

CORROSION AND TRIBOLOGY INVESTIGATION ON MAGNESIUM RARE EARTH ALLOYS

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

BY

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**DEPARTMENT OF MECHANICAL ENGINEERING
SCHOOL OF MECHANICAL ENGINEERING**

SATHYABAMA

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

Accredited with Grade "A" by NAAC

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **S. NITHISH (38150073)** who carried out the project entitled "**CORROSION AND TRIBOLOGY INVESTIGATION ON MAGNESIUM RARE EARTH ALLOYS**" under my supervision from 01.11.2021 to 10.05.2022.

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1)

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ABSTRACT

The one of the lightest structure metal in the earth is magnesium element. In some of the various industries magnesium element has a high demand due to its lightest structure. For orthopedic application (Mg) magnesium has been researched in various type.

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 alloys system (ternary and binary) and composites. Furthermore the magnesium composites importance are pointed out.

In this research work an attempt is made to investigate Magnesium–Strontium–Gadolinium rare earth element alloy is casted using gravity casting method and the mechanical and microstructure properties corrosion and tribology of Mg-REE alloy are investigated.

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LIST OF ABBREVIATIONS

COF	-	Coefficient Of Friction
FAA	-	Federal Aviation Administration
Gd	-	Gadolinium
ICDD	-	International Centre for Diffraction Data
LVDT	-	Linear Variable Differential Transformer
Mg	-	Magnesium
Mg-Sr	-	Magnesium Strontium
Mg-Sr-Gd	-	Magnesium Strontium Gadolinium
Mg-Sr-RE	-	Magnesium-Strontium Rare Earth
REE	-	Rare Earth Alloys
SEM	-	Scanning Electron Microscopy
Sr	-	Strontium
XRD	-	X-Ray Diffraction

CHAPTER 1

INTRODUCTION

1.1 MAGNESIUM ALLOYS

Magnesium (Mg) element is considered as the lightest structural alloy commercially available and have great prospective for various field of applications. The biodegradation and its alloy were documented in the nineteenth century. The better support and high initial biomechanical stability are provided by Mg and Mg alloys.

In this modern world the magnesium plays the major role and holds wide range off application in important field like automotive, aeronautics, astronautics, etc, because of their high stiffness to density ratio environmental protection and high strength to density ratio.

Apart from the mentioned applications the Mg plays the very important role in biomedical field. Mainly Magnesium alloy plays a major and specific role in orthopedic application especially in bone implants. The fractured or broken bone are attached by a plates, nuts, bolts are made up off Magnesium alloys and Magnesium rare earth alloys (REE). The surgery or implants are classified in to two types (1) temporary implants (2) permanent implants. These implants or surgery are mainly done for human bone joints, bone plate pins, hip replacements, prosthetics etc. Due to the requirement of material which are likely to have good corrosion properties and biomedical properties and tribological properties the selection of material of biomedical purpose are getting harder these days.

The significant observation the biodegradable behavior of magnesium has changed the perspective towards implants. They have good compatibility, exclusive antimicrobial better support and stability than the biodegradable polymers.

The pure magnesium has poor content properties which cannot be used in those application as it has to be casted with another element like aluminum, zinc, silicon, titanium, etc. these combinations are known as Magnesium alloys. Rare earth elements like neodymium, yttrium, cerium, scandium, gadolinium, strontium etc. when these REE are combined with Magnesium to form Magnesium rare earth alloys. These REE elements form very rare in nature and relatively very expensive. Due to its cost effect these REE are not used in all areas only in few areas are used, mainly in orthopedic medical application. Due to the biocompatibility nature and degradability magnesium are considered as the best possible solution. In recent days few research studies have concluded that corrosion of magnesium is quick and release hydrogen analyzed by corrosion kinetics. Due these problems it is risk to use these Mg REE alloys in human body for bone fix and tissue problems. Then there are several strategies are grown to control the wear condition of Magnesium which do not go for second surgery.

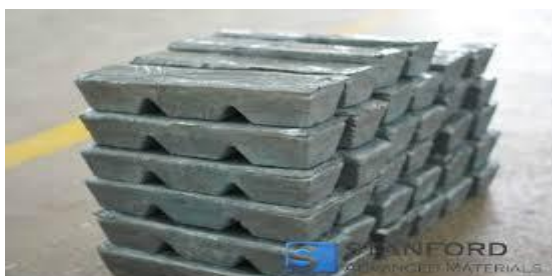
In this study, Mg-2Sr-xGd magnesium alloy specimens were prepared by mass fraction of 2%, 5%, 8% of Gd addition in Mg-2Sr alloy and the effect of Gd addition was investigated with respect to the wear and corrosion properties at gravity casting.



Fig.1.1: (A) Properties of Magnesium (B) Magnesium element
(Source: www.material-properties.org)

1.2 MAGNESIUM RARE EARTH ALLOYS

The rare earth elements REE, also called the rare earth metals which are soft silvery white metals. Due to the character of same ore deposits occurring where lanthanides exhibits some similar chemical properties strontium as well as the gadolinium are considered as the rare earth elements, but these elements have different magnetic properties and electronic properties. The other rare earth elements act similarly as effect of strengthening addition of magnesium because these rare earth elements chemical properties are looks similar. The specific addition amount of gadolinium and strontium to magnesium research and its results are explained in the article.



***Fig. 1.2: Photograph of rare earth alloys
(Source: www.samaterials.com)***

The works based on the wear test and corrosion test include investigations of the behavior of the alloys during casting, determinations of the connection with the structure and composition of alloys and tribological properties of alloys. Binary Mg-Gd alloy, Mg-Sr alloy ternary Mg-Sr-Gd alloys are been investigated because gadolinium was considered as a feasible addition to magnesium together with strontium.



***Fig. 1.3: Turbo charger made of magnesium alloys
(Source: www.material-properties.org)***

Magnesium alloys are combined from of magnesium (the lightest structural metal) with other metals, often with manganese, copper, silicon, zirconium, zinc, aluminum and rare earth element. The fundamental properties of these combining elements are affected due to hexagonal lattice structure of magnesium.

Magnesium alloy are usually used cast alloys due to the formation of hexagonal lattice structure which are more complicated than in cubic latticed elements like steel, aluminum and copper.

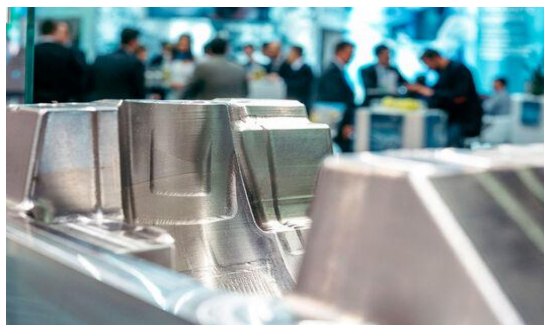


Fig. 1.4: Magnesium alloy in light weight construction
(Source: www.spotlightmetal.com)

The density of magnesium alloy is about less than 30% when compared to aluminum, Due to its density issue the magnesium alloy are considered as the lightest metallic construction material and have very low market share when compared to aluminum alloys. Magnesium can be used in sufficient quantity and even can extract it from sea water. The magnesium are known as seventh most abundant element on earth.

Die cast magnesium are used to make the body of DSLR camera and some specific components in lens and casted magnesium alloys are used to make many components for automobile manufacturing and used in high performance vehicle. Magnesium (Mg) alloys are widely applicable in many manufacturing industries like automobile, air Boeings, electronic etc due to the alloys lightest structure.

The pure (alpha) magnesium has very low strength and cannot be used directly. This is the reason, Magnesium (Mg) is combined or cast with elements like zinc, strontium, calcium, aluminum and even to improve their wear properties, corrosion properties and some mechanical properties the Mg is combined or casted with some rare earth alloys. Magnesium is used widely for various applications from metallurgical to chemical and pyrotechnic and medical.

1.3 STRUCTURAL APPLICATIONS

The prime reason for considering the magnesium in engineering design field is because of high strength to weight ratio of magnesium. The desirable properties of magnesium alloys are machinability high stiffness to weight, excellent damping and cast ability and these properties are very much helpful in the material selection process.

The Ashby diagram (plot diagram used for comparison of property of multiple alloys) of young's modulus against the density among the material the uniqueness of the magnesium alloys are illustrated. The all engineering alloys and its position are positioned at a corner of the triangular shape. The warm properties of magnesium factor into the cast capacity of the compounds and serve in application. On the opposite side of the record, the solid galvanic capability of magnesium and its frail surface oxidation make consumption conduct a significant thought.

Luckily, great plan practices and preventive measures are accessible to enhance natural debasement. Primary applications incorporate car, modern, materials dealing with, business, and aviation hardware. The automobile components like brake and clutch, brake pedal, Column lock housings, manual transmission housings and break. The industrial machines such as printing machines and textile the parts which operates at the high speed and it must be lightweight to minimize the inertial flow are made by magnesium alloys.

Materials-handling equipment includes gravity conveyors, dock boards, and grain shovels. Day today applications include computer parts, handled tools,

ladders and luggage. The lightweight, stiffness and good strength of magnesium alloys has valuable applications in aerospace industries.



Fig. 1.5: Magnesium sheets in manufacturing industries
(Source: www.material-properties.org.com)

The structural applications of magnesium alloys uses have great potential for the light weighting of transportation vehicles. Some of the important problem related to the application of magnesium in its structural application is found by Research within the CAST Cooperative Research Centre. There similarly up to 6000 series aluminum alloys has been developed with extrudability and similar properties. To joint between the dissimilar metals and magnesium or magnesium components a method of laser heating mechanism alloys are further enabled. The feature such as tribology investigation, corrosion, work and wear rate are considered as the key metallurgical feature of deformed behavior of wrought magnesium alloy are discussed in this research.

In automobile industries these magnesium are in sheet type material. Those sheets are cut into a specific size and molded in to specific part by high pressure molding for the vehicle body parts.

1.3.1 Pyrotechnics Applications

The first applications of magnesium powder which are used as components of flare, fireworks and some other devices which has ability to create a bright light. The flash light bulb of photographic camera is made by using fine

magnesium wires. Most of the safety kits in fire starters are still made by use of magnesium.

1.3.2 *Metallurgical Applications*

In the nonferrous alloys such as zinc, lead and aluminum magnesium are used as an alloying element. The oxygen absorber in copper and nickel alloy and as sulfur remover in steel and iron production is made by use of magnesium alloy. By making the graphite particle nodular the magnesium improves the ductility and toughness of cast irons. This is the greatest use of magnesium by weight.

1.3.3 *Electrochemical Applications*

Among the electromotive series the magnesium are highest in salt water making it desirable as a sacrificial anode cathode protection. Constructive uses of this mechanism are employed in batteries.

1.3.4 *Medical Applications*

The light weight advantage of the magnesium is very use full in making the portable medical equipment. It can be used for wheelchairs used in sporting activities. The alloys with other biocompatible elements are being evaluated for orthopedic devices and cardiovascular stents for inter bone fixation is because of magnesium's bioabsorbability and biocompatibility.

1.4 ADVANTAGES AND DISADVANTAGES OF MAGNESIUM ALLOYS

The disadvantage and advantage of magnesium alloys over reinforced or combined alloys like natural made fibers, aluminum, polymers, titanium and stain steel are given below.

1.4.1 *Advantages of Magnesium Alloys*

The following are advantages of Mg alloy :

- Lowest density when compared to other metallic constructional materials
- It gives maximum acceleration due to its less density
- Magnesium alloys have High specific strength
- Can be turned and milled at high speed
- Good cast ability, suitable for high-pressure die casting
- Good weld ability under a controlled atmosphere
- By using high-purity magnesium the corrosion resistance is much improved
- Commercially available and can even it can be used for day to day life.

Comparing with the polymeric materials the Mg has good ageing resistance, recyclable, better mechanical properties, and improved thermal and electronically conductivity. Compared with Aluminum, Its dormant hotness is low, so more projecting can be created per unit time. - Better surface quality and dimensionality. - Smaller draft point and bended surfaces. - High unambiguous strength (14% higher than aluminum)

1.4.2 *Disadvantages of Magnesium Alloys*

The following are the disadvantage of Mg alloy:

- Low elastic modulus
- Limited cold workability and toughness
- Limited strength and creep resistance at elevated temperatures
- High degree of shrinkage on solidification
- High chemical reactivity.

1.5 APPLICATIONS Mg ALLOYS AND RARE EARTH ALLOYS

The present and future world is heavily depends on Mg alloys and Mg REE because it plays the major role and applicable in various industrial application and biomedical field. In the manufacturing field like aerospace industries and automobile industries the magnesium plays a crucial role due to its low density property. In automobile industries the components like car engine block components like cylinders and pistons are made by WE alloys. Besides, given their prevalent downer obstruction and high temperature solidness, as opposed to other magnesium amalgams, WE series combinations are supposed to be appropriate for power train applications.

