed, and the expected utilization of each compound as a alloy material for rot materials was examined.

Of specific worry in this examination is the expansion of Gadolinium (Gd) and strontium (Sr) to the mechanical and optical microstructure of magnesium due to their improved (contradictory) impact on mechanical strength and grain refinement. A solitary combination of Mg-2Sr parallel and a ternary Mg-2Sr-2Gd was concentrated to test its microstructure. The mechanical test is completed inside, utilizing a microhardness testing machine to find out the hardness value and tensile tests to fin UTS, YS, and EL (%). The outcomes show that, contrasted and the two-fold combination Mg-2Sr, the incorporation of 2% (by weight) of Gd in the Mg-2Sr-2Gd ternary amalgam can decrease the grain size and increment the strength.

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LIST OF ABBREVIATIONS

Al	Aluminum
Ar	Argon gas
ATP	Adenosine triphosphate
Co-Cr	Cobalt-Chromium
Ca	Calcium
Ce	Cerium
CCD	Charge-Coupled device
EL	Elongation
Er	Elongation to rupture
Gd	Gadolinium
Gpa	Giga pascal
gf	Gram force
H ₂	Hydrogen
HV	Vickers pyramid number
Li	Lithium
M	Magnesium
Mpa	Mega pascal
Mn	Manganese
MZZS	Magnesium Zinc Zirconium Strontium
MZS	Magnesium Zinc Strontium
MZZ	Magnesium Zinc Zirconium
mm	Millimeters
Pr	Praseodymium
REE	Rare Earth Element
Sr	Strontium
SS	Stainless Steel
Sic	Silicon carbide
SG	Specific Gravity
Ti	Titanium
UTS	Ultimate tensile strength
Y	Yttrium
YS	Yield strength

Zr

Zirconium

μm

Micrometer

CHAPTER 1

INTRODUCTION

1.1 ABOUT MAGNESIUM AND ITS ALLOY

Magnesium and its combinations have pulled in a ton of consideration as mixtures that can be handily disintegrated because of organic changeability and rot [57]. This is essentially because of their fascinating properties, like light handling, low thickness, high strength, and Young modulus-like bone [7], 44]. Although the utilization of magnesium in biomaterial bundling can be followed back to the nineteenth and mid-20th hundreds of years, the pace of unreasonable decrease of magnesium under physiological conditions presented critical difficulties [57], [63].

Without a proportion of controlled harm, polymer-based, completely adaptable contraptions structure a completely alluring climate for the clinical market. Be that as it may, with the improvement of removable metal, preparing techniques and erosion avoidance [63], the utilization of magnesium composites in rot applications will turn into a reality. Particularly in bone biomedical applications, contrasted with earthen-ware production and other basic metals (titanium compounds, hardened steel, and so forth).

Magnesium is the least difficult metal and can be utilized in mix with different metals to improve bone structure. Manganese, aluminum, zinc, silicon, copper, zirconium and rare earth metals are a portion of the materials in this gathering [7]. Low gravity and high specific strength are two useful properties of magnesium. Hence, this material is appropriate for a wide scope of uses in the auto, aviation, producing, gadgets, clinical and business areas. Magnesium amalgam is appealing because of its high strength-to-mass proportion, free machining and inexpensive. Contrasted with other regular combinations, (for example, aluminum or steel amalgams), they have a low-ratio density of 1.74 g/cm³ and low's modulus (42GPa). The third most regular metal utilized is magnesium amalgam. The actual properties of the compound are influenced by its synthetic structure. In the event that utilize distinctive alloy materials, the combination properties will shift as per the

circumstance. For instance, rare earth metals can improve strength and protection from erosion obstruction at high temperatures. In the past decade, different melodies of magnesium amalgam have been tried for their wellness as a bone marrow relocate. Many combinations are changed over from "off the rack" structure and were not initially intended to be cooperated or relieved by bones. Aluminum (Al), zirconium (Zr), rare earth metals and other unsafe materials are normally found in this compound arrangement. These segments are not found in the fundamental substance construction of humans. They can cause resistant reactions, prompting apoplexy, dementia or Alzheimer's infection [15], [18], [55], [61], [71].

1.2 MANUFACTURING OF MAGNESIUM ALLOY

Metal alloys with thick, high-quality mechanical properties are created using gravity casting. The method, which is also known as permanent mold casting, entails pouring molten metal into molds with a ladle and relying solely on gravity to fill them. Other die casting methods necessitate the use of gases or vacuums to apply enough pressure to the alloy for it to settle into all of the mold's channels. Smoother surfaces, excellent dimensional precision, and quicker development times are only a few of the advantages of the gravity system as shown in Table 1.1.

Table 1.1 Advantages of gravity casting

TYPE OF CASTING	ADVANTAGES
Gravity casting	Smoother surfaces
	Excellent dimensional accuracy
	High development rate
	Suitable for high volumes

Gravity casting is also less costly than other methods because it does not require any massive or complicated equipment to inject the metal into the molds. Furthermore, the molds themselves can be reused indefinitely, minimizing the amount of time and energy required to create new dies. This method produces high-volume, high-quality casts with minimal finishing requirements.

During the gravity casting process, preheating of mould much be done at a constant heating rate to avoid sticking to the wall and improper defects to be removed like impurities, shrinkage etc., electrical resistance furnace is usually preferred to do the process under protective atmosphere and also the rate of heating will be high and also the temperature at which the container gets heat cannot be escaped out from the furnace. Since, it's like a closed rigid container and it can resist under high temperatures for liquifying Mg, Sr master amalgam, and Gd materials than the existing liquifying point temperatures of those materials.

In the electrical resistance furnace, the container preferred for heating the material is stainless steel crucible. Because of its high resistance in the container temperature where it cannot melt under at higher temperatures even though the material which is to be casted during the casting process. The stainless steel crucible has several advantages like high resistance to erosion, has good strength etc.

Skimming is done during the gravity casting process, to remove the material or impurities present near top of the container which floats during casting of an amalgam or in other names like removal of slag from hot molten metal. Also, which is used to concentrate on refining the alloy or valuable matter to concentrate.

Stirring is done during the gravity casting process, to shake the hot molten metal present near top of the container which floats during casting of an alloy or in other to stir the hot molten and to homogenize the mixture. Also, which is used to concentrate on refining the alloy or valuable matter to concentrate.

After the preheating of die cast steel mould, were it maintains at a constant heating rate and thereby pouring the hot liquid ferrous material into preheated die cast steel mould and has to wait for some time and the shrinkage happens as usually during solidification process or in other name it also called as case hardening.

1.2.1 *Melting Temperatures of Elements in Magnesium Alloy*

In the Table 1.2, Mg element has the liquifying temperature of 650°C, whereas in Sr it has the liquifying temperature of 777°C and in Gd has the liquefying

temperature of 1313°C. Based on these three elements it is observed that gadolinium exhibits higher melting temperature when compared to strontium and magnesium, therefore melting of gadolinium element inhibits more time when compared to magnesium and strontium elements

Table 1.2 Melting temperatures of the Magnesium, Strontium and Gadolinium element of Magnesium alloy

Elements	Melting Temperature
Magnesium	650°C
Strontium	777°C
Gadolinium	1313°C

1.3 MECHANICAL PROPERTIES

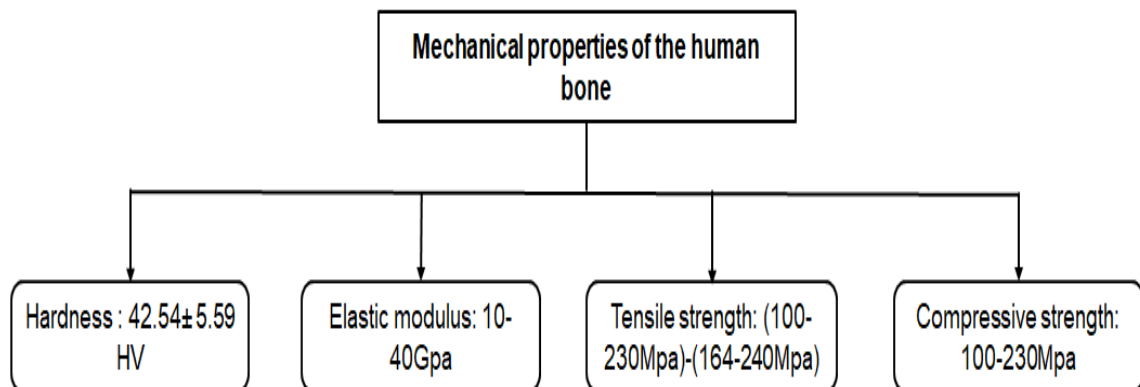


Fig 1.1 Mechanical properties of human bone

Magnesium amalgam has the most reasonable mechanical properties for characteristic bones, like density (1.8-2.1 g/cm³), Elastic modulus (10-40 GPa), compressive strength (100-230 MPa) and tensile strength (100- 230 MPa)- (164-240 MPa) [16, 31], the flowchart of mechanical properties of human bone as shown in Fig.1.1.

As per the accompanying prerequisites for assessing the properties of Mg combinations and the specialized necessities for handling rotted materials, the yield potential (YS) ought to be more prominent than 200 MPa, and the length (EL) ought to be more noteworthy than 15%. Be that as it may, many amalgams of magnesium got from rotting organic entities are endeavoring to meet both mechanical and consumption checking necessities [43].

Their presentation mix can help diminish worries about pressure assurance and mechanical disappointment during establishment [16]. What's more, the rot of magnesium amalgams can lessen the weight on patients identified with the evacuation of inserts through different surgeries by securely delivering damaging items in the wake of applying a bone infection impact in ruinous items. Tragically, magnesium amalgams have not been seriously harmed because of their physiological properties, and worries about high corruption levels of offices and hardware in the body are the primary impediments to their utilization in clinical practice [37]. Notwithstanding many metal amalgams, alloy materials and ecological changes, essential alloying is additionally perhaps the main way to improve the bio-bonding, consumption opposition and mechanical properties of Mg combinations [28, 37, 48, 72]. As of now, magnesium particles are associated with practically all metabolic cycles, like the fourth biggest normal cation in the human body after potassium particles, sodium particles and calcium particles. Magnesium particles disintegrated in magnesium combinations can help protein amalgamation, catalysis, chemical actuation and bone cell development [8, 72].