WE43 (type of casted magnesium) and WE54 are both used in helicopters. For example, WE43 is used in the gearboxes of the *Eurocopter* EC120, *Eurocopter* NH90, and *Sikorsky* S92. In aerospace industries the jet engines particularly in accessory drives, engine gear boxes, constant speed drives, auxiliary power units are made by WE series magnesium due to their temperature stability. Luxfer MEL Technologies and Engines, 2019). The Lockheed Martin F-16 and F-35 are two instances of contender airplane that utilize magnesium alloys as motor parts (Luxfer MEL Technologies and Engines, 2019).

In the early past days the usage of magnesium alloys in application in commercial aircrafts interior design then later it is said to be stopped due to the concerns about flammability of these material in general. However, extensive tests conducted by the FAA (Federal Aviation Administration U.S) have shown that in aircraft infrastructure the safety and necessary performance are done by using Mg alloys. As a matter of fact, the positive result of the FAA combustibility tests directed on WE43 was a significant main impetus in the choice to lift the well established boycott of the utilization of magnesium composites in airplane insides in 2015. Consequently, WE43 turned out to be especially intriguing for application with regards to lodge seat outlines.

Not only in industrial field have the magnesium alloys played a major role in biomedical field. In biomedical application the magnesium alloy has a major part due to its biodegradability nature. The clinical problems in medical field can be cured

by the magnesium alloy. When compared to the WE43 while displaying some same yield strength the common stent material has higher young's modulus. The good corrosion resistance and improved biocompatibility of magnesium made the researches to make the use of the magnesium alloy material and are highly investigated in recent years. For example, clinical preliminaries have been performed with WE43-based bioresorbable screws and cardiovascular stents, decidedly exhibiting the materialness of this amalgam in the clinical field. Nonetheless, notwithstanding of the promising outcomes, these composites must be additionally examined to assess the possibly hurtful impact of certain alloying components on human wellbeing.

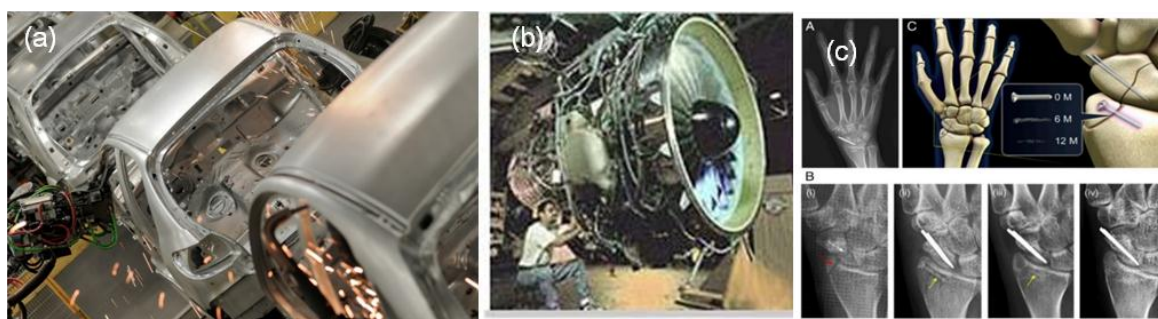


Fig. 1.6: Application of Mg alloy (A) Mg alloy application in automotive industries, (B) Mg alloys application in aero space industries, (C) Mg alloys application in medical industries especially in orthopedic industries

(Source: www.thermofisher.com)

1.6 Mg REE

Mg alloys is nothing but the mixture of magnesium and other related elements by casting and other applications are known as magnesium alloys. There is a another type of Mg alloys is named as magnesium rare earth alloys. This is same as the Mg alloys but the mixtures of other elements are lanthanum, neodymium, cerium, yttrium, gadolinium, strontium etc, these elements are known as rare earth elements. These rare earth elements are found very rare in the earth and contain very good properties than other elements. When these elements are tends to mix with Mg it becomes Mg rare earth alloys (REE). These Mg rare earth elements are very cost effective and expensive and it is very rarely applied in industries.

Besides the application of Mg rare earth alloys in industries its highly used in biomedical field especially in orthopedic area. Bone surgery, bone attachments, hip replacement, teeth problems etc. in the past for the treatment of these problems are solved by treating the bone attachments are done by using surgical steel or titanium. But it has the big disadvantages that loosening, intolerance, weight age etc. due to these disadvantages the fixed plates will be removed by involving in secondary surgery which results in high amount of cost and creates high stress for the patients. For the sufficient for weight handling application the restorable bone attaching implant material are needed.



Fig. 1.7: Photograph of casted Mg REE
(Source: www.samaterials.com)

Then to resolve this issue, researchers found that magnesium will be suitable for the implants by some research. Magnesium is the lightest structure element; by mixing the rare earth elements to Mg to create Mg REE can be suitable for this implant process. Mg density is 1.74 g/cm³ at room temperature and therewith 1.6 fold resp. 4.5 fold lower than aluminum or steel. With respect to the orthopedic use, its advantages are its approximate compressive and tensile strengths as well as its Young's Modulus (41-45 GPa), which is considerably closer to cortical bone compared to other metallic implant materials. The corrosion rate ranges between aluminum and unalloyed steel. Magnesium as a mineral occurs naturally in the body and is eliminated through the kidneys. Therefore, magnesium and MA are intensively investigated to develop a basic material for the production of degradable osteo synthesis implants e.g. intramedullary nails, plates etc.

1.6.1 Magnesium Strontium (Mg-Sr) alloy

Strontium (Sr) is a rare earth element and its atomic number is 38. It is an alkaline earth metal. Strontium is soft silver-whiten color yellowish metallic element. This element is highly chemically reactive. When the element is exposed to air it forms a dark oxide layer on its surface. Strontium plays important role in human body that it is essential in human body because it promotes the growth of osteoblast and prevents bone restoration. Due to intergranular distribution of second phase and micro galvanic corrosion when compared to as extruded alloy the As casted Mg-Sr alloy shows a rapid degradation rate.



***Fig. 1.8: Photograph of casted Mg-Sr
(Source: www.material-properties.com)***

When strontium is combined with magnesium creep resistance, replicates the effects of rare earth elements, texture anisotropy and reduces grain seize. For the further investigation on strontium on plasticity and mechanical properties of magnesium alloy comparison test have been performed and were joint with non destructive measurement given by the acoustic emission monitoring and digital image correlation. by using the novel mechanical characteristic procedure which involves in targeted mechanical tested joined with the use of two noon destructive techniques volume monitoring and combined surface of micro structural changes the effect of adding some specific amount of strontium in magnesium alloy have been investigated. While suppressing orthoclastic activity the magnesium and strontium promotes ontogenesis. Making magnesium phosphate bio ceramics ideal for treating the osteoporotic bone defects because of high concentration of non toxic of magnesium strontium alloy. It is also stated strontium has a good biocompatibility and it is used to cure osteoporosis. Therefore, these characters and properties make Strontium (Sr) as good alloying element substitute in Mg based implants materials,

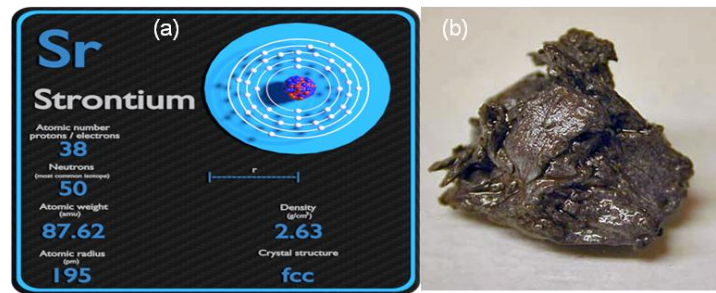


Fig. 1.9: (A) Properties of strontium (B) photograph of pure strontium
(source: www.material-properties.org)

In mechanics of materials, the **strontium's strength of material has the ability to handle the load applied without plastic deformation or failure**. The relationship between the resulting deformation or change in material dimensions and external load applied on material are considered by the strength of material. It is said to be consider the factors in order that the selected material have specific strength to retain its original shape or to resist the applied loads in machines and designing structure. **The ability of a material to tolerate the applied load without plastic deformation or failure are said to be strength of material**. In mechanics of materials, the **strength of a material of strontium** is its ability to withstand an applied load without plastic deformation or failure.

The role of strontium inducing micro structural changes that relate to twinning suppression stringer formation, dislocation activity and grain seize all these factors causes some serious bulk mechanical change behavior investigated by both perpendicular and parallel to axis. The grain growth restriction mechanism of secondary phase particle which distributes on the advancing interface of the solid liquid while the proposed behavior is due to addition of strontium element in the excess of solid solubility limit Mg Sr alloys where our result or in agreement with it. To validate the grain refinement effect observed in the Mg Sr alloy dictated by same mechanism the further investigation is mandatory.

Magnesium-strontium rare earth (Mg-Sr-RE) amalgams for stent applications in light of a miniature alloying procedure that objectives to control bio wellbeing and furthermore improves bio debasement property. The outcomes show that the created Mg-Sr-RE combinations are near being a solitary stage strong

arrangement, with absolute alloying increments restricted up to 0.5 %. The magnesium-strontium intriguing earth MgSr-RE combination created has 0.5 to twice further developed pliability than that of the twofold magnesium-strontium Mg-Sr compound having 45 to 66% lower wears rates.

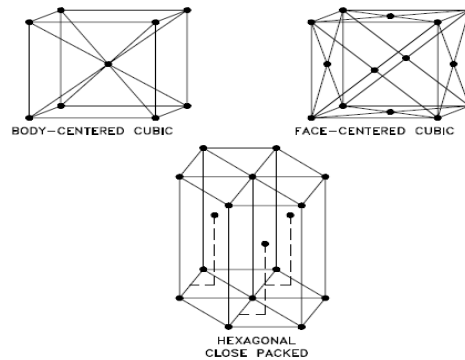


Fig. 1.10: Crystallographic structure of strontium
(Source: www.material-properties.org)

1.6.2 Magnesium Gadolinium (Mg-Sr) alloy

In strontium study it is said that our human body contains strontium content naturally. But when it comes to our human body bone (orthopedic) implants, the density of the material which we use for implants plays a major role. If the density property is poor it implies that wear resistance of the material is poor and it leads to removal of material from our body and involves in secondary surgery for the patient. As said in earlier the wear resistance is poor for the alpha (pure) magnesium and this is the reason the other elements are combined with Mg to form Mg alloy and rare earth alloy. For the implant condition the gadolinium is a perfect combination for Mg due to its density. The density of the gadolinium is 7.9 g/cm³. When compared to other elements gadolinium is better in density and wears resistance. In American element magnesium gadolinium alloy are the good improved wear resistance and high numerous purity rare earth alloys are manufactured. Due to the master alloy magnesium gadolinium which can be used in improving alloy, refining and hardening performance by enhancing the properties such as mach inability and ductility.

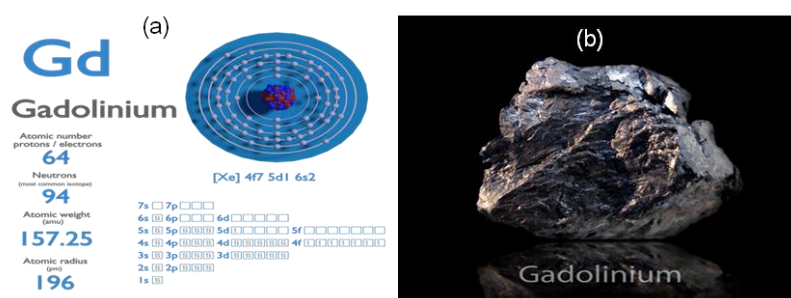


Fig. 1.11: (A) Properties of gadolinium, (B) Pure gadolinium
(Source: material-properties.org)

The inter metallic phases which forms in (Mg Gd) magnesium gadolinium alloys are highly stable and can sustain at high temperatures and shows well improved creep resistance. The refined grain formed by the casting of magnesium and gadolinium is highly improved one, these improved refined grain cannot be seen in other rare earth alloys. Gadolinium (Gd) has a high solubility micro alloyed with Mg and suitable biocompatibility property.

To improve the wear resistance, corrosion mechanical properties of magnesium gadolinium is added to the magnesium to form Mg-Gd alloy. The corrosion, mechanical properties and microstructure were evaluated by scanning electron microscopy (SEM), energy dispersive spectroscopy, X-ray diffraction (XRD), mechanical stretch methods and electrochemical methods.

1.6.2.1 Chemical and mechanical properties of gadolinium

These elements when in compound form it exists in the form of trivalent state. in the room temperature the gadolinium is paramagnetic in nature and when it is cooled or kept in low temperature of about 20°C it changes into ferromagnetic. The curie point of gadolinium element is about 17°C.

Gadolinium has naturally occurring isotopes which are 13 numbers of isotopes naturally occur and around 27 are synthetic isotopes. The gadolinium when mixed with components like selenium, silicon, boron, sulfur, nitrogen at high temperature it forms binary compounds.

1.6.3 *Magnesium Strontium Gadolinium (Mg-Sr-Gd) alloy*

The magnesium rare earth alloys Mg Sr alloy are being developed as the possible material for human bone fixing and implants application are stated by recent investigation studies. The promotion of ontogenesis by the suppressing orthoclastic activity is done by strontium. The grain size refination and altered structure by leading in developing a novel magnesium rare earth alloys for orthopedic application is due to addition of strontium. When magnesium casted alloyed with gadolinium the refined grain seize is improves than other rare earth alloys being alloyed with magnesium. Gadolinium (Gd) has high solubility and has suitable biocompatibility property when being alloyed with magnesium. The magnesium gadolinium alloy are best material for human bone fixing and implants application are stated by the recent investigation on magnesium rare earth alloys.

1.7 DEFECTS IN MAGNESIUM ALLOYS

The relativity poor corrosion resistance and high low temperature are the two major disadvantages of magnesium alloys seems to be in general agreement as use in automotive application.

1.7.1 *During Casting Defects*

Permanent mold casting and sand of non ferrous alloys like zinc, aluminum which can applicable to magnesium are considered as the casting defects in magnesium. Still the major issue during the lost foam casting of Mg alloys is fold formation. Fold formation and oxidation can cause more issues to Magnesium alloys in comparison with aluminum alloys.

1.8 GRAVITY CASTING PROCESS OF MG REE ALLOY

1.8.1 *Indufurr Preheating Oven*

A preheated oven is one that 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

1.8.2 *Die Cast Steel Mold*

Die casting also known as high pressure die casting, when the liquefied or molten alloys are poured in to a pressure chamber or cavity of steel mould where filled with the prepared molten state alloy at high speed. Those poured molten alloy are solidified under pressure and forms casting. The high pressure and high speed are main characteristics of die casting.

1.8.3 *Stainless Steel Crucible*

Crucibles are large made of steel by dissolving pig iron cast iron and frequently alongside glass, sand remains and different transitions in a pot. In old times steel and iron were difficult to liquefy charcoal or coal fires which couldn't deliver temperature sufficiently high.

1.8.4 *Electrical Resistance Furnace*

The resistance furnace in other words it known as electrical resistance furnace. The heat generated by the electrical furnace by the conductors that offers resistance to the passage of current through them. These furnaces are widely used in heat treatment for heating prior to pressure shaping and to dry or melt materials.

1.8.5 *Application of Resistance Furnace*

The resistance furnace and ovens are for the following application. Heat treatment of materials such as hardening and annealing process etc.

1.8.6 *Shrinkage during Cooling Process*

As a result of the differences in thermal expansion coefficient of plastic and metals molded article that lightly fit mould cavities at elevated temperature will shrink upon room temperature.

1.9 PRIMARY PROCESS OF CASTING

The magnesium based alloy and its properties are mainly depends on the processing and technique. The primary processing of biodegradable magnesium is classified in to two types' liquid state technique and solid state technique. Power metallurgy is the solid state synthesis technique by blending the metal powders of foe the desired composition, compaction followed by stirring the material below its solidus temperature found to be expensive. Casting is considered as the most economic method of processing Mg based material by super heating in a furnace above 750°C in an inert gas atmosphere to protect the oxidation followed by transferring the metal in to mould to solidify. The processing sequence of biodegradable magnesium and its alloys from raw material to the final medical devices are extremely important which is schematically shown. The cold and hot working to get a specific form like wire, lathe, tube and rods. Joining and machining are the secondary processing which has applied for implant of products.

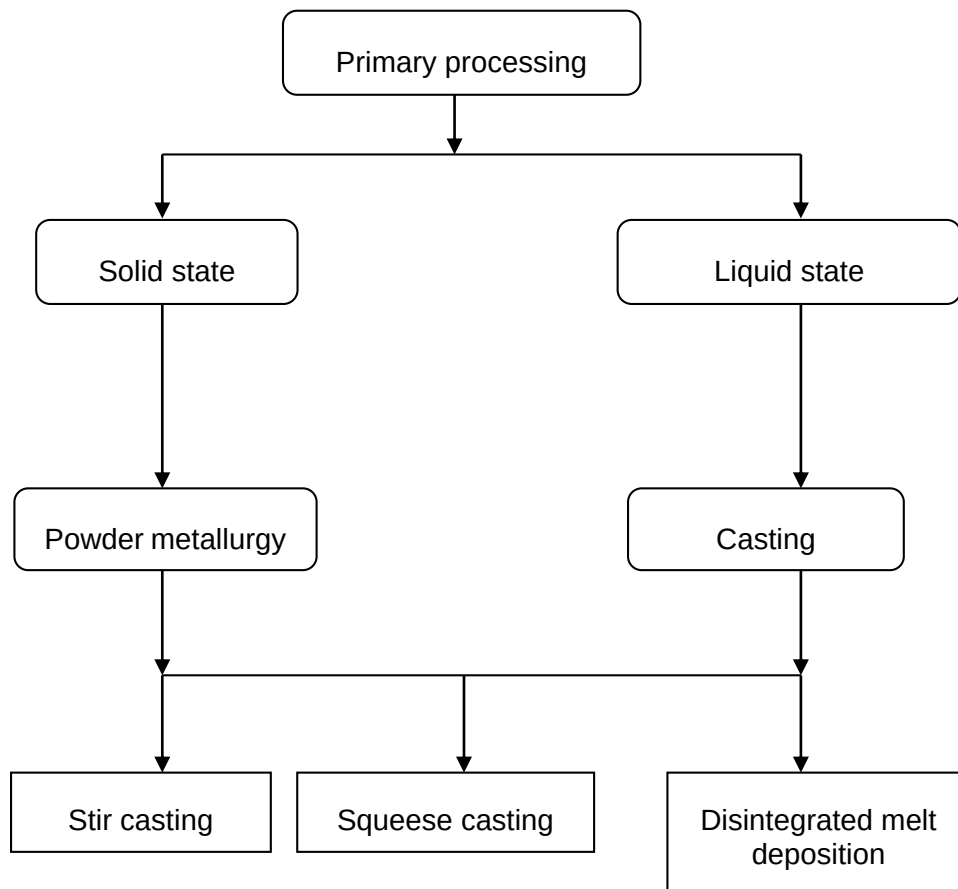


Fig. 1.12: Primary process of casting

1.9.1 Stir Casting

The another state which is liquid state process for fabricating the composite materials is known as stir casting, in which a dispersed components is mixed with a molten matrix metal by means of mechanical stirring. This method is most cost effective and simple method for liquid state fabrication. Stir casting method is a best suitable method for casting of Mg alloys. Due to its simplicity, less processing and flexibility for the metal matrix composites production one of the best economical process is stir casting method. By the different priority methods the inside the matrix the particle is done and with the help of stirrer the mixing of particles into molten metal was performed.

The reaction between reinforcement phase, settling or floating of reinforcing particle and agglomeration of the reinforced particle are considered as the main issue related to stir casting. By mixing the reinforcing particle in to solid condition of metallic matrix these problems are avoided. On of the widely and best used method for metal formation done by material melting's and changed into customized shape is known as stir casting. The stirring of melt in which the melt is stirred continuously in stir casting process which tends to continuous oxidation aluminum melt by the expose on the melt surface to the atmosphere. As a result of continuous oxidation the wettability of the aluminum reduces and the reinforcement particles remained unmixed. This furnace is used to melt the metals like magnesium, aluminum, zinc, copper for casting making in to metal alloy and metal matrix composites metal with oxide ceramics.

CHAPTER 2

LITERATURE SURVEY

The following research articles based on pin on disc wear test and XRD analysis of magnesium rare earth elements alloys are studied:

The main reason that Mg is reinforced with other material like zinc, aluminum, gold and even the rare earth alloys is because to improve the mechanical, tribology, corrosion, chemical, metallurgical properties. Some research work in orthopedic and has also given good positive result in wear properties.

2.1 LITERATURE SURVEY PIN ON DISC WEAR TESTS

- L.M. Wang (2007) confessed that with the load of 20-380N and 20-280N, against steel plate the AZ91 and Mg97Zn1Y2 alloys pin on disc wear sliding test has been carried out. When compared to AZ91 alloy the Mg97Zn1Y2 alloy shows low wear rate and coefficient of friction (COF). The delimitation, melting, thermal softening, oxidation and abrasion, these the process considered as the five wear mechanism.
- M. Srinivasan (2011) The nano composites and AZ31B magnesium alloys are investigated on the basis of sliding wear behavior. For both the nano composite and alloys the speed of sliding increases, due to this there is a decrease in the wear rate. The adhesion, oxidation and groove characterize the nano composites and alloy which are analyzed by SEM analysis. The range of 1500m sliding distance thermal softening transferred from the dominant wear mechanism which is adhesion and abrasion.

- E. Ilanaganar (2018) has when load applied to the sliding velocities increases, due to that there is a increase in wear rate. The applies load increases up to 20N then there is a increase In wear rate. Therefore when the applied load increases then the wear rate also increases. The 0.3 m/s ranged sliding velocity increases simultaneously with the wear rate increase. The steady state has been achieved due to that simultaneous relationship. In the high applied load the slope of the wear rate is occurred due to sliding velocity further increased more than the 0.3 m/s. So that mild wear occurred from the transition
- L.M. Wang (2007) The raise in surface temperature during the dry sliding with mechanical properties and microstructure controls the wear behavior of testing magnesium alloys. Due the superior thermal stability of the high levitated temperature mechanical properties and intermetallic superior thermal property, the Mg97Zn1Y2 alloy has good thermal property.
- E. Ilanaganar (2018) the wear rate increases rapidly in slight wear regime due to the applying load increases and at critical condition (high load) the wear rate increases abnormally. In varying slide velocity it shows the similar results as before. The mechanisms like oxidation, melting delamination, abrasion and plastic deformation. During the dry sliding condition these are the five mechanisms which are occurred. Delamination, abrasion and oxidation are occurring dominant mechanisms during the sliding wear condition and apply of lower load. Melting and plastic deformation are dominant occurring mechanism during the sliding velocity condition and apply of higher load. The sliding velocity and applied load controls the wear behavior of AZ31B Mg alloy.
- H.R. Lashgari (2009) by the addition of strontium content it is resulted that Al-B4C composites wear resistance increases in the all type of applied loads. The change of eutectic silicon morphology to well refined fibrous structure from coarse plate like structure of Al-Si alloy due to the addition of specific amount of strontium is well known. The addition of

modifier and grain refiner to the Al-Si alloy, the wear mechanism changes to abrasive from adhesive.

- L.M. Wang (2007) at the surface layer of pin the wear behavior changes mechanical property and microstructure due to the raise of temperature on the worn surface during the dry sliding condition.
- V. Ngal (2008) The ultra high molecular weight polyethylene (UHMWPE) wear performance has not been affected by gadolinium and Eu. The wear determined by the tracer is heavily correlated with wear grain which is not equal. The rare earth elements will be successfully tracks the polyethylene wear and the problems can be resolved.
- Stephen L. RICE a reduction in wear of pin with increasing velocity, the aluminum pin against the titanium disc are expected and each metallic pair are been seen by the effect of increasing slide velocity. For a specific time it is detected that there is no trace for magnesium disc with aluminum. Even aluminum disc tends to not to wear the magnesium disc at the sliding velocity. The derbies ratio of 50% of Mg and 50% of Al are created by this contact.

2.2 LITERATURE SURVEY ON XRD ANALYSIS

- Dokyol Lee (2007) at the temperature of 1400°C heat the mixture LSGM8282/LSM are heated for 4hrs and the XRD patterns are also obtained for LSGM8282/LSM mixture. It becomes uneasy to differentiate the XRD patterns because the both LSM and LSGM have the same perov site structure. But fortunately the LSM XRD patterns are appeared at lower angle because of LSGM has larger parameter. It is very difficult that there is no difference found between on XRD pattern and even after heating there are no traces of peaks found elsewhere in the pattern. At the side of cathode interface the LSGM8282 is fairly stable.
- J.R. DeepaK (2021) the improvement of metallurgical properties and mechanical properties is leaded by the increase in FWHM result due to

the addition of specific amount of (Gd) gadolinium to the Mg-2Sr (base alloy). When compared to the Mg-2Sr alloy the crystal nature of Mg-2Sr-2Gd magnesium REE alloy is low. 35 ± 10 mm is grain size of pure magnesium. But the grain size decreases up to 23.9 ± 8.3 mm due to the addition of strontium and becomes Mg-2Sr alloy. Then the grain size further decreased up to 20.5 ± 7 due to addition of gadolinium and becomes Mg-2Sr-2Gd alloy. It is concluded that addition of strontium and gadolinium to magnesium involves in grain refinement.

- K. Saranya (2020) the presence of magnesium oxide, gadolinium oxide, crystal magnesium and magnesium fluoride are revealed by XRD analyzed gadolinium coated magnesium alloy. By following the International Centre for Diffraction Data (ICDD) card no. 01-079-6692, the magnesium base metal exhibits the hexagonal crystal structure.
- Yang Mingbo (2011) in the Mg-3Sn-1Mn alloy XRD results it is found that Mg-3Sn-1Mn ternary alloy is majorly composed by Mg₂Sn and D-Mg phases. The formation of extra phase like GdMgSn, YMgSn and Mg₁₂Ce is due to the addition of specific amount of gadolinium to the Mg-3Sn-1Mn alloy.
- Karuna Ratnakaran Athul (2017) due to added Gd alloy has low quantity; the peak corresponding to Al₂Gd has low intensities for Gd added alloys.
- N. Hort (2009) the presence of gadolinium on Mg₅Gd is not proved by the XRD results. Even the presence of oxides In the Mg₁₀Gd, Mg₂Gd, Mg₂Gd is not proved. Only magnesium alloys peaks are present in the results.
- Mengqi Cong (2015) by adding the gadolinium to the pure magnesium alloy is shows that the changes occurs in the microstructure and the pure magnesium in the as cast alloys are dendrite in nature is observed. The binary alloy Mg-5Sn dendrite arm is generally large but it becomes more uniform by increasing content of gadolinium, this is due to the broken dendrite crystals.