The investigation of cast combinations can give a total comprehension of consumption security and upgrade the instrument of explicit amalgam arrangement. In the previous ten years, the pertinence of different magnesium amalgam tunes in bone marrow transplantation has been tried. Many alloys have been changed from "off-the-rack" plans and have not been intended for ideal biocompatibility or early bone mending. Aluminum (Al), zirconium (Zr), rare earth metals and other destructive substances were found in these arrangements. These substances are not found in the essential compound segments of people and can trigger an invulnerable reaction, prompting apoplexy, dementia or Alzheimer's illness [15, 55].

1.3.1 Density of Elements in Magnesium Alloy

Table 1.3 Density values of the Magnesium, Strontium and Gadolinium elements of Magnesium alloy

Element symbol	Element Name	Density
Mg	Magnesium	1.73 g/cm ³
Sr	Strontium	2.64 g/cm ³
Gd	Gadolinium	7.9 g/cm ³

In the Table 1.3, Magnesium element with symbol Mg and has a density of 1.73g/cm³, whereas in Strontium element with a symbol Sr and has a density of 2.64g/cm³, and Gadolinium element with a symbol Gd and has a density of 7.9g/cm³. Based on these three elements, it is observed that gadolinium element exhibits higher density means heavier in weight when compared to strontium and magnesium elements, therefore gadolinium inhibits light weight during alloying and implantations. Since, Gadolinium being the highest in density then it has to sustain with the body depending upon the composition during implantation in biomedical applications.

1.4 MICROSTRUCTURE

Contrasted with different plans, the bones of the Mg-Zn-Sr amalgam were contemplated, and it was reasoned that the Mg-2Zn-0.5Sr and Mg-4Zn-0.5Sr combinations are required to become transitory alloys because of their low corrosion and moderate mechanical properties [30]. Analysts have as of late found

that Sr cannot just improve the microstructure of sans silicon alloys, yet additionally improve its mechanical properties [13, 75].

1.5 FUNCTIONAL USAGE OF MAGNESIUM ALLOYS IN IMPLANTS

Metal fittings are frequently used to reestablish work after a break and crumbling brought about by maturing, mishaps, and sports wounds. For load-bearing mixtures, metal biomaterials are ordinarily utilized, for example, alloy titanium (Ti), cobalt chromium (Co-Cr) amalgam and treated steel (like SS 316L) [3, 36, 52]. Although these metals have mechanical properties, they are far heavier than human bones. The misalignment of the modulus and the adaptability between the embed and the encompassing bone can prompt pressing factor insurance, which can prompt osteoporosis. As the machine load recovers and advances bone resorption and fix [19, 70], this interaction will make the embed more agreeable and at last lead to untimely disappointment. After implantation, the consumption of these metal organic entities in the body region and resulting arrival of particles from the blending material can cause an unwanted response of the body. Perpetual inserts incorporate SS, Co-Cr, and Ti. These inserts stay in the body longer and require reconstructive medical procedure after the bone has recuperated. Breaking down items like magnesium (Mg) and other amalgams will disintegrate normally in the human body and be supplanted with new tissue. Subsequently, the embed can be eliminated without extra strides after the bone has mended [1, 19, 29, 46, 54, 73].

1.6 ADDITION OF ELEMENTS IN MAGNESIUM ALLOY

1.6.1 Addition of Sr in Magnesium Alloy

Sr is one of the normal parts of bones and teeth. Also, Sr. is firmly identified with bone and veins. The job of Sr. in forestalling atherosclerosis and apoplexy. Likewise, Sr assists with decreasing bone thickness and bone development, in this way expanding bone strength and firmness. In this way, it is accepted that adding Sr to the amalgam can improve the similarity of execution and natural movement. As an anticipated and powerful indicator, Sr. can fundamentally refine grains, lessen shrinkage porosity and increment projecting thickness, along these lines improving mechanical properties and protection from erosion of Mg combinations [9, 10, 58].

Likewise, after consumption, a layer of straightforward Sr-substituted hydroxyapatite covering was framed on the outside of the combination, which solidified the blend and decreased its corruption rate [10]. On account of its capacity to separate synthetic substances at the constraints of grain, Sr is frequently added to Mg as a grain channel [74]. It has been demonstrated that Sr can improve the consumption obstruction of Mg combinations by improving soil security and decreasing miniature shrinkage porosity [24].

At last, Mg's virtue profoundly affects the degree of rust. Although super high virtue (> 99.9% immaculateness) magnesium is more impervious to erosion than other (however not all) compounds, creating high magnesium is more costly to apply. Mg-Gd is one of the rare earth combinations of the American Elements Corporation. Magnesium Gadolinium can be utilized as an amalgam ace for grain absorption, strength and effectiveness of the alloy by expanding malleability and execution. The sorts of amalgam accessible incorporate little plates, circles, foils, bars, tubes and different sorts.

1.6.2 Addition of Rare Earth Elements in Magnesium Alloy

An enormous number of studies have shown that magnesium amalgams containing rare earths have brilliant similarity, great mechanical properties and consumption obstruction, so they can be utilized for natural purposes [17]. Nonetheless, certain rare earth components, like lanthanum, cerium and ease, might be harmful and in this way should be utilized reasonably in biomedical applications [18, 40]. The primary uses of magnesium alloys in bone uniting gadgets are screws, pins, ropes, and so forth.

Among the alloy frameworks contemplated, the Mg-Gd combination framework has the best application potential since it has great mechanical properties, and Gd is a significant minor component for the human body. As of late, other examination has zeroed in on the improvement of little undertakings, mechanical properties, biocorrosion opposition, and the common similarity of the Mg-Gd framework with little mixes, for example, Zn [11, 25, 42, 51, 62] and Ca [65, 75], Mn [77], Zr [40, 77].

Strontium acts also to calcium and is broadly accessible as a segment of calcium in biomedical synthetics, (for example hydroxyapatite). Lamentably, substances for example Al and other rare earth metals that have shown great consequences for upgrading mechanical properties and opposing consumption of magnesium compounds are destructive to human wellbeing [25, 40, 68]. In any case, the mix of Gd and Sr in analysis in magnesium combinations is as yet questionable.

The principle components for improving the danger of magnesium alloys have been proposed, including cleaning, blending or microalloying, heat treatment and ecological adjustment [38, 60]. As of late, alloying has been broadly concentrated to improve the mouthpiece development, construction and biodegradability of magnesium alloys.

In light of the above contemplations, Gd and Sr are chosen as alloy materials to improve the mechanical properties (UTS, YS and stretching (%)) and optical microstructure of magnesium amalgams to create biomedical magnesium compound grains. Furthermore, the impacts of binary and ternary frameworks on the microstructure and mechanical properties are deliberately contemplated.

1.7 EFFECTS IN MAGNESIUM BASED ALLOYS

The issue with magnesium-based managed impregnation is that it rapidly corrupts the picture of the human body. The biodegradation of magnesium in the human body adversely affects its capacity to keep up mechanical respectability during the suspension hardening stage and its capacity to produce a lot of hydrogen (H₂) (determined at 1 ml/Mg) [28, 29, 30]. Too high a centralization of Mg infusion will frame H₂ bubbles, which will shape air pockets in the encompassing tissues, increment neighborhood pH, and defer tissue maintenance and even progression [2, 4, 23]. Due to its solid similarity with Zn and Ca, the Mg-Zn-Ca blend has pulled to individual's advantage. In any case, it has numerous sorts of imperfections, including powerless protection from rot and low strength. By adding Sr to the Mg-Zn-Ca amalgam, biocompatibility, consumption opposition and engineered materials can be improved. It can likewise help bone development and give hostile to tumor properties to the alloy [10, 26, 64].

Then again, large numbers of the melodies on the rack made of mechanical combinations are intended for designing applications [21, 27]. While enhancing magnesium, for instance alloy materials Al, Mn, Zn, Zr, Li, Y and RE are utilized [32, 41, 49, 53]. AZ91, AZ31 and other Mg-Al arrangement combinations and compounds containing rare earths like Mg-3.99Y-3.81Nd-0.53Zr (WE43) have gotten broad consideration [34,50]. Notwithstanding, practically nothing unless there are other options referenced combinations have been created as segments of the first rotting material, among which biosafety and biocompatibility are the most important necessities. Aluminum is known to cause neurotoxicity and cutoff human development. It has additionally been shown that Al restrains phosphorylation and ATP amalgamation, lessening intracellular energy saves [35,47]. Extraordinary soil was additionally discovered to be poisonous. In the wake of taking cerium, lanthanum and yttrium, inordinate liver harmfulness has been recognized [40, 47].

1.8 MAJOR MANUFACTURERS OF MAGNESIUM ALLOY

The market for magnesium alloys is valued at \$1.30 billion in 2011 and is expected to grow to \$2.3 billion by 2023. Corporations such as

- Magnesium Elektron (ENG),
- Ka Sheel International Holdings (Kerala, INDIA),
- Sanghal regal magnesium (China),
- Nanging Yunal Special Metals (China),
- U.S Magnesium (U.S) are some of the top firms in the global magnesium alloy market.

1.9 APPLICATIONS OF MAGNESIUM ALLOY

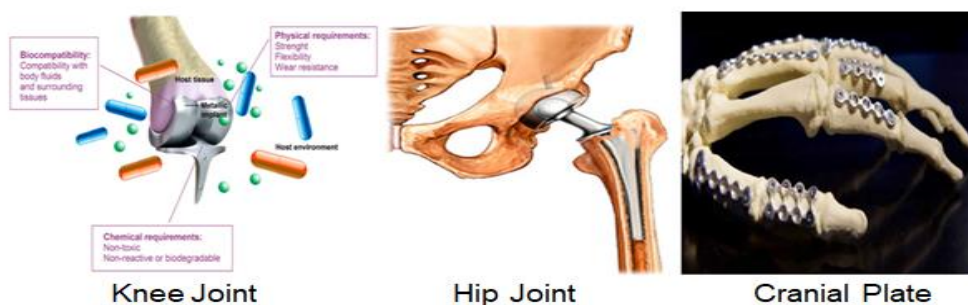


Fig 1.2 Applications of Magnesium alloy in biomedical field

The Fig 1.2 shows the major Applications of magnesium amalgams in biomedical implants are Knee joint, Hip joint and Cranial plate. Knee joint are majorly like a hinge type synovial joint suitably for flexion as well as extension means a little movement of medial and also the lateral rotation. The shapes used in biomedical implant field are pins and screws as fixations devices. These applications are majorly used in biomedical implants from magnesium alloys because of their Non-toxicity or Non-reactive or biodegradable alloy material in Chemical requirements, also they are compatibility with the surrounding tissues as well as with the body fluids. In Bio-compatibility, they have high strength, Flexibility and wear resistance in physical requirement.

1.10 CHEMICAL COMPOSITION OF MAGNESIUM ALLOY

The chemical composition of binary Mg-2Sr alloy and ternary Mg-2Sr-2Gd alloy were shown in table 1.4. In binary Mg-2Sr alloy system, strontium containing 2% by weight and containing 98% pure magnesium. Whereas, in ternary Mg-2Sr-2Gd contains 2% strontium, 2% gadolinium and 96% pure magnesium present in the alloy.

Table 1.4 Chemical composition of the binary and ternary alloy

Alloy	Code	Sr (% wt.)	Gd (% wt.)	Mg (% wt.)
Mg-2Sr	A84	2.0	-	Balance
Mg-2Sr-2Gd	A81	2.0	2.0	Balance

CHAPTER 2

LITERATURE SURVEY

Rissa, et al., 2010, considered grain size, optical microstructure and grain dispersion of unadulterated magnesium, Mg-2Ag, and Mg-10Gd pins with a measurement of 1.6mm diameter and a length of 8mm. The three-dimensional construction shows all the grain size dispersion on the flat side, showing closeness, and complete repeat is seen after extraction, and the normal size of grains is found in Mg - 10Gd is $25.8 \pm 14.2\mu\text{m}$, Pure Mg is $21.0 \pm 13.1\mu\text{m}$, Mg2 Ag is $18.1 \pm 13.1\mu\text{m}$, particularly in the longitudinal bearing, expulsion impact changes, and unadulterated mg by examination, grain size of Mg10 Gd and Mg2Ag little [5].

Yuanyuan Li, et al., 2016, considered the optical microstructures and mechanical properties, which are 2mm thick, 3mm wide and 5mm long check, separately, utilized for the extending strategy. Obviously the compound microstructure of Mg-3.0Gd-2.7Zn-0.4Zr-0.1Mn (GZKM-1), the grain size of as-projected alloy is in the scope of 50-200 μm at both cross areas and longitudinal segment, although because of the utilization of a quicker conveyance technique, precious stone grains produce a similar letter structure in 3-D. UTS, YS and EL of the hot-expelled combination arrived at 341.5Mpa, 315.2Mpa and 21.3%, individually, and the elongation ratio was 8:1. It was noticed that the properties of the hot-expelled compound machine were better rather than cast-combinations and warmth the executives [76].

Hort et al., 2013, led an investigation on the mechanical properties of as-projected double Mg-10Gd alloy and Mg-10Gd-0.5Zr castings. The length of the ductile model is 30 mm, the breadth is 6 mm, and the width of 10mm, hardness estimated by the Vickers hardness analyzer, the heap was 5 kg, and the sitting time was 10s. The alloy shows the UTS, YS and elongation of the Mg-10Dy-0.2Zr (D10k) alloy is 185MPa, 105Mpa and 23.05%, and the Mg-8Dy-2Gd-0.2Zr (DG82K) alloy is 200Mpa, 110Mpa and 22.13%, Mg-5Dy-5Gd-0.2Zr (DG55K) alloy is 210Mpa, 120Mpa and 17.05%, Mg-2Dy-8Gd-0.2Zr (DG28K) is 220MPa, 125Mpa and 16.7%, separately. The hardness level shows that D10k is 58.2HV, DG82K is 64.4HV, DG55K is 85.5HV, DG28K is 100.2HV [40].

M Cheng, et al., 2017, considered Sr expansion (0, 0.2, 0.6 and 1.0% by weight), and examined the mechanical properties and microstructure of the as-projected Mg-5Zn based combination framework utilizing optical microstructure. The impersonation plate is handled into a strong test strip with a cross part of 15 mm× 4mm× 2mm. The solidness test was performed on the Instron 3369 hardness test machine, and the underlying hardness level at room temperature was $1.1 \times 10^{-3} \text{ s}^{-1}$. The last strength (UTS) and versatility throughout the break (Er) of the three samples were evaluated. The microhardness test was performed on the MHV-2000 microhardness test, with a heap of 0.98 N and a length of 15s. The normal grain size of as-projected Mg-5Zn combination is 129 μm , and the normal grain size of Mg-5Zn-0.2Sr alloy is 73 μm , which is about 43% better than that of as-projected Mg-5Zn alloy. The normal grain size of as-projected Mg-5Zn-0.6Sr alloy is 63 μm , which is about 51% more refined than as-projected Mg-5Zn. The normal grain size of Mg-5Zn-1Sr as-projected alloy is 99 μm . The Mg-5Zn-0.2Sr as-projected combination has a little grain size and a little part of the grain limit, mirroring the coordinated alloy designs ultimate tensile, yield and flexible strength are 233MPa, 117MPa and 15% separately [45].

X. Meng et al., 2020, examined the construction and mechanical properties of the new Mg-2Zn-0.3Ca-xSr quaternary machine, and broke down the hardness test tests into a 25mm breadth chamber Vickers hardness analyzer estimating 15 seconds with a width and thickness of 13 mm and with a limit of 100 gf. With a modest quantity of Sr. added, the second area along the grain limits and the spaces between the dendritic can be refined. Notwithstanding, because of the strengthening of the climate and the refinement of the grain, microhardness showed an expanding propensity, while Mg-2Zn-0.3Ca-1Sr arrived at 54HV. Appropriate tensile strength and yield strength of Mg-2Zn-0.3Ca-0.3Sr combination (441 ± 18) MPa and (317 ± 13) MPa, individually, are half and elongation 20% higher than Mg-2Zn-0.3Ca compound separately [65].

M. Cong et al., 2014, tried for Sr (0, 0.1 wt.%, 0.5 wt.%, 1.0 wt.%, 1.5 wt.%, 2.0 (wt.%) with solidness test and size 50mm length. It is identified with the construction of the microstructure of the model with a width of 12mm. With the increment of Sr content, the grain size of the principle Mg₂Si diminishes first, and afterward bit by

bit increments. At room temperature, Mg-6Zn-4Si is 51Mpa and 2.7%. The Mg-6Zn-4Si-0.1Sr blend is 138Mpa and 3.01%, and the Mg-6Zn-4Si-0.5Sr combination is 160Mpa. The versatility (%) is extremely solid. The 142Mpa and 3.1% for Mg-6Zn-4Si-2Sr blend, and Mg-6Zn-4Si 1.0Sr combination 155Mpa and 3.5%, Mg-6Zn-4Si-1.5Sr of 152Mpa and 3.25%. At surrounding temperature and 150°C, adding Sr can build the greatest strength and flexibility of Mg-6Zn-4Si alloy. [42].

C Tong et al. 2012, considered the investigation of Mg-Zn-Sr combinations with various Sr substance (0.15 wt.%, 0.5 wt.%, 1.0 wt.%, 1.5 wt.%). Check the machine, cut a 25mmx 10mmx 10mm magnesium alloy sheet from a strong canine bone, and measure the hardness with a Vickers hardness analyzer. The heap is 5 kg and the life is 10s. At the point when the substance of component Sr is 1.0% by weight, a little precious stone grain size of 38 μm is acquired, and when it is expanded to 1.5% by weight, the gem grain size is solid. The infused stage in the composite sheet is appropriate and consistently disseminated for 8 hours at 175°C to acquire well known attributes like 230MPa strength, 76.1HV hardness and 12.7% elongation rate [51].

R. Guan et al. in 2013, contemplated the new Mg-4.0Zn-1.0Sr compound (weight rate; ZSr41). The old ZSr41 and unadulterated Mg amalgam flimsy plates were cut into 20×20 mm square and refined utilizing 1200 coarseness silicon carbide dainty plates to eliminate overabundance oxides. The grain size of the ZSr41 compound is a lot more modest than that of unadulterated Mg since it contains the parts of Mg, Mg-Zn, Mg-17Sr₂, Mg-Zn₂ and Zn-13Sr. Contrasted and unadulterated Mg, the ZSr41 blend shows essentially improved execution in the wake of rolling and maturing at 175°C for 8 hours, making it more appropriate for stacking applications in clinical applications. The ZSr41 compound has an exceptionally solid strength of 270 MPa, a hardness of 71.5 HV and a break flexibility of 12.8% [11].