- Xiaoqin Zeng due to the low volume fraction in the casting the Mg₁₇Al₁₂ peaks are not identified. But the magnesium and strontium content phase were identified in AZ31-1 alloy. Even in the Mg-Al-Sr die cast alloy these phases are reported. The formation of insular Mg₁₆(Al,Zn)₂Sr particles and acicular Mg₂₀Al₂₀Mn₅Sr particles is due to addition of specific amount of strontium, at the same time when the addition of strontium is above 0.5 pct the Mg₁₇Al₁₂ intermetallic phase formation is suppressed.

CHAPTER 3

AIM AND SCOPE OF THIS PROJECT

3.1 AIM OF THIS PROJECT

- To collect experimental wear test and corrosion test data of magnesium alloys of strontium and gadolinium in various biomedical implants from the existing literature.
- To develop the material of magnesium alloy with gravity casting process and produce as binary Mg-2Sr alloy and ternary Mg-2Sr-2Gd, 5Gd and 8Gd alloy depending upon bio medical application.
- To find and investigate the wear test values of casted binary Mg-2Sr alloy ternary Mg-2Sr-2Gd, 5Gd, 8Gd alloy by using pin on disc wear testing machine.
- To perform and investigate the corrosion resistance by using XRD diffraction machine.
- Identifying and investigating the results of both wear test and corrosion test.

3.2 SCOPE OF THE PROJECT

- The outcome of the project will be a detailed report presented in a journal with characteristic properties of Magnesium alloy (Mg-Sr-Gd) of casted material in the form of cylindrical rod.
- This report contains the values of the tribological test and corrosion test graph

- This tribological test and corrosion value test predicts that how strength the mechanical and tribological properties. And will be helpful in suitability for biomedical application like 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 research work is illuminated as follows.

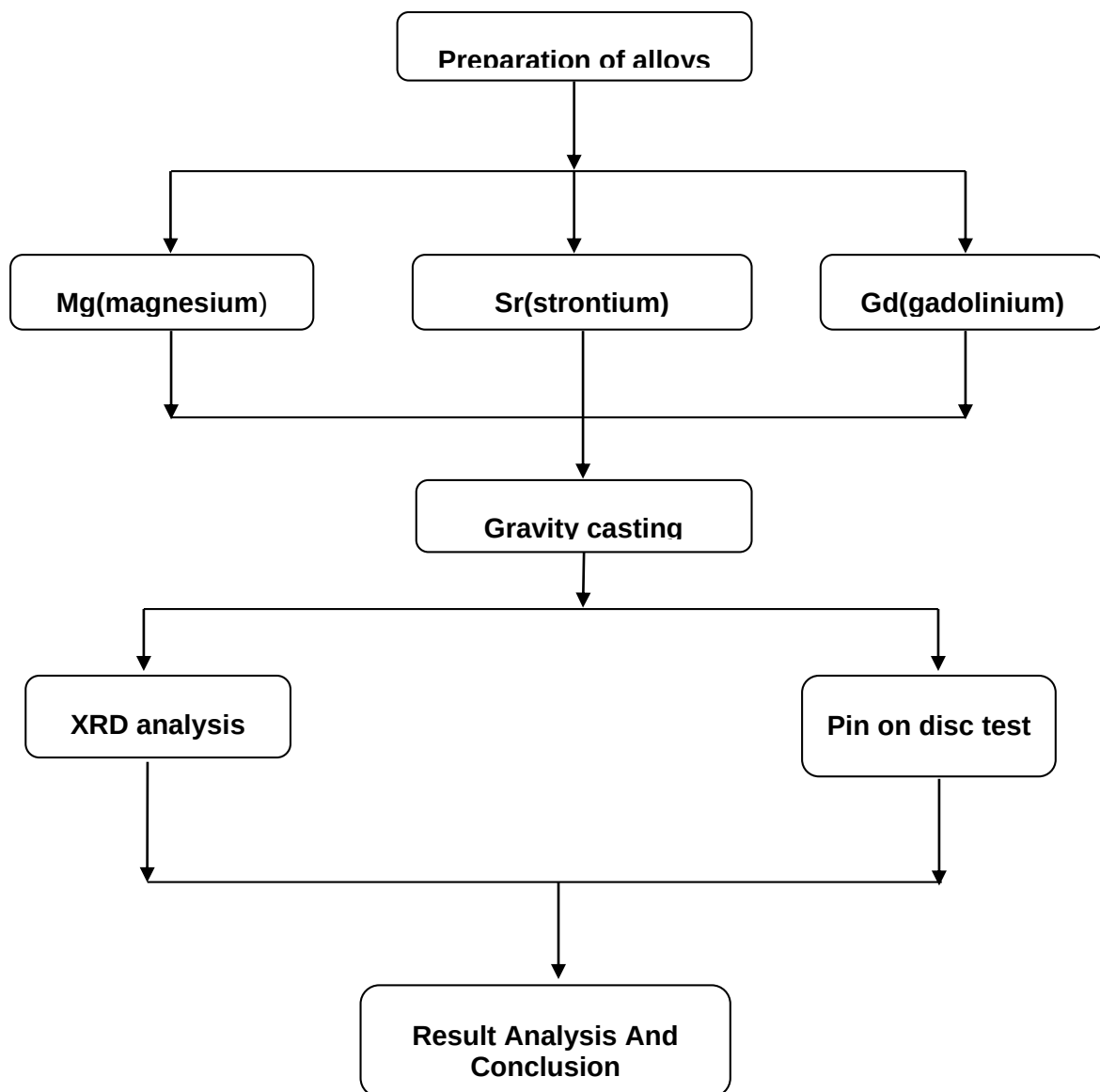


Fig.3.1: Flow chart of preparation of alloys

3.4 WORKFLOW PROCESS

The first step in the workflow process collects required for investigation, where the material consist of base element Mg-2Sr magnesium strontium alloy with 98% of elemental composition pure (alpha) magnesium and 2% of strontium are being casted as the base alloy. Similarly the Mg-2Sr-2Gd magnesium strontium gadolinium alloy with 96% of elemental composition of pure Mg, 2% of strontium and 2% of gadolinium being casted as magnesium Mg-2Sr-2Gd REE alloy. Similarly keeping the 2% of strontium constant the specific amount of gadolinium is varied from 2%, 5% and 8%.

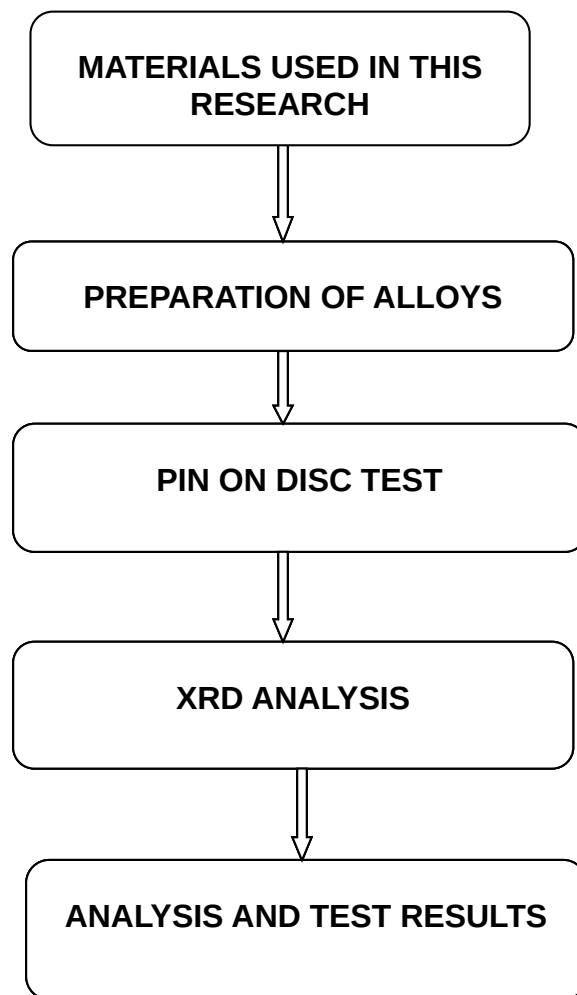


Fig. 3.2: Flow chart of methodology

After the preparations of amalgams, the amalgams were further machined to carry out the corrosion and tribology (wear) test. Based on these test the analysis is being carried out between the two amalgams.

3.5 DEFECTS IN MAGNESIUM ALLOYS

Magnesium has several disadvantages, in that there are two main disadvantage are mentioned at the field of automotive and aerospace industry field, namely relatively poor corrosion resistance and high low temperature (creep) strength.

3.5.1 *Defects of Magnesium Alloy during Casting*

The nonferrous alloys which are aluminum applicable to magnesium during the permanent mold casting and sand the casting defect is identified. The fold formation during the lost foam casting magnesium alloy are considered as the major defect.

CHAPTER 4

MATERIALS AND METHODS

4.1 PREPARATION OF ALLOYS

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 $0.3\mu\text{m}$ with silica gel.

In pure Mg has 650°C liquefying point the time being to liquefy the magnesium material will take up to 35-40 minutes, and has 1.73g/cm^3 density since the magnesium density material is less and has better advantage to biomedical applications and has the composition of 99.9%. Whereas in Sr master amalgam has the liquefying point of 777°C and it takes more time to liquefy 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 liquefying point of 1313°C , being the highest liquefying temperature in comparison to Mg and Sr master amalgam takes more time to liquefy the gadolinium depending on composition being taken during the preparation of amalgam. As per our experimental study,

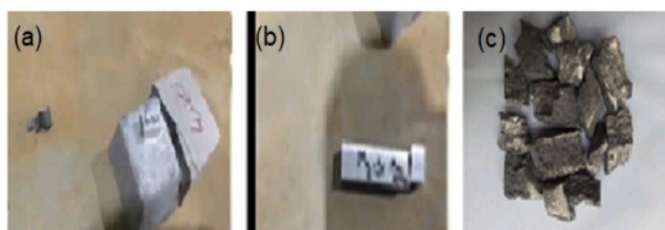


Fig. 4.1: Sample images of (a) pure magnesium, (b) strontium, and (c) gadolinium

Gd material is taken as the composition of 2% by weight, and being the maximum density in the material of 7.9g/cm³. 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. 4.2: Indfurr pre heating 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



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

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.

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.

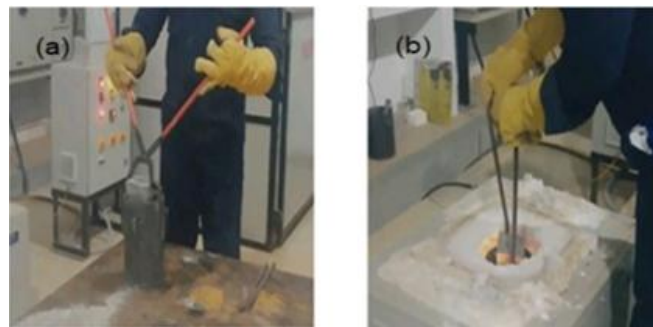


Fig. 4.4: (a) Placing pure magnesium in stainless steel crucible and (b) placing of stainless steel crucible in the electrical steel furnace

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. 4.5: 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. Adding the Sr master alloy in to the pure Mg molten metal as shown in figure 4.7.



Fig. 4.6: 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. 4.7: Removal of pre heated die cast steel mould from pre heated Owen

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. 4.8: (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 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. 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. 4.9: (a) Pouring the alloy molten metal into the preheated die cast steel mould, (b) shrinking during the cooling process and (c) as cast Mg-2Sr and 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 4.10.