Yuan Zhang et al., 2018, considered Mg-2Zn-xSr alloys with various Sr content (0.1-0.5 wt.%), including optical microstructure and mechanical tests (YS, UTS, prolongation (%)) Related investigations. The two finishes (1) As the expansion of Sr increments from 0.1% by weight to 0.5% by weight, the normal grain size of Mg-Zn-Sr combination diminishes altogether from 358 microns to 189 microns, while the

extent of the second volume class. But it is little to increment from 0.25 to 1.45%. At the point when Sr increments from 0.1 to 0.2% by weight, the YS, UTS and versatility at crack, Mg-2Zn-based compounds increment by 13.4%, 3.7%, and 25.1%, separately, and these mechanical qualities are decreased by roughly 21.5% and 17.6%, and 56.1%, in light of the fact that the utilization measure of Sr referenced above is up to 0.5 wt. % Grains improve the strength and adaptability of the material, while a lot of optional steel decreases execution. The high proficiency of Mg-2Zn-0.2Sr alloy advantages from the blend of fine grains and second-rate materials [33].

Xiwei Liu et al., 2015, investigated sort of Sr (0.1wt% and 0.5wt%) substance of Zn-Mg-x Sr alloys was contemplated, including light parts and the mechanical properties of the new Zn-Mg-Sr composite. The YS, UTS and hardness of Zn-Mg-x Sr compound are 108.93 ± 14.30 MPa, 132.72 ± 9.57 MPa and 93.70 ± 6.81 Hv of Zn-1Mg-0.1Sr combination, and 129.08 ± 5.07 MPa, 144.15 ± 14.97 MPa and 109.33 ± 8.43 Hv of 0.5Sr alloy are a lot higher than unadulterated Zn, and it has the best productivity in the improvement of its mechanical properties. Contrasted and unadulterated zinc, Zn-Mg-Sr compound is made with Zn network and the subsequent interaction. Their solidarity, solidness and level of rust are high, yet their length and hemolysis time are extremely short. After hot moving, Zn-1Mg-0.1Sr, YS combination, UTS, flexibility and hardness are totally improved. Every one of these discoveries show that subsequent to thermosetting, Zn-1Mg-0.1Sr compound will be relied upon to be a biomedical gadget with incredible mechanical properties, consumption opposition and great attachment [66].

Dexue Liu et al., 2017, examined Mg-Dy-Sr-Nd-Zr amalgam and added 2, 6 and 10 wt.% to Mg-2.4Nd. % Dy and 0.5, 1.5 and 2 wt. % Sr. component. The combination of - 0.5Zr was tried for microstructure and mechanical properties (strength, hardness and versatility). The length of the check and the easy route of the strong sample test is 15 mm and $(3.5 * 9.2)$ mm², separately. The grain size of magnesium amalgam has been changed from 130µm to 100µm and 60µm, with the expansion of 2 to 6 wt.% Up to 10 wt.% Ye-Dy. Sr material has little impact on magnesium compound grain size, and grain size is changed from Sr substance to 0.5 wt. % 70µm diminished to Sr substance of 2 wt. % At 60µm. The kick the bucket projecting cycle is utilized to plan and deliver another mix of Mg-10Dy-0.5Sr-2.4Nd-0.5Zr. The kick

the bucket reenactment creates a 18 μ m refined grain structure from another compound with a grain size of 70 μ m. With the expansion in Dy content and the diminishing in Sr content, the high strength of the Mg-Dy-Sr-Nd-Zr amalgam increments. The tensile strength of the Mg-10Dy-0.5Sr-2.4Nd-0.5Zr amalgam is 203 MPa. The tensile strength of the kick the bucket projecting combination is decreased, however the versatility increments, and the flexibility increments from 7.4% to 10.2% [14].

Wang et al., 2016, analyzed a quaternary report Mg-1.38Si-xSr-yCa (x, y = 0.5-1 wt.%) combination utilizing an optical magnifying instrument and strength testing. An sample strength of M10 string of Mg-Si-Sr-Ca composite with a length of 30 mm and a diameter across of 5 mm was prepared from ingot. At room temperature, it disseminates Mg-1.38Si-0.5Sr-0.6Ca combination UTS, YS and extension (%) by 74Mpa, 59Mpa and 2.7%, Mg-1.38Si-1Sr-0.6Ca amalgam UTS, YS and EL are 78%, 64Mpa and 2.7%. For Al-Mg-1.38Sy 1Sr-1Ca compound, it is 74Mpa, 60Mpa and 2.4% separately. It has been discovered that Ca can successfully upgrade the arrangement of little compound particles and influence Mg-2Si particles to change from round morphology to little polygonal morphology, while Sr is available in recently shaped Mg in the Mg₁₇-Sr₂ stage. Mg-Si-Sr-Ca is a magnesium alloy, Contrasted and the morphology of Mg-2Si particles caught in an as-projected climate, the bond brings about less Mg-2Si particles. The expansion in Ca and Sr improves solid designs, identified with primary development and the intermetallic stage [62].

Brar. S et al., 2012, with test sizes of Mg-Sr two-fold compound, the breadth taken as 4.6 mm, width of 4.1mm. Mg-Sr double and Mg-Zn-Sr ternary combination microstructure debased conduct Read. The sample size of the Mg-Zn-Sr ternary composite is the breadth taken as 4.6 mm, length is 32 mm, and its alternate route segment is 4 mm wide. The distance across of the Mg-Sr double combination is 3.3 mm and the length is 32 mm and the width of 4.1mm. Mg - 2.0wt% Zn - 0.5wt% Sr and Mg - 4.0wt% Zn - 0.5wt% Sr have shown guarantee of rotting amalgams because of the decrease of their dangerous levels and restricted mechanical properties. The expansion of Zn to the Mg-0.5wt% Sr compound, because of the strong stage reaction and Zn environment response, brings about an increment in

yield and the conclusion of the strength of every fiber. It has been shown that motorized and harmed houses depend vigorously on the development of little things. It is tracked down that mechanical and underlying harm is profoundly reliant on the development of little items. Also, in this arrangement of composites, the fine mechanical properties and protection from consumption are frequently reasonably unique, so the expansion in one material unavoidably disintegrates in another. Thusly, controlling the arrangement of the amalgam microstructure is especially significant in expanding mechanical properties and properties of combination debasement [25].

N. Hort et al., 2010, directed an examination on Mg - x Gd, in which the substance of Gd was (2 wt.%, 5 wt.%, 10 wt.%, 15 wt.%) Which included mechanical testing and optical microstructure. For the strength test, utilize an sample measure length of 25 mm, width 5 mm, and a wire head. In the optical magnifying instrument test, the gem size of Mg₂Gd grains is 720μm, the size of Mg₅Gd is 600μm, the size of Mg₁₀Gd is 580μm, and the size of Mg₁₅Gd is 400μm. Because of the snugness of the climate, Gd substance of over 10% by weight builds strength and congruity. As Gd solvency increments with temperature, Mg-Gd gadgets are more fit to warm treatment to adjust mechanical properties, in this way consenting to the portrayals of the bend highlight of helpful applications. By changing the treatment of Gd fixation and warmth treatment, the mechanical properties and rust conduct of these Mg-Gd mixtures can be modified in numerous structures. The last firmness can be changed between 79 MPa and 250 MPa [46].

Zhen Li et al. 2017, examined a grade able Mg-Zn-Zr-Sr alloy for mechanical testing. Ductile samples of 25 mm check and 5 mm breadth were machined from expelled poles. The straight bearing is equivalent to the expulsion course. The expansion of Zr and Sr to the as-projected Mg-Zn-Zr-Sr (MZZS) compound caused the Mg₁₇-Sr₂ measure (second line segment) to part at the grain limits, bringing about a huge decrease in grain size. Over - 60μm to 19μm. Moreover, in the expelled MZZS amalgam, the collaboration of Zr and Sr influences the grain refinement and the Mg-Zn second stage, bringing about a huge expansion in strength. As indicated by the strength test, the fine and dispersible second stage refinement and sticking impact can essentially improve the solidness of the MZZS combination in the

extricated state, as demonstrated by the MZZS amalgam, YTS and UTS are 322.363 MPa and 376,400 MPa, individually which is essentially higher than Mg-Zn-Sr (MZS) and Mg-Zr-Zn (MZZ) amalgams [76].

A Kania et al., 2019 contemplated the composite of $\text{MgCa}_{5-x}\text{Zn}_1\text{Gd}_x$ ($x = 1, 2$ and 3 wt.%) in 2019 and led mechanical tests. Set up a barrel shaped sample with a breadth of 5 mm and a length of 90 mm for unbending nature testing. The increment of Gd content in Mg combination will influence the change of the design. Because of the little volume of the optional periods of Mg_2Ca and $\text{Ca}_2\text{Mg}_6\text{Zn}_3$, the volume of the eutectic is somewhat diminished. Adding Gd to the contemplated composite can expand the strong strength (strong compounds with 1, 2, and 3 weight percent Gd (74, 78, and 89 MPa combinations, individually)), and lessen flexibility (from 4.8% to 4.2 %). In alloys containing 1-3% Gd, the Vickers weight increments from 55 HV to 61 HV [6].

Ling-ling Shi et al., 2015, examined the microstructure and Mg-Gd-Ca-Zr compound. For the strength test, an sample with a measure length of 30 mm and a width of 6 mm with a head mounted on was utilized. The yield strength of the as-projected combination increments with the increment of the Ca content, while the versatility diminishes. After T6 treatment, adaptable conditions and bases were seen at full solidness, bringing about higher strength altogether parts of compressive strength. While decreasing the harm range, high unbending nature is accomplished. As per mechanical and consumption examines [90], the $\text{Mg}_{10}\text{Gd}_{0.3}\text{Ca}_{0.5}\text{Zr}$ compound after T6 treatment is a likely wellspring of possible harmed metal inserts [39].