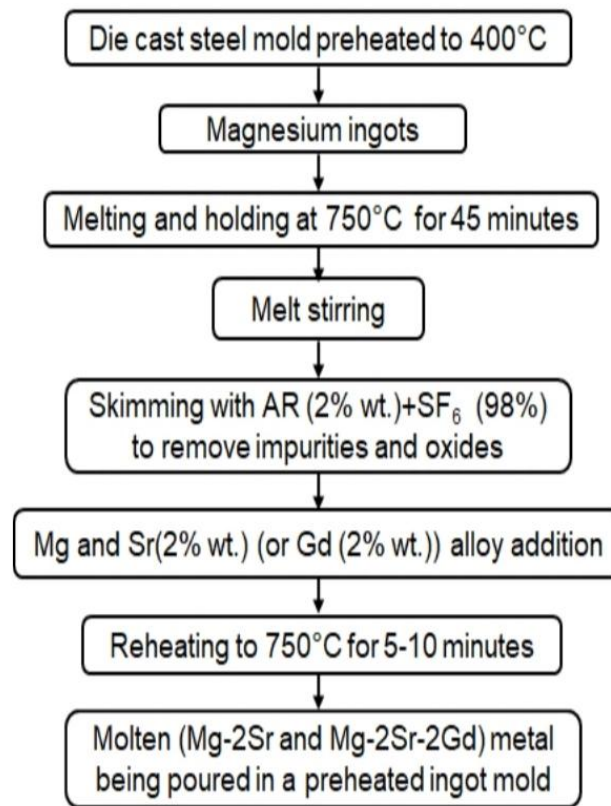


Fig. 4.10: Flow chart of casting of an alloy

4.2 SHEAR CUTTING AND CLEANING

Shearing is a simple process used for the cutting of metals. It is basically a metal fabrication process and is being used in rolling mills at several places for hot as well as for cold cutting of the steel material. Shears can be used to cut steel and other materials of any size or shape. In the shearing process, metal is separated by applying a great force enough to cause the material to fail. The most common shearing processes such as shearing, punching, piercing, slitting, and blanking etc. Are performed by applying a shearing force. When a very large shearing force is applied, the shear stress in the material exceeds the ultimate shear strength and the material fails and separates at the cut location.

4.2.1 *Cleaning with Acetone*

Once the shear cutting is done the samples are cleaned with acetone solution so that dust and other particles can be removed before testing process

4.3 WIRE CUT EDM CNC

Wire cut EDM machine puts impulse voltage between electrode wire and workpiece through impulse source, controlled by servo system, to get a certain gap, and realize impulse discharging in the working liquid between electrode wire and workpiece. Electrode wire is connecting to cathode of impulse power source, and workpiece is connecting to anode of impulse power source. When workpiece is approaching electrode wire in the insulating liquid and gap between them getting small to a certain value, insulating liquid was broken through; very shortly, discharging channel forms, and electrical discharging happens. The standard wear testing on pin on disc wear test is ASTM G-99. For XRD analysis after the casting process the sample casted alloy was cut into ASTM standard sample size of 10 mm 10 mm 3 mm. These are further polished and prepare the specimen for the examination following the ASTM standards.

4.4 PIN ON DISC WEAR TEST

The study of lubricant, characteristic of material are done by using Pin On Disc wear testing machine. Some researchers by using the pin on disc experiment studied the materials, coating and studies the characteristic of lubricant on material. In this study the simulation on the sliding part of gear contact by using the pin on disc wear machine. The pin on disc machine contains a loaded calibrated pin and rotating disc in horizontal shape. For these tests, the tip of the pin was a non-rotating half sphere with a radius of 5 mm. in pin on disc machine the vertical displacement and friction force of the pin is automatically measure by the use of linear variable differential transformer (LVDT).

The triboconditioning system (pre-treatment) consolidates outrageous strain mechanical treatment of the part surface with a tribo-compound affidavit of a film in view of tungsten disulphide. An instrument is squeezed and slid against the

circle within the sight of an extraordinary cycle liquid. As the instrument ignores the surface it sets off a tribo-compound response inside the interaction liquid which bit by bit stores a tribo-film on the outer layer of the part. The pressure which applied on the device additionally prompts a polishing impact as a portion of the ill tempers on a superficial level are decreased and the valleys are bit by bit loaded up with the compound. In this analysis just the plate was covered in light of the fact that it was hard to apply the exceptional methodology to the pin tip given its hemispherical shape become somewhat smoother after the pre-treatment

Base alloy Mg-2Sr magnesium strontium alloy with the 98% of elemental composition of alpha (pure) Mg and 2% of Sr being casted as the base alloy. Similarly the Magnesium-Strontium-Gadolinium Mg-2Sr-2Gd alloy with its elemental composition of 96 wt% of alpha Mg, 2% of Sr and 2 % of Gd are being casted as magnesium REE Mg-2Sr-2Gd alloy. Similarly by keeping the 2% of Sr constant the % of Gadolinium (Gd) is varied from 2%, 4%, 6%, 8%. The binary Magnesium-Strontium Mg-2Sr alloy and the Magnesium REE Mg-2Sr-2Gd alloy is casted by gravity casting process at Metrics technological solutions, kalpadi, Tamil Nadu, India. The die steel mold form in which the casting to be arranged is pre warmed to a temperature of 350 C in a broiler. Then the Magnesium (Mg) metal put inside a hardened steel cauldron and is accused and softened of the assistance of a high temperature heater which is set at a temperature of 800C. Skimming is completed within the sight of SF₆ and Ar gas to eliminate any material or particles that floats on the liquid Magnesium (Mg) surface. After the complete melting of pure Mg, 2 wt% of Sr is added to the molten Magnesium (Mg) in the stainless-steel crucible. Same process is repeated for other samples where Mg-2Sr will be kept constant as the base alloy and addition of 2 wt%, 4 wt%, 6 wt%, 8 wt% of Gadolinium (Gd) is carried out. The pre warmed die steel mold is taken out from the broiler. The liquid Mg compounds are filled the pre warmed form independently in a steady progression and casted utilizing gravity projecting strategy. Then these castings are permitted to chill off. After the projecting system the Mg-2Sr, Mg-2Sr-2Gd, 5Gd, 8Gd casted magnesium REE composite was cut into required size according to ASTM G133 02 norms.

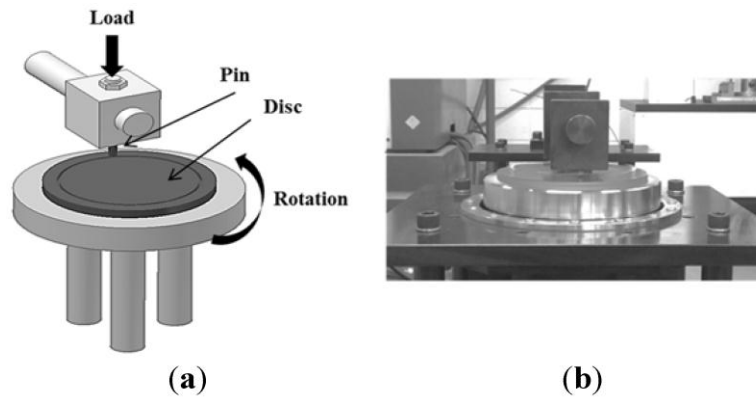


Fig. 4.11: Photograph of pin on disc experiment process
(Source: www.mdpi.com)

After the test, the tried examples were estimated utilizing a Taylor Hobson Form Talysurf with tip range of 2 μm to decide the surface unpleasantness and plentifulness boundaries of the reaching part of the pin and circle example. A miniature hardness analyzer (Matsuzawa MMT-7) was utilized to decide the hardness profiles of the pin and plate examples. The metallurgical microstructure of the pins was likewise analyzed to concentrate on the metallurgical contrast among AQ and M.

4.5 XRD ANALYSIS

An essential utilization of XRD examination is observing the recognizable proof of materials in light of their diffraction design as either precious stone example or nebulous example. As well as stage distinguishing proof, XRD likewise yields data on how the genuine construction goes amiss from the best one, attributable to inner anxieties and deformities. X-beams considers the precious stone standard cluster of particles as the floods of electromagnetic electron Crystal iota's disperse occurrence X-beams, basically through cooperation with the molecules' electrons. This peculiarity is known as the flexible dissipating and the electron called as disperse. A normal cluster of scatterers delivers an ordinary exhibit of round waves. In most of bearings, these waves counteract each other through horrendous obstruction, in any case, they add productively in a couple of explicit, not entirely set in stone by Bragg's regulation:

$$2d\sin\theta = n\lambda$$

In the Bragg's regulation, the d notices the dividing between diffracting planes, θ alludes to the $\{\displaystyle \theta\}$ is the point of episode, n alludes to a whole number, and λ is the bar frequency. The particular headings show up as spots on the diffraction design called reflections. Indeed, even the x-beam diffraction design subsequently results from electromagnetic waves impinging on a normal cluster of scatterers. The diffraction design are created by utilizing X-beam because of its frequency, λ , is in many cases a similar significant degree as the separating, d , between the precious stone planes (1-100 angstroms). X-beam diffract meters comprise of 3 essential components which are an example holder, a X beam locator, and X beam tube. by heating of a fibre to create electrons which promotes X beams in cathode beam tube, speeding up the electrons toward an objective by applying a voltage, and barraging the objective material with electrons. Whenever electrons have adequate energy to remove inward shell electrons of the objective material, trademark X-beam spectra are delivered. The natural arrangement of Mg-2Sr is 2 wt% of Sr and equilibrium wt% of Mg and comparatively the essential piece of Mg-2Sr-2Gd is 2 wt% of Sr, 2 wt% of Gd and equilibrium wt% of Mg. These Mg-2Sr and Mg-2Sr-2Gd magnesium amalgams are ready by gravity projecting cycle at Matrics materials examination and development driven arrangements Vellimalai, Tamilnadu. The steel kick the bucket form is pre warmed to 350 C in a stove. Unadulterated magnesium (Mg) metal is set in a treated steel cauldron which is charged and softened, at a heater temperature set at 800C. Skimming is completed utilizing Sulfur hexafluoride gas (SF6) gas and Ar gas to eliminate any undesirable material or particles that floats on the liquid Mg surface. After unadulterated Mg dissolves totally

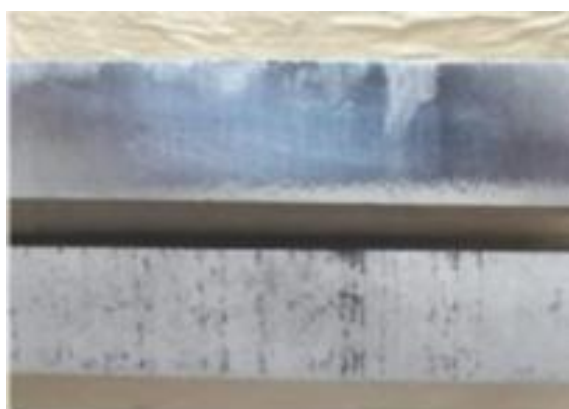


Fig. 4.12: Gravitational casted Mg-REE samples

Addition of 2% of strontium to Mg. by adding another 2% of gadolinium to the base alloy of Mg-2Sr the Mg-2Sr-2Gd alloy is created. From the Oven the pre heated mould is taken out. Using the gravity casting method the melted Mg-2Sr-2Gd and Mg-2Sr alloy which is poured in to pre heated mould separately. The samples alloy are cutted in to 10 mm 10 mm 3 mm at specific length by following the ASTM standard after the casting process. These are further polished and prepare the stage change of the Mg-2Sr and Mg-2Sr-2Gd magnesium REE composites were explored with the X-Ray diffraction to track down the stage change. XRD was performed on the magnesium REE composites example utilizing a Bruker D2 phaser X-Ray diffract meter with Cu ka radiation.

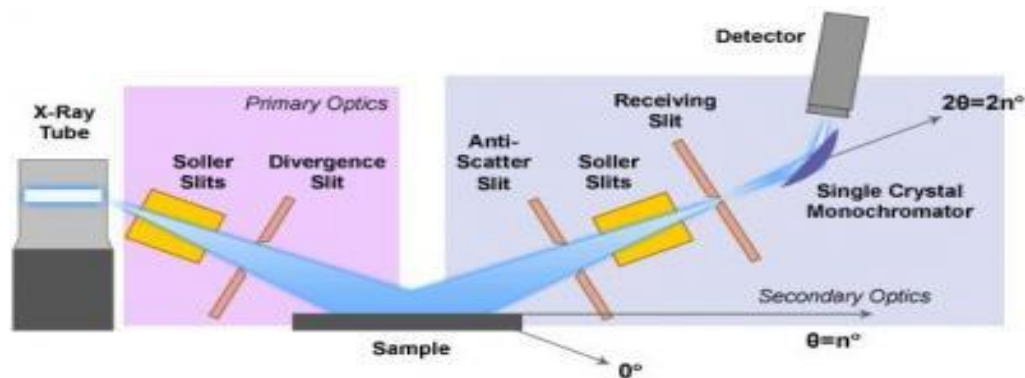


Fig. 4.13: Photograph explains the process of XRD
(Source: material properties.com)

The x-ray from x-ray tube passes through the two slits named soller slits and divergence slits and then falls on sample on sample holder. Then the fallen ray reflect at certain angle. The reflected ray passes through three different slits anti scatter slit, soller slit, receiving slit. The X-ray after passing these three slits it falls and reflects on single crystal monochromatic crystal and detected by an detector.

CHAPTER 5

RESULT AND DISSCUSION

As per the ASTM G133 02 standards the wear experiments tests has been carried out for the wear analysis and performance. To perform these test the weight 20Kg and 40Kg (20N and 40N) has been applied for the test. By adding the different specific weight of gadolinium (Gd) to the prepared base alloy Mg-2Sr, we can infer that there is wear rate reduction. In the application of 20N load the wear rate is more when compare to the application of 40N to the base alloy. The combination alloy Mg-2Sr-8Gd has come out with lowest percentage that 0.12 and 0.17 by the addition of 20N and 40N load to the base alloy. In the research work of Guohua Wu et al., (2017), inferred the similar result as got now.

It is also inferred that there is a decrease in the percentage of wear rate of Mg-2Sr by the increase of load from 20N to 40N. It is found that there is a massive rugged groves are formed which makes the wear surface rough due to leading the mechanism to lower the coefficient of friction while adding the load of 20N.

It also observed that there is an increase in friction contact area due to the apply of higher loads which may cause surface asperities due to the formation of rugged groves in worm surface. Due to the plastic deformation at the higher load apply of 40N the surface is smoothly leading to the lowering of coefficient of friction.

The co efficient of friction get reduced due to the formation of region of large oxidation at the top of the surface. The frictional pair contacts and protection at the top surface are reduced by the formation of large oxide layers. During the wear mechanism the friction heat is produced which affects the coefficient of friction and wear rate. The magnesium strontium rare earth micro alloys has some variations which are represented by graph.

5.1 EFFECT OF WEAR RATE WEAR RESISTANCE AND COEFFICIENT OF FRICTION IN Mg-2Sr-2Gd ALLOY WITH 20N AND 40N

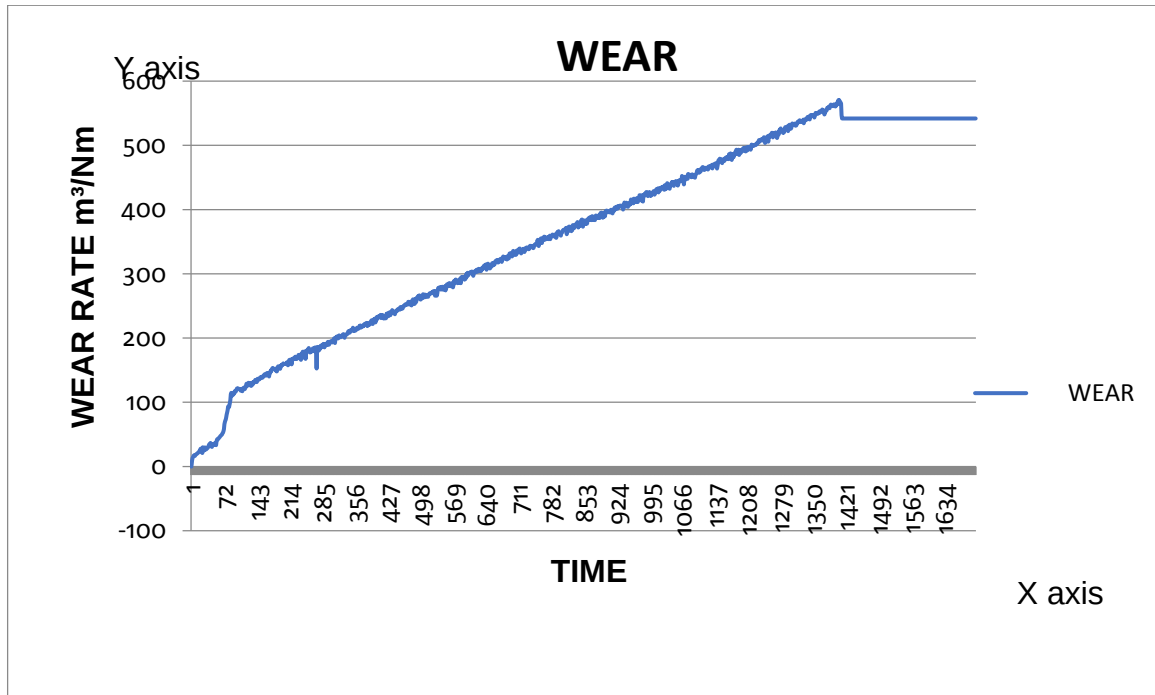


Fig. 5.1: Graph of wear rate of Mg-2Sr -2Gd alloy with 20N

The values of Mg-2Sr-2Gd alloy with base alloy of Mg-2Sr of wear test are shown by graph above. From the above graph we can clearly see that 28% reduction in the wear rate with 20N load. The wear rate from the graph starts from 0% and gradually increases upto 28% and a sudden drop at 28% and goes down to 26%, from there no further increase in wear rate and travel along the x-axis. It is evident from the wear results that due to addition of gadolinium the wear rate reduces. From the graph, When the Gadolinium percentage increases then there is a subsequent reduction in the wear rate. By the proportion of Gd the wear rate decreases.

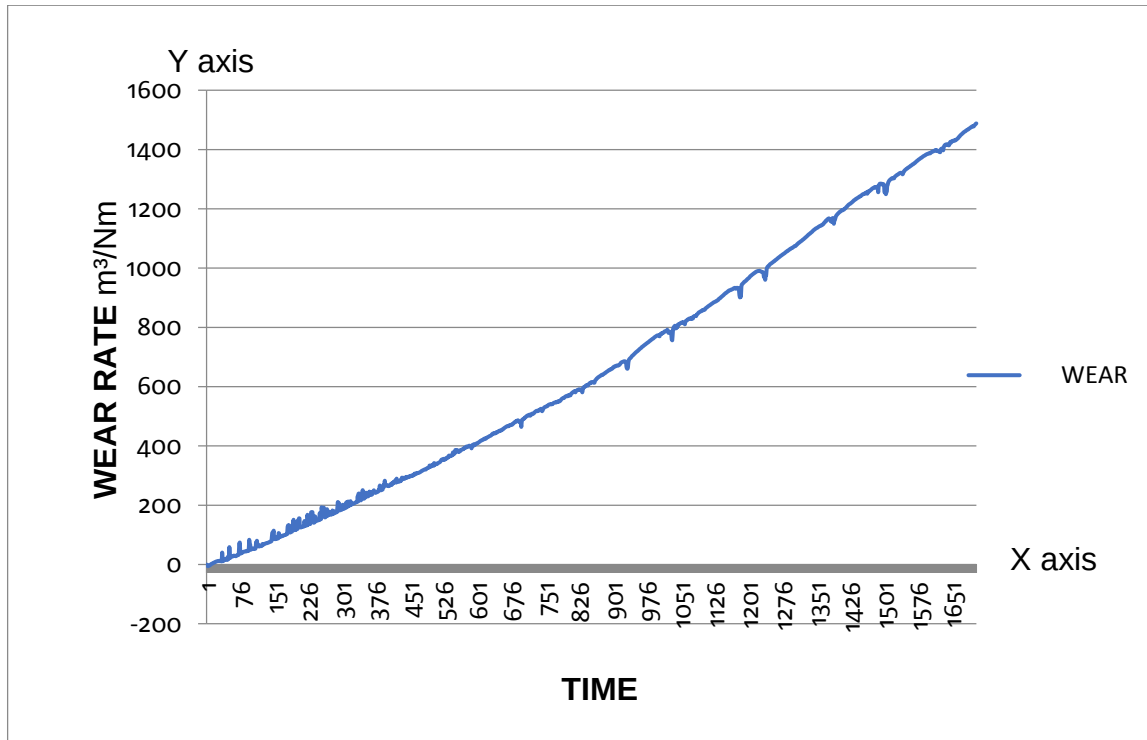


Fig. 5.2: Graph of wear rate of Mg-2Sr -2Gd alloy with 40N

The values of Mg-2Sr-2Gd alloy with base alloy of Mg-2Sr of wear test with 40N are shown by graph above. . From the above graph we can clearly see that 35% reduction in the wear rate with 40N load. The wear rate from the graph starts from 0% and gradually increases up to 38% and there is no drop at the graph line. When compared to Mg-2Sr-2Gd alloy with 20N the addition of load of 40N load resulted in increase of wear rate up to 10%. From the graph it is inferred that the wear rate subsequently reduced.

But still the wear resistance shows improvement in addition of Gd to the base alloys of Mg-2Sr.

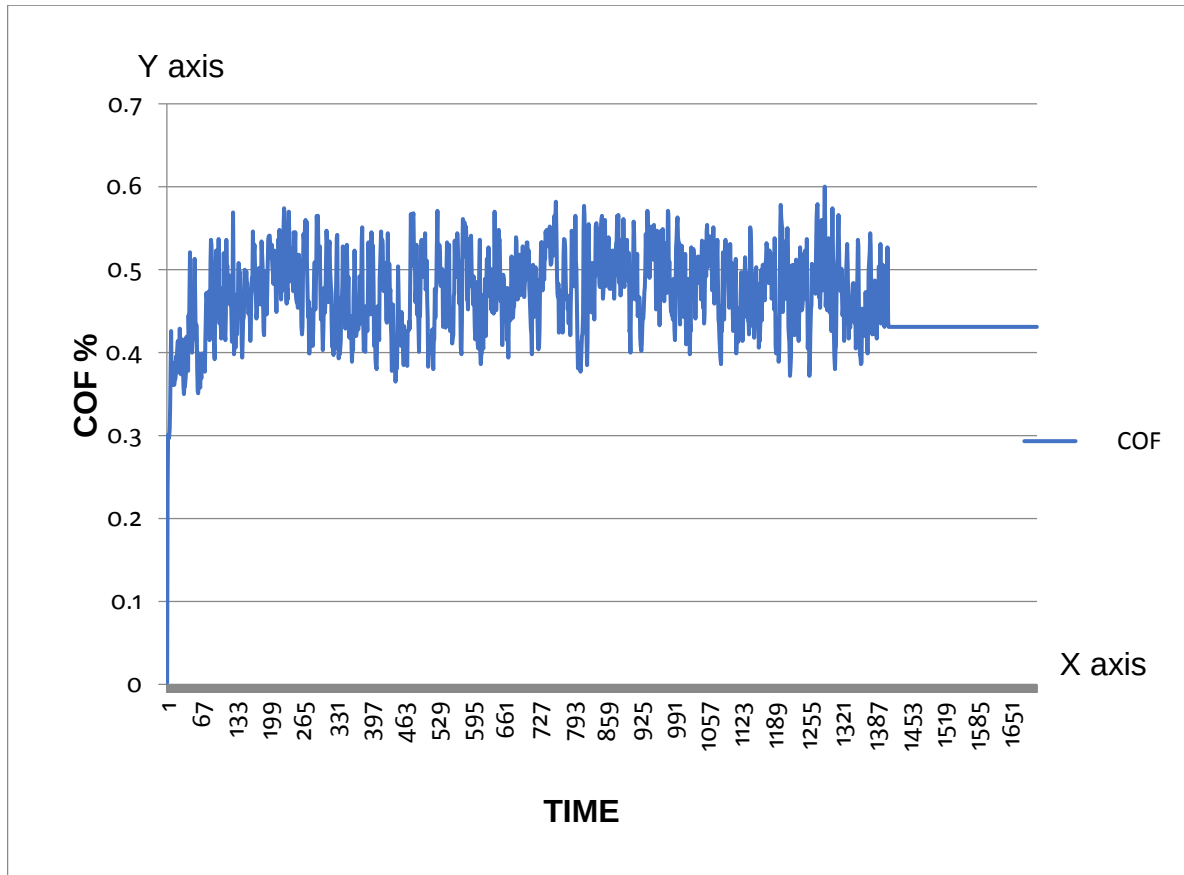


Fig. 5.3: Graph of coefficient friction of Mg-2Sr-2Gd alloy with 20N

The values of coefficient of friction of Mg-2Sr-2Gd alloy with base alloy of Mg-2Sr of wear test with 20N are shown by the graph above.

Co-efficient of friction effect At 20 N load the coefficient of friction gradually increases. From the above graph we can find that by adding gadolinium to the base alloy of Mg-2Sr the coefficient of friction significantly increase. Jie Zhang et al. (2016) in his research work found the similar results which we got. There is a maximum increase in COF values of alloy up to 25% and then moves on horizontally along the xaxis with random variations in between 20% and 30%. The coefficient of friction of this wear tested alloy amount is clearly seen when the amount od Gd is added to the base alloy.