Guangyu Li et al., 2017, contemplated Mg-0.5Ca-X (Sr, Zr, Sn) bio-alloys identified with visual microscopy and mechanical testing (the cross-part of the scale is 50 mm long, 12.5 mm wide and 3 mm thick). The compound is made of $\alpha\text{-Mg}$, $\alpha\text{-Zr}$, $\text{Mg}_{12}\text{Sr}_7$ and Ca-Mg-Sn, and their grain size is a lot more modest than unadulterated Mg as estimated by obvious magnifying lens. The overall mechanical properties of the Zr compound have been significantly improved; the most extreme strength of the Mg-0.5Ca-3Sr-1.5Zr combination is around 200 MPa, and the exceptionally high pressing factor is 350 MPa. Then again, the consumption

opposition of Mg-Ca-Sr-Zr amalgam isn't just about as high as that of unadulterated Mg. The compound has moderate mechanical properties, with a strong strength of 180 MPa and a compressive strength of 340 MPa, which is somewhat lower than the Mg-0.5Ca-3Sr-1.5Zr amalgam, yet higher than that of unadulterated Mg [69].

Ziquan Li et al.,2014, carried out the research on as-cast Mg–6Zn–4Si alloy with Sr (0 wt.%, 0.1 wt.%, 0.5 wt.%, 1.0 wt.%, 1.5 wt.%, 2.0 wt.%) additions were examined concerning tensile test and optical microstructure with specimen of dimension of gauge length 50mm and diameter of 12mm diameter. With increasing Sr content, the grain size of the primary Mg₂-Si decreases at first, then gradually increases. At room temperature ultimate tensile strength and elongation (%) for Mg–6Zn–4Si of 51Mpa and 2.7%, for Mg–6Zn–4Si-0.1Sr alloy of 138Mpa and 3.01%, for Mg–6Zn–4Si-0.5Sr alloy of 160Mpa and 4.5%, for Mg–6Zn–4Si-1.0Sr alloy of 155Mpa and 3.7%, for Mg–6Zn–4Si-1.5Sr alloy of 152Mpa and 3.25%, for Mg–6Zn–4Si-2Sr alloy of 142Mpa & 3.1%. At both ambient and 150°C, the addition of Sr increases the ultimate tensile strength and elongation of the Mg–6Zn–4Si alloys [42].

Manuel, et al.,2012, carried out the research on the microstructural, mechanical, and degradation behavior of binary Mg–Sr and ternary Mg–Zn–Sr alloys of dimensions for Mg–Sr binary alloy specimens was of approximately 4.6mm wide, 4.1mm thick and 32mm in length of Mg–Zn–Sr ternary alloy specimens had a gauge section of 4mm wide, 3.3mm thick and 32mm long of Mg–Sr binary alloy were investigated. The Mg–2.0(wt.%) Zn–0.5(wt.%) Sr and Mg–4.0(wt.%) Zn–0.5(wt.%) Sr showed to be promising biodegradable alloy candidates due to their low degradation rate and moderate mechanical properties. The addition of Zn to Mg–0.5(wt.%) Sr alloys resulted in an increase in each yield and closing tensile strengths of the fabric due to Zn's favorable solid answer and precipitation reaction. It became observed that the mechanical and degradation homes have a sturdy dependence on the microstructure. The mechanical and degradation properties were found to be highly dependent on the microstructure. Furthermore, in these series of alloys, good mechanical properties and corrosion resistance tend to be inversely related, so that having a gain in one property inevitably degrades the other. Therefore, it is important to control the microstructure for optimization of both mechanical and degradation behavior of the alloys [25].

Zhanga et al., 2016 examined the mechanical properties of Mg-xGd-1Zn ($x = 3, 6$ and $9\text{wt}\%$) and Mg-9Gd-1Zn-y Ca ($y = 0, 0.2$ and $0.6\text{wt}\%$) compounds. Testing the strength of a standard substance of $55\text{ mm} \times 15\text{ mm} \times 2\text{ mm}$ will bring about the arrangement of higher Gd, which will bring about better grains and more eutectic stages, while higher Ca expansion will bring about the development of isolated. The decrease of the eutectic stage (Mg, Zn) 3Gd and (Mg-Zn) 3Gd. The YS of Mg-9Gd-1Zn-0.6Ca (Gz91-0.6Ca) is $88 \pm 0.4\text{ Mpa}$ and the hardness is $87 \pm 0.4\text{ HV}$. Gd is valuable in expanding the yield potential, while Ca is prevalent in expanding the base [67].

H. Tang et al., 2020, carried out the investigation on microalloying Mg-Sr-RE alloys examined concerning reveal fine-grained microstructure and high ductility (EL: 20–40%). Microalloying with Nd or Gd results in 2 or 1.5 times increment for elongation due to the significantly weakened extrusion textures. La addition contributes little to the alloy ductility, while the largest improvement of strength is achieved. Mg-Sr-La exhibits the highest YS (172 MPa) and UTS (235 MPa) [12].

X.N. Gu et al., 2012, summarized that the effect of the Sr content in Mg was proved to be dose dependent with respect to the mechanical and corrosion properties. The optimal Sr content was 2 wt.%. Sr concentrations below 2 wt.% improved the strength of Mg, whereas excessive Sr addition resulted in poorer mechanical properties of the as-rolled Mg–Sr alloys. The mechanical properties obtained by tension testing. Pure Mg's yield tensile strength (YTS) and ultimate tensile strength (UTS) were both improved by adding Sr. As the amount of added Sr was increased up to 2 wt. percent, the YTS and UTS values of the as-rolled Mg–Sr alloys increased, but as the amount of Sr was increased further, the YTS and UTS values decreased. In contrast, elongation of the as-rolled Mg–Sr alloys decreased with increasing Sr content as the as-rolled Mg–2Sr alloy showed the best combination of strength and ductility, with values of $213.3 \pm 17.2\text{ MPa}$ for UTS and $3.2 \pm 0.3\%$ for elongation [24].

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 gravity casting process and produce as cast binary Mg-2Sr alloy and ternary Mg-2Sr-2Gd alloy depending upon Bio-Medical applications.
- To find and investigate the hardness values of casted binary Mg-2Sr Alloy and ternaryMg-2Sr-2Gd alloy by using micro hardness testing machine.
- To perform and investigate the strength of magnesium alloys using micro tensile testing setup.
- Identifying and investigating the microscope images of binary and ternary magnesium alloy using 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 in the form of cylindrical rod
- This report consists 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 orthopaedics.

CHAPTER 4

MATERIALS AND METHODS

4.1 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

4.2 WORKFLOW PROCESS

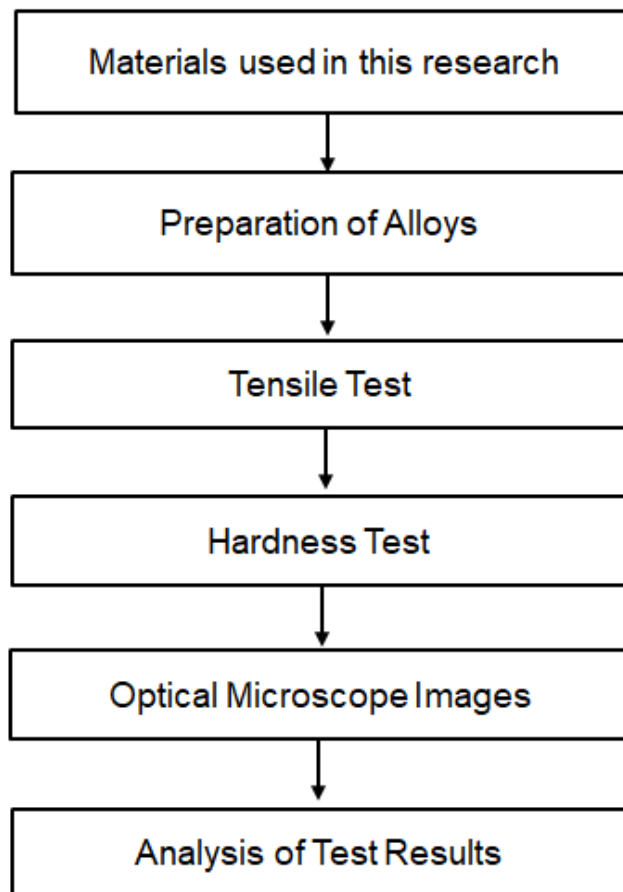


Fig. 4.1 Workflow process

The First step in the workflow process collects the materials required for investigation, where the material consist of Mg, Sr, and Gd. After the material collections, casting of Mg-Sr and Mg- Sr-Gd were carried out to prepare the ingots.

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

4.3 MATERIALS USED IN THIS RESEARCH

The prerequisites for this test study are unadulterated magnesium, strontium acetate compound and Gd. The magnesium combination is prepared into a bar with a length of 25 mm and a width of 5 mm. After 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 μ 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/cm³ 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/cm³.

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/cm³. The materials of pure magnesium, strontium master alloy and gadolinium as shown in figure 4.2.

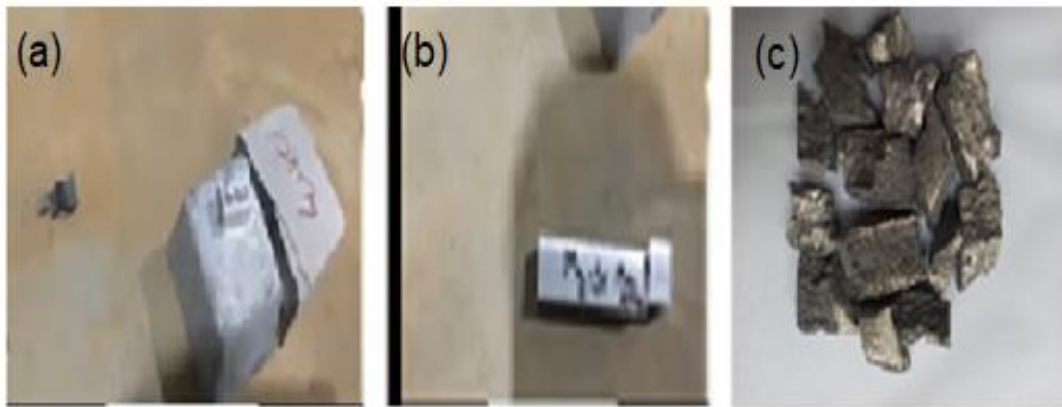


Fig. 4.2 **Materials of (a) Pure Magnesium, (b) Strontium master alloy, and (c) Gadolinium**

4.4 PREPARATION OF ALLOYS

Two magnesium-based mixtures were utilized in this investigation: Mg2Sr and Mg2Gd. These things are disseminated in matrix technological solutions, Kalpadi, Tamilnadu. In the splash, unadulterated materials are utilized: Mg (99.98%), Gd (99.98%), Sr (99.98%).