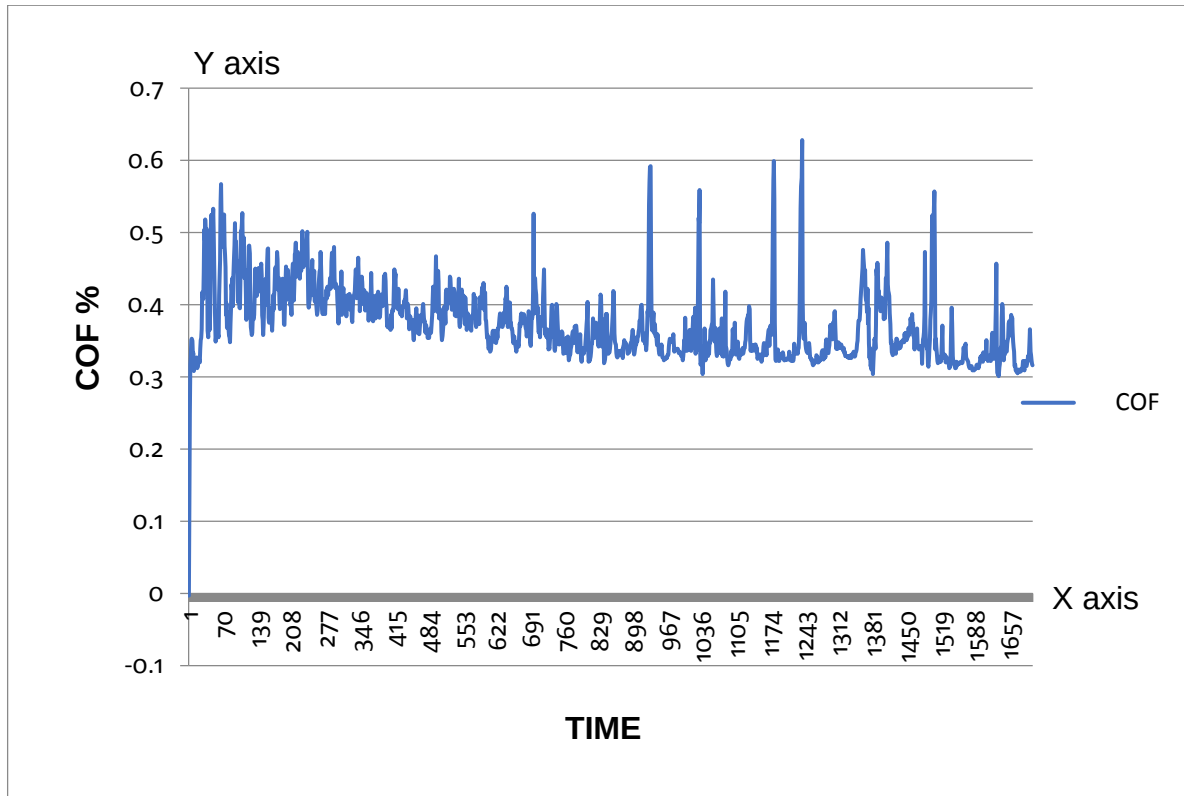


Fig. 5.4: Graph of coefficient of friction of Mg-2Sr-2Gd alloy with 40N

The values of coefficient of friction of Mg-2Sr-2Gd alloy with base alloy of Mg-2Sr of wear test with 40N are shown by the graph above.

The friction coefficient effect at 40 N load the coefficient of friction gradually increases. From the above graph we can infer that there is a varying of increase and decrease upon adding Gd to Mg-2Sr base alloy with 40N. Deepak (2021) in his research got the similar results.

At first there is gradual increase from 0% to 25% and it moves along the xaxis. In the horizontal movement there is rapid variation of increasing and decreasing in coefficient percentage, in that variation the increased up to 30% and above.

5.2 EFFECT OF WEAR RATE WEAR RESISTANCE AND COEFFICIENT OF FRICTION IN Mg-2Sr-5Gd ALLOY WITH 20N AND 40N

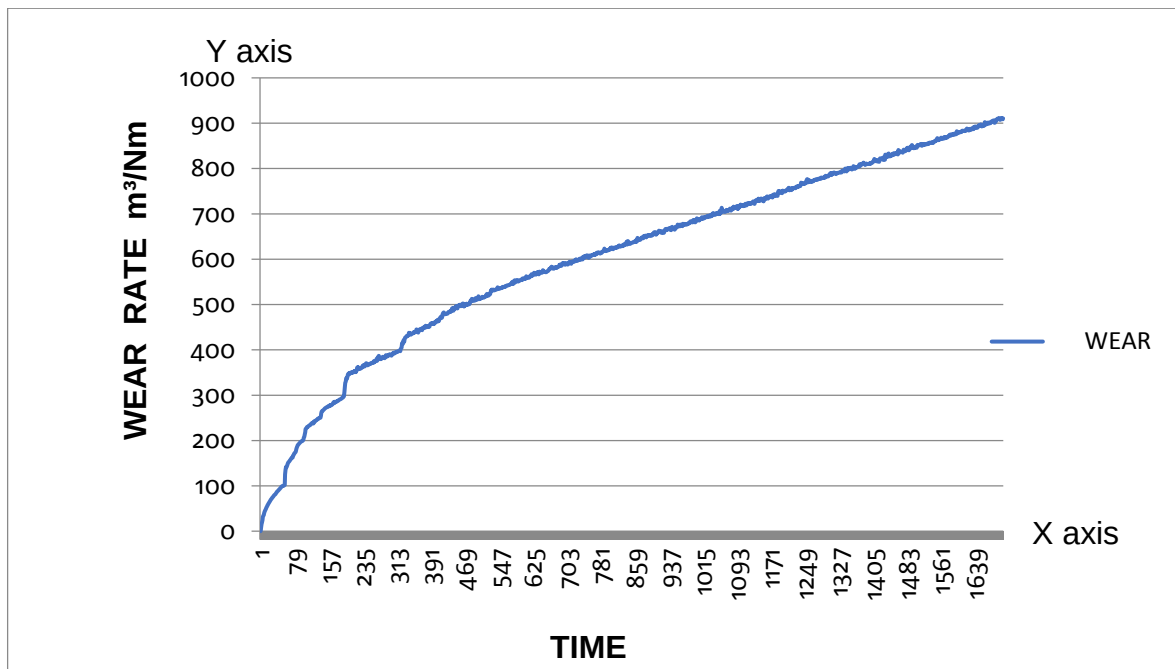


Fig. 5.5: Graph of wear rate of Mg-2Sr-5Gd with 20N

The values of Mg-2Sr-5Gd alloy with base alloy of Mg-2Sr of wear test with 20N are shown by graph above.

From the above graph it shows that the the wear line goes upto 45%. This improvement is due to addition of large amount (5Gd) when compared to previous prepared alloy. The wear resistance

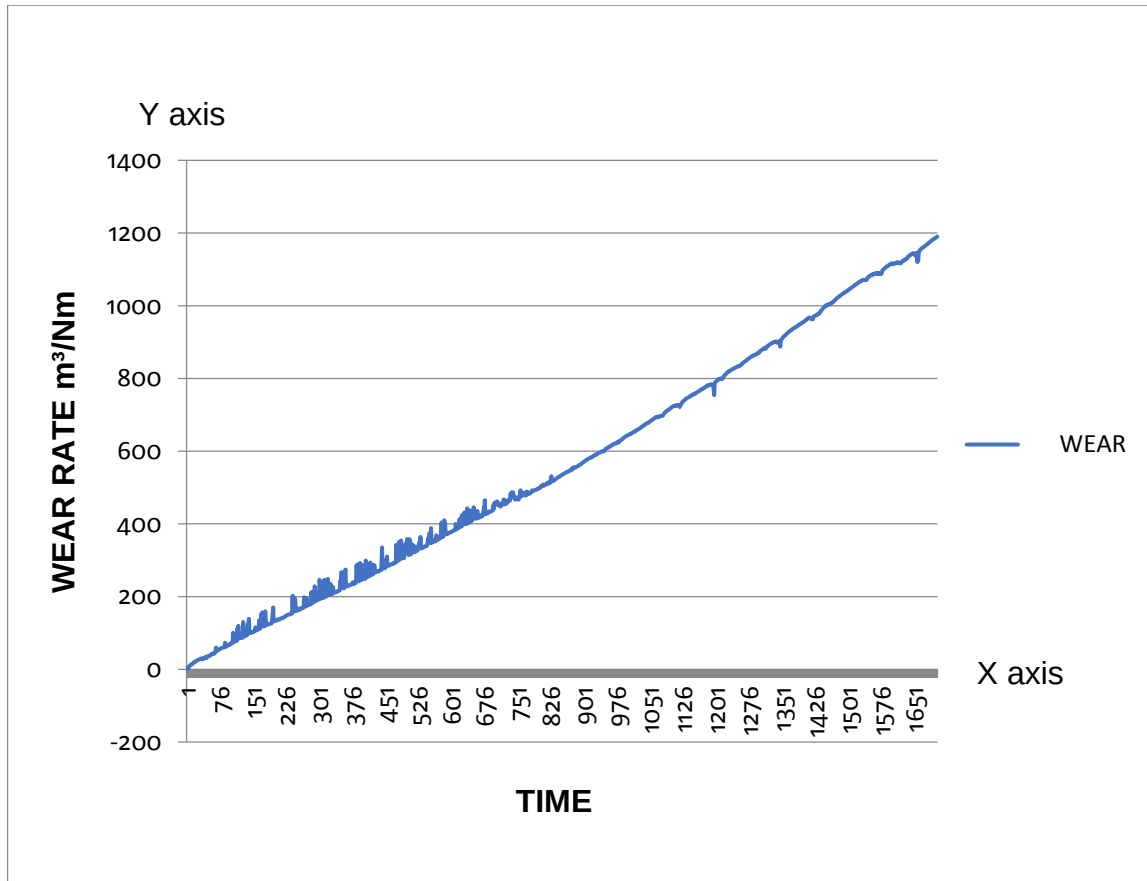


Fig. 5.6: Graph of wear rate of Mg-2Sr-5Gd with 40N

The values of Mg-2Sr-5Gd alloy with base alloy of Mg-2Sr of wear test with 40N are shown by graph above.

From the above graph it shows that there is increased in the wear rate when compared the previous graph that is from 45% to 60%.

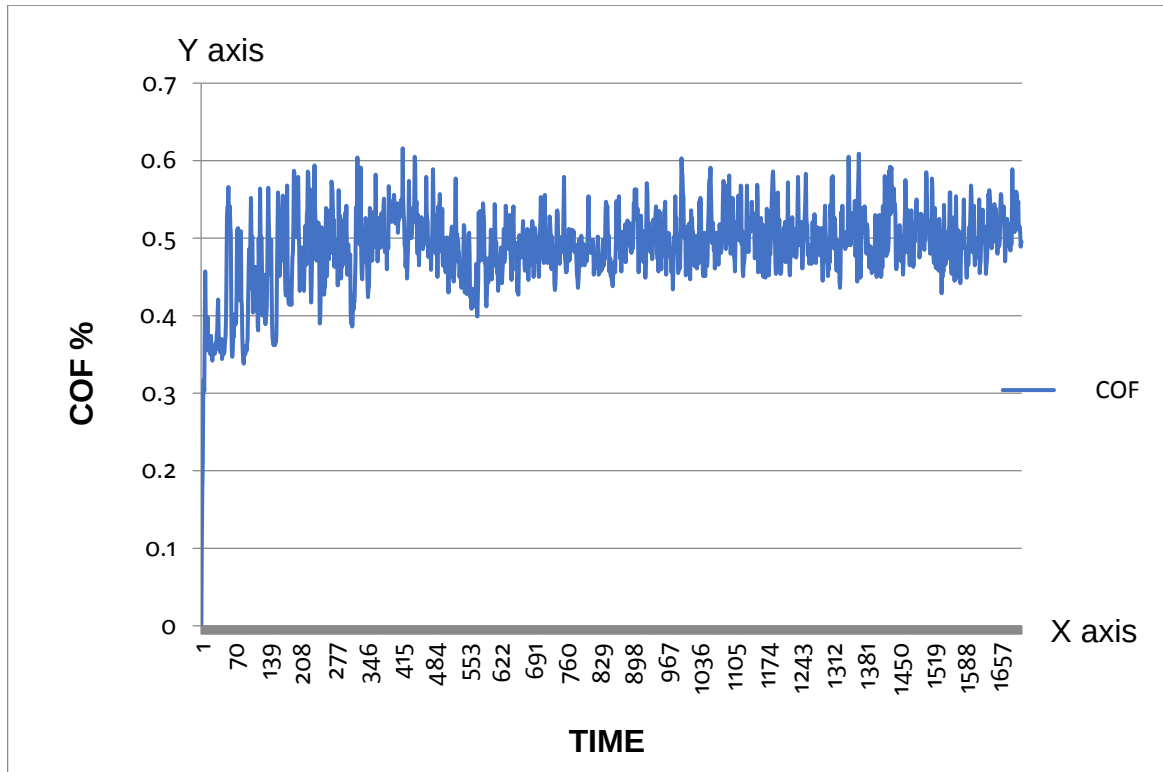


Fig. 5.7: Graph coefficient of friction of Mg-2Sr-5Gd alloy with 20N

The values of coefficient of friction of Mg-2Sr-5Gd alloy with base alloy of Mg-2Sr of wear test with 20N are shown by the graph above.