The capacity of the warming heater is to utilize the pre-INDFURR warming heater to warm the metal form, as demonstrated in Figure 4.3. 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. 4.3 INDFURR Preheating oven

Then, as demonstrated in Figure 4.4, 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. 4.4 Die cast steel mold about to be kept in the oven

In the pot, the iron in pig (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. Also, stainless steel crucible is generally preferred during the casting process due to high temperature resistance and high resistance to corrosion and also has the ability to resist themselves by placing different materials for castings. As demonstrated in Figure 4.5, unadulterated magnesium is added to the tempered steel cauldron.



Fig. 4.5 (a) *Placing pure magnesium in Stainless Steel Crucible and (b) Placing of stainless-steel crucible in the Electrical resistance furnace*

Then, lessen treatment in the defensive climate of metal filtration innovation. Eliminate any gliding material or particles on the top. Numerous impurities buoy 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. 4.6 *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. Adding the Sr master alloy in to the pure Mg molten metal as shown in figure 4.7.



Fig. 4.7 Addition of Mg-Sr master alloy (or) gadolinium

Next, die cast steel mold is taken out from the furnace which is preheated at 450°C. 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.



Fig. 4.8 Removal of preheated die cast steel mold from preheated oven

Next, hand stirring step is been carried out in the stainless-steel crucible which is been taken out 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. In the similar way for addition of gadolinium in pure magnesium molten metal in electrical resistance furnace, the hand stirring and skimming process is carried out.



Fig. 4.9 (a) Hand stirring process and (b) Skimming process

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 were 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. 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.



Fig. 4.10 (a) *Pouring the alloy molten metal into the preheated die cast steel mold, (b) Shrinkage during the cooling process and (c) As cast Mg-2Sr & Mg-2Sr-2Gd alloy material*

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).

The combination of Mg-2Sr-2Gd (wt.%) is delivered by a steady gravitational cycle. 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. 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) 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 casting of an alloy as shown in figure 4.11.

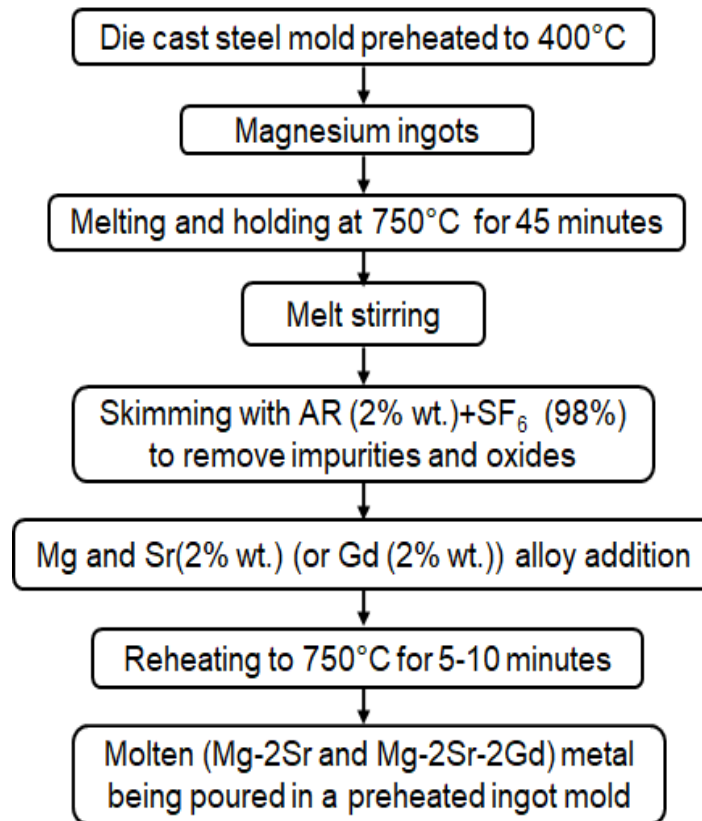


Fig. 4.11 Flow Chart of Casting of an Alloy

4.5 TESTINGS INVOLVED

4.5.1 Tensile and hardness Test

By Hardness testing, Yield Strength (YS) and Ultimate Tensile Strength (UTS) 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. 4.12 Micro tensile testing setup

There are numerous approaches to make an 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 work piece prepared by the stock bar can be made in similar parts as the stock.

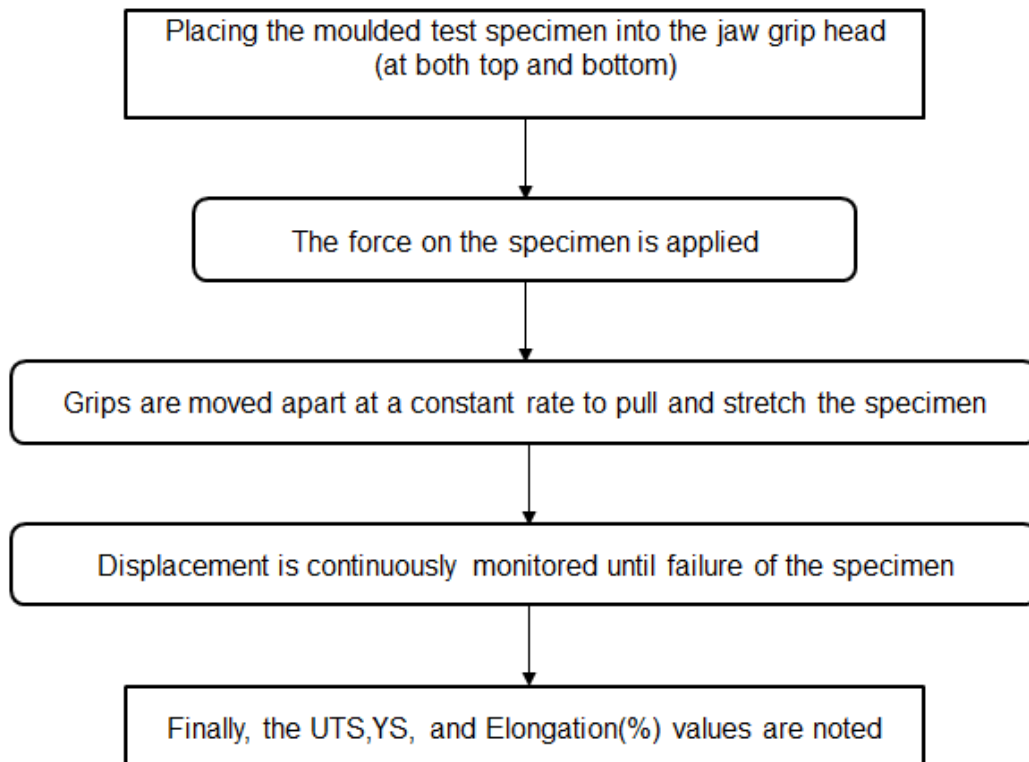


Fig. 4.13 Flow chart of tensile testing method

The following steps take place during the tensile testing for finding out the UTS, YS and EL (%) as shown in the figure 4.13. 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 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 have been noted.

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 Vickers 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.



Fig. 4.14 Specimens after tensile testing

The combination was cut into round shapes, partitioned into 4 samples as per the size of every blend, and 4 tests were performed on each amalgam. An assortment of strength of the Mg-2Sr amalgam and ternary Mg-2Sr-2Gd combination with a normal length of 25mm and a diameter of 5mm have been thought as per ASTM- E8/E8M – 11 standard. Vickers microhardness testing was utilized to quantify the heaviness of the Mg-2Sr parallel compound and the ternary Mg-2Sr-2Gd 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 μ m to lessen the effect of additional mistakes on investigation.

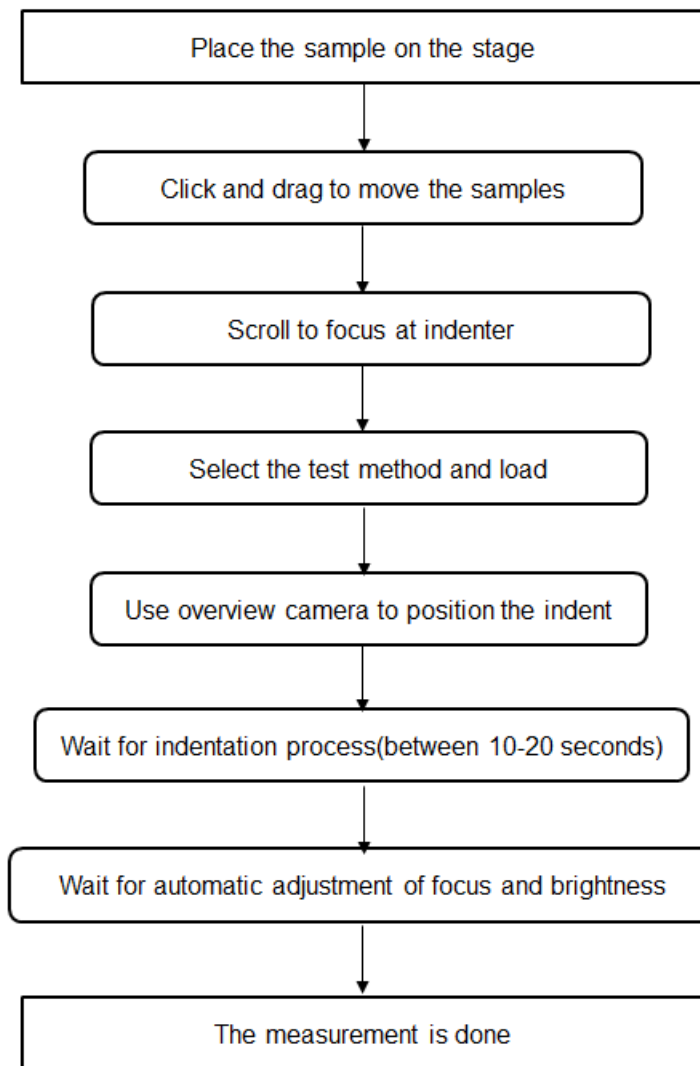


Fig. 4.15 Flow chart of hardness testing method

The figure 4.15 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. 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.

4.5.2 Optical Microstructure

The optical microscope, also known as the "light optical microscope" is a type of microscope that magnifies images of small samples using visible light and a lens device. Optical microscopes are the oldest type of microscope, probably dating back to the seventeenth century in their current compound form. While there are several advanced designs that seek to improve resolution and sample contrast, basic optical microscopes can be very simple. Optical microscopes have long been common because they use visible light, allowing samples to be viewed directly with the naked eye.

A micrograph can be created by capturing an image from an optical microscope with ordinary light-sensitive cameras. Images were once captured on photographic film, but recent advances in complementary metal-oxide-semiconductor (CMOS) and charge-coupled device (CCD) cameras have allowed the capturing of digital images. Purely optical microscopes, which use a CCD camera to examine a sample and display the image directly on a computer screen without the use of eyepieces.

Samples for microstructural characterization were prepared with silicon carbide (Si-C) grinding papers up to 4000 grit, 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, where it enhances the contrast on surfaces in order to visualize the microstructure. Etching in metallography exerts a controlled influence on the surface profile or optical properties at grain boundaries, phases, or grain surfaces, thus enabling microscopic inspection and additional use of optical fibers in the microscope. The microstructure of the prepared samples was investigated using an optical microscope.

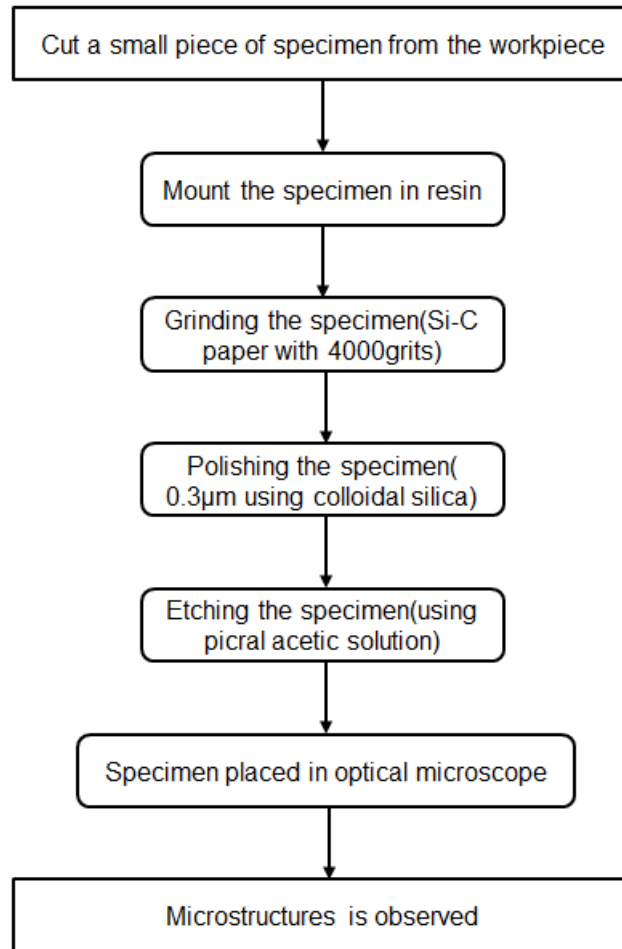


Fig. 4.16 Flowchart for finding the optical microstructure

The figure 4.16 shows the following steps which has 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-2Gd 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 0.3µm using colloidal silica, were it removes the artifacts of grinding but very little shock, 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-2Gd alloy is placed in optical microscope to obtain the microstructure.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 OPTICAL MICROSTRUCTURE

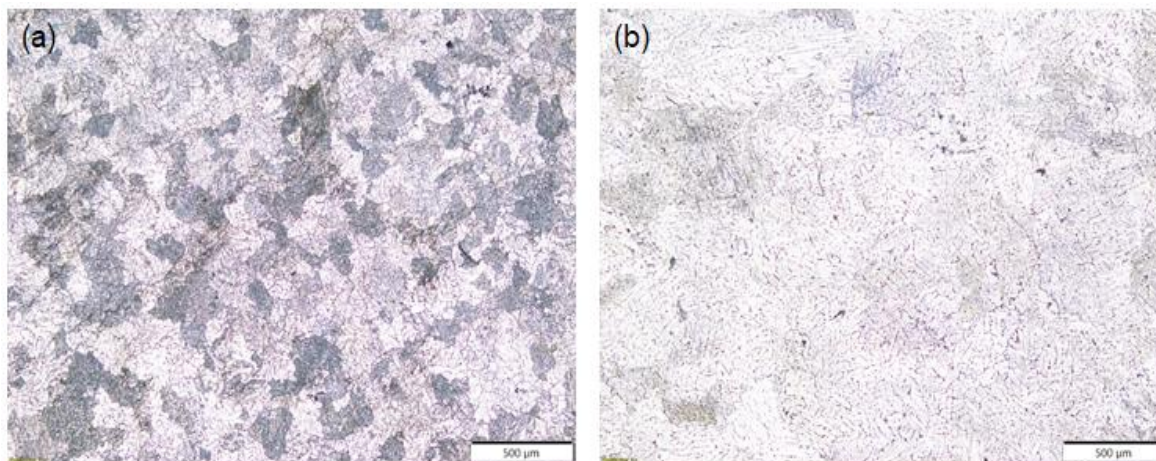


Fig. 5.1 optical microscope images of (a) Mg-2Sr and (b) Mg-2Sr-2Gd

The optical microstructure of the binary Mg-2 (wt.%) Sr alloy and ternary Mg-2(wt.%) Sr-2(wt.%) Gd alloy. It is observed that Mg-2(wt.%) Sr-2 (wt.%) Gd alloy has the largest grains when compared to binary Mg-2Sr alloy. Due to the grain refinement in ternary Mg-2Sr-2Gd alloy brings better enhancement with the skin during implantation and also during aging 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-2Gd-2Sr alloy when compared to binary Mg-2Sr alloy. The optical microstructure of the binary and ternary alloy is shown in figure 5.1.

5.2 TENSILE AND HARDNESS TEST

The tensile test property variations like UTS, YS, and elongation (%) of the samples of both binary and ternary alloy are listed in table 5.1. The effect of Sr content in binary alloy had a nominal effect on the strength of the alloy. However, the effect of Gd content in ternary alloy significantly improved the mechanical properties with a high yield strength (YS) and high ultimate tensile strength (UTS)

with an average of 104Mpa and 202Mpa when compared to binary alloy with an average of 186Mpa UTS and 98Mpa YS. And also shows that the average % elongation in ternary Mg-2Sr-2Gd alloy of 9.5% is higher than when compared to binary Mg-2Sr alloy of 4.8%. table 5.2 shows the Vickers hardness (HV) values for homogenized binary Mg–2Sr alloy and ternary Mg-2Sr-2Gd alloy of four trials in each alloy. It can be seen that there is an increase in hardness value in ternary Mg-2Sr-2Gd alloy when compared to binary Mg-2Sr alloy due to the effect of gadolinium in the ternary alloy system. Also, due to grain refinement in the ternary alloy by the involvement of Gd element which improved ultimate tensile strength, tensile strength value, and better elongation.

Table 5.1 Tensile test values containing UTS, YS, and Elongation of binary and ternary magnesium alloy

Magnesium Alloy	Trial	UTS	UTS	YS	YS	% Elongation
Mg – 2Sr	T-1	189	186	98	98	4.8
	T-2	182		96		
	T-3	190		101		
	T-4	183		97		
Mg – 2Sr – 2Gd	T-1	199	202	106	104	9.5
	T-2	201		99		
	T-3	203		103		
	T-4	205		107		

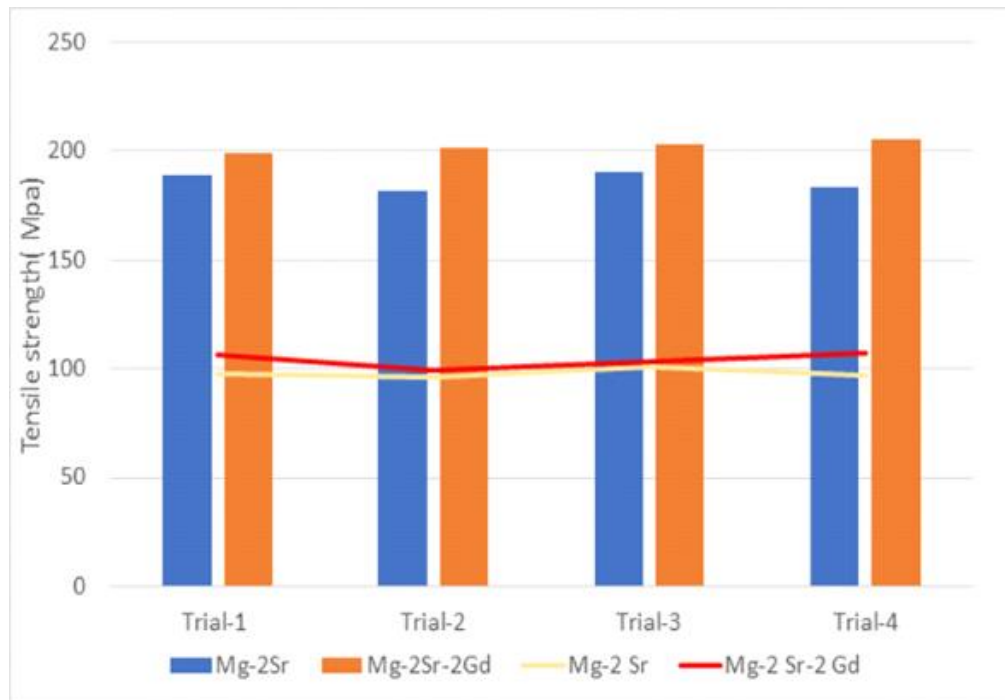


Fig. 5.2 *Graph of tensile strength (UTS & YS) for binary and ternary magnesium alloy*

The graph of Figure 5.2 shows tensile strength plotted on vertical axis and their respective four trials in the horizontal axis for both the binary and ternary alloy of magnesium. The line graph represents yield strength (YS) and the bar graph represents the ultimate tensile strength (UTS). Both for UTS and YS has represented by a unit Mpa.

In binary Mg-2Sr, ultimate tensile strength shows in trial-1 with the value of 189Mpa, and in trial-2 shows the value of 182Mpa, and in trial-3 shows the value of 190Mpa, and in trial-4 shows the value of 183Mpa, based on the above four trials in binary Mg-2Sr alloy shows an average value of 186Mpa. whereas in ternary Mg-2Sr-2Gd alloy, ultimate tensile strength shows in trial-1 shows the value of 199Mpa, in trial-2 shows the value of 201Mpa, in trial-3 shows the value of 203Mpa, in trial-4 shows the value of 205Mpa. Based on the above four trials in ternary Mg-2Sr-2Gd alloy shows an average value of 202Mpa. In trial-4 ternary Mg-2Sr-2Gd alloy shows the maximum UTS value of 205Mpa.

In binary Mg-2Sr, yield strength shows in trial-1 with the value of 98Mpa, and in trial-2 shows the value of 96Mpa, and in trial-3 shows the value of 101Mpa, and in trial-4 shows the value of 97Mpa, based on the above four trials in binary Mg-2Sr alloy shows an average value of 98Mpa. whereas in ternary Mg-2Sr-2Gd alloy, yield strength shows in trial-1 shows the value of 106Mpa, in trial-2 shows the value of 99Mpa, in trial-3 shows the value of 103Mpa, in trial-4 shows the value of 107Mpa. Based on the above four trials in ternary Mg-2Sr-2Gd alloy shows an average value of 104Mpa. In trial-4 ternary Mg-2Sr-2Gd alloy shows the maximum YS value of 107Mpa.

For elongation (%) in binary Mg-2Sr alloy shows an average value of 4.8% whereas in ternary Mg-2Sr-2Gd alloy shows an average value of 9.5%. Based on the above two values of magnesium alloy, ternary Mg-2Sr-2Gd alloy shows the maximum elongation of 9.5% when compared to binary Mg-2Sr alloy. Due to higher elongation (%) in ternary Mg-2Sr-2Gd alloy shows higher capacity to resist elongation in the material in biomedical implants. Therefore, ternary Mg-2Sr-2Gd shows better advantage in tensile strength when compared to binary Mg-2Sr alloy

Table 5.2 Hardness number values of binary and ternary magnesium alloy

Magnesium Alloy	Trial	Hardness (HV)	Hardness (HV)
Mg – 2Sr	T-1	50	48
	T-2	45	
	T-3	52	
	T-4	46	
Mg – 2Sr – 2Gd	T-1	67	64
	T-2	62	
	T-3	63	
	T-4	69	

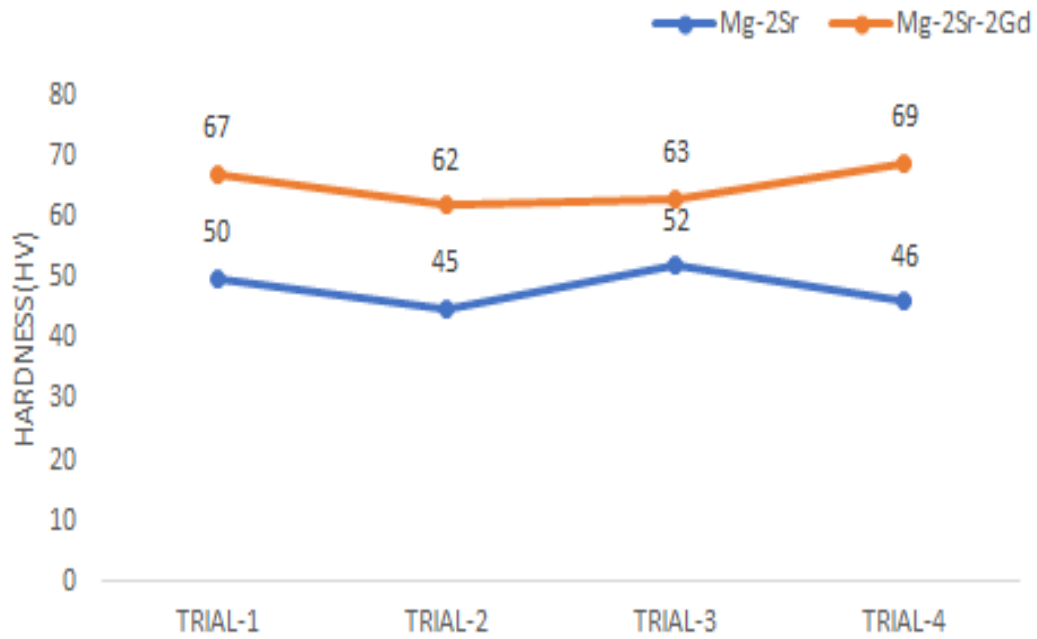


Fig. 5.3 Graph of hardness values of binary and ternary magnesium alloy

The graph of Figure 5.3 shows Hardness plotted on vertical axis and their respective four trials in the horizontal axis for both the binary and ternary alloy of magnesium. The line graph represents variation of hardness values in different. Hardness has represented by a unit HV. In binary Mg-2Sr amalgam, Hardness shows in trial-1 with the value of 50HV, and in trial-2 shows the value of 45HV, and in trial-3 shows the value of 52HV, and in trial-4 shows the value of 46HV, based on the above four trials in binary Mg-2Sr alloy shows an average value of 48HV. whereas in ternary Mg-2Sr-2Gd alloy, Hardness shows in trial-1 shows the value of 67HV, in trial-2 shows the value of 62HV, in trial-3 shows the value of 63HV, in trial-4 shows the value of 69HV. Based on the above four trials in ternary Mg-2Sr-2Gd amalgam shows an average value of 64HV. In trial-4 ternary Mg-2Sr-2Gd alloy shows the maximum hardness value of 69 HV. Therefore, ternary Mg-2Sr-2Gd shows better advantage in hardness when compared to binary Mg-2Sr alloy.

CHAPTER 6

CONCLUSION AND SUMMARY

6.1 SUMMARY

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 and Mg-2(%wt.) Sr-2(% 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.

Tensile test is being carried out using micro tensile testing machine and shows that the Mg-2(% wt.) Sr Binary amalgam consisting low values of UTS, low values of YS and the EL (%) is also low when compared to ternary Mg-2(% wt.) Sr-2(% wt.)-2(% wt.) Gd amalgam. The average value of UTS for Mg-2(% wt.) Sr blend is 186Mpa which is lower than that of Mg-2(% wt.) Sr-2(% wt.) Gd amalgam with an average value of 202MPa. The average value of YS in Mg-2(% wt.) Sr amalgam is 98Mpa which is lower than that of Mg-2(%wt.) Sr-2(%wt.) Gd amalgam with an average value of 104Mpa. The average value of EL in (%) in Mg-2(% wt.) Sr blend is 4.8% which is lower than that of Mg-2(%wt.) Sr-2(%wt.) Gd amalgam with an average value of 9.5%.

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-2(%wt.)-2(%wt.) Gd amalgam shows that smaller refine grain boundaries and smaller refine particle size.

Hardness test is being carried out using micro hardness testing machine were the Hardness value of Mg-2(%wt.) Sr amalgam shows lesser when compared to hardness value of Mg-2(%wt.) Sr -2(%wt.) Gd amalgam. The average Hardness value of Mg-2(%wt.) Sr blend is 48HV, were as in Mg-2(%wt.) Sr-2(%wt.) Gd average value of hardness is 64HV.

6.2 CONCLUSION

In this study, Mg-2Sr-2Gd alloys were developed for the first time, and their tensile test, Vickers hardness, and optical microstructure were systematically investigated for bone implant applications. The results indicated that as an alloying element Gd has the potential in tuning the optical microstructure, Ultimate tensile strength, yield strength, elongation, and hardness of ternary Mg-2Sr-2Gd-based Mg alloys.

Due to the good mechanical properties like tensile strength and hardness and finer crystal size makes the suitability in ternary Mg-2Sr-2Gd alloy for biomedical applications.

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APPENDIX

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SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS
PRIMARY SOURCES			
1	Harpreet S. Brar, Joey Wong, Michele V. Manuel. "Investigation of the mechanical and degradation properties of Mg–Sr and Mg–Zn–Sr alloys for use as potential biodegradable implant materials", Journal of the Mechanical Behavior of Biomedical Materials, 2012 Publication	2%	
2	lbmd.coe.pku.edu.cn Internet Source	1%	
3	Mengqi Cong, Ziquan Li, Jinsong Liu, Shaohua Li. "Effect of Sr on microstructure, tensile properties and wear behavior of as-cast Mg–6Zn–4Si alloy", Materials & Design, 2014 Publication	1%	
4	Huiying Lai, Jingyuan Li, Jianxing Li, Yuan Zhang, Yuzhao Xu. "Effects of Sr on the microstructure, mechanical properties and corrosion behavior of Mg-2Zn-xSr alloys", Journal of Materials Science: Materials in Medicine, 2018 Publication	1%	

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