The Co-efficient of friction effect At 20 N load there is a gradual increase in Co-efficient of friction. From the above graph we the addition of Gd to the Mg-2Sr base alloy the COF value significantly increases. The coefficient values from 0% and goes up to 20%, and from that 20% the values rapidly vary between 20% and 30%

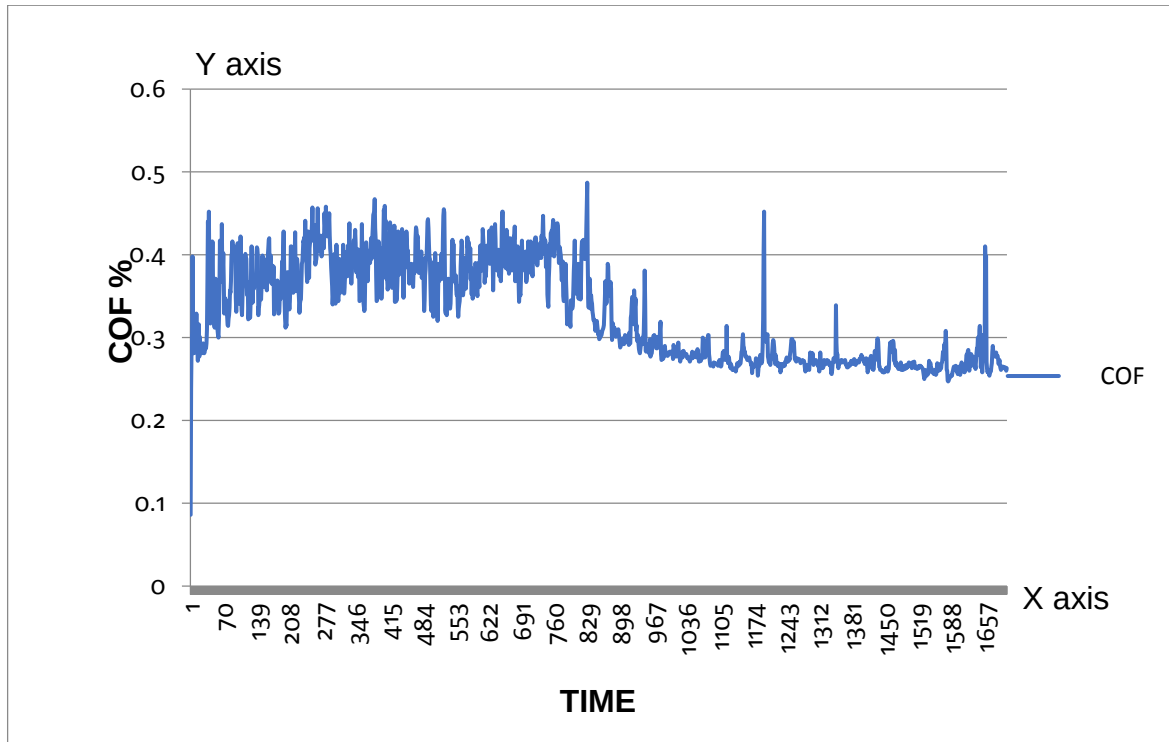


Fig. 5.8: Graph of coefficient of friction of Mg-2Sr-5Gd alloy with 40N

The values of coefficient of friction of Mg-2Sr-5Gd alloy with base alloy of Mg-2Sr of wear test with 40N are shown by the graph above.

The Co-efficient of friction effect At 40 N load there is a slight decrease in Co-efficient of friction. From the above graph we can infer that adding of Gd to base alloy of Mg-2Sr the COF increases the coefficient of friction values starts from 0% to 20%, and from the 20% it starts varies from 20% to 30%, and the variation line as usual in the previous graphs travels along the x axis and slightly decrease and goes down up to the range between 10% to 15%.

5.3 EFFECT OF WEAR RATE WEAR RESISTANCE AND COEFFICIENT OF FRICTION IN Mg-2Sr-8Gd ALLOY WITH 20N AND 40N

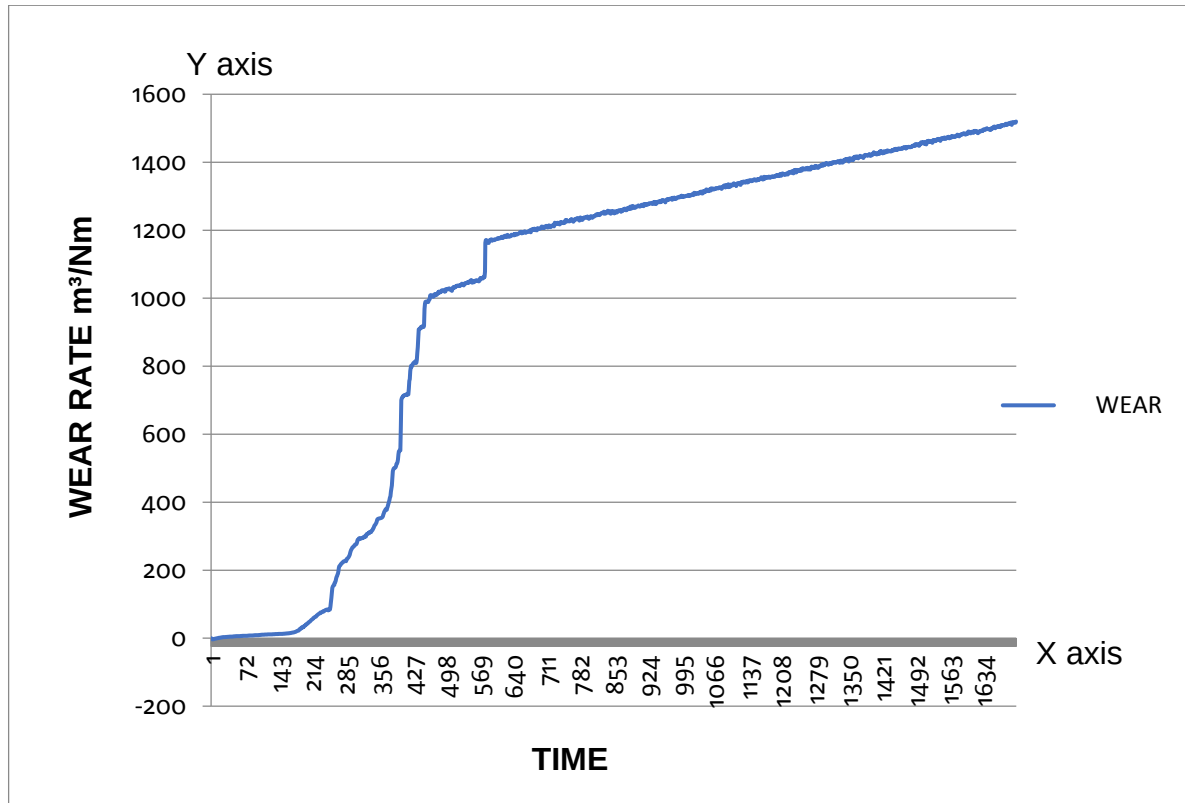


Fig. 5.9: Graph of wear rate of Mg-2Sr-8Gd alloy with 20N

The values of Mg-2Sr-5Gd alloy with base alloy of Mg-2Sr of wear test with 20N are shown by graph above. From the above graph it is shown that there is gradual increase in wear rate when compared to other casted alloys in before, goes up to 75%. This is an rapid improvement of wear rate and occurred due to addition the specific amount of Gd.

The wear line starts from 0% and rapidly increases goes up 50% , from 50% again with some variations goes for 60% upto 75%.

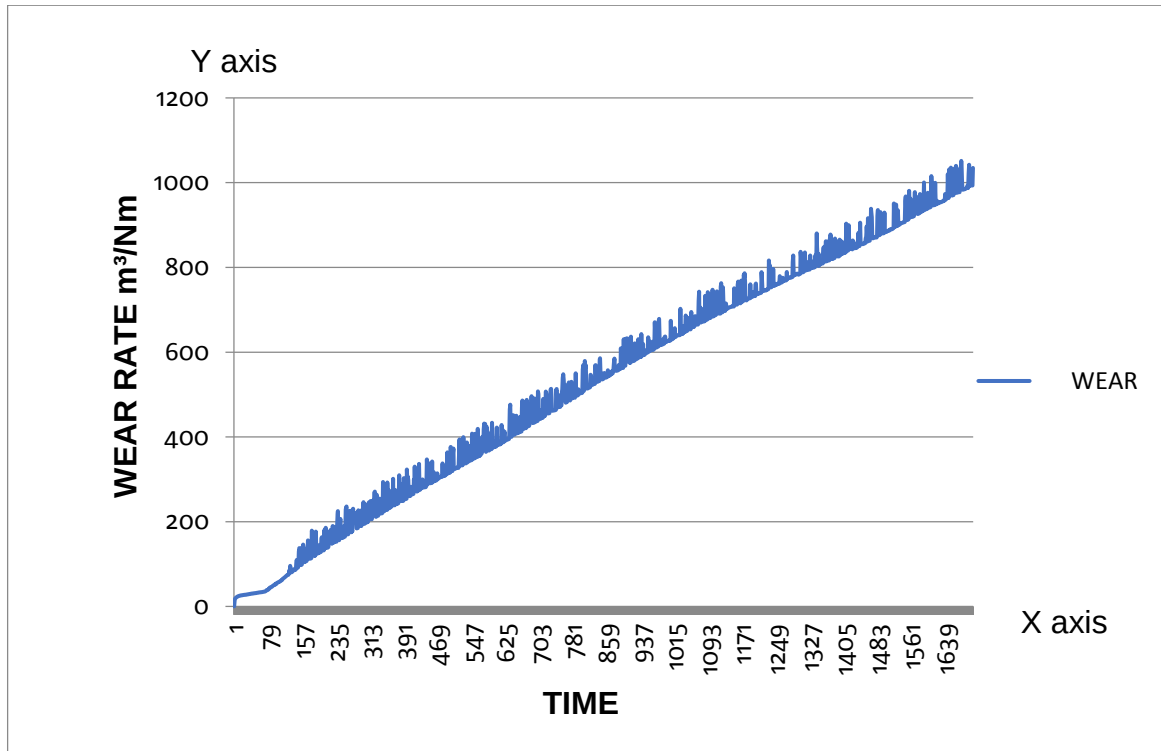


Fig. 5.10: Graph of wear rate of Mg-2Sr-8Gd alloy with 40N

The values of Mg-2Sr-8Gd alloy with base alloy of Mg-2Sr of wear test with 40N are shown by graph above. From the above graph it is shown that the wear rate is goes up to 52%. When compared to the same casted alloy with 20N it shows that there is decrease in wear rate from 75% to 52%. It shows that with increase of load and increase specific amount of Gd the wear rate decreases.

The wear graph line starts from 0% to 52% with rapid increase of wear rate. While increase in wear graph line there are lot of rapid variation which looks like frequency line.

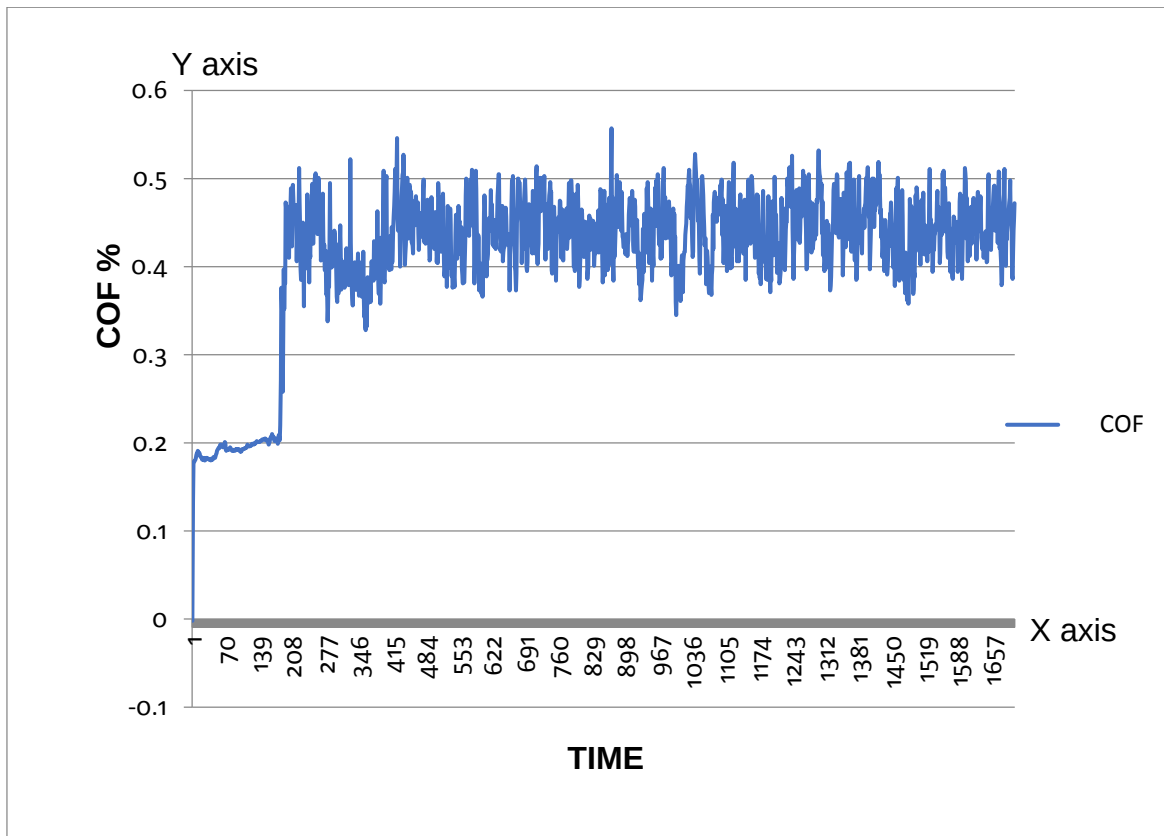


Fig. 5.11: Graph of coefficient rate of friction of Mg-2Sr-8Gd alloy with 20N

The values of coefficient of friction of Mg-2Sr-8Gd alloy with base alloy of Mg-2Sr of wear test with 20N is shown by the graph above. The effect of coefficient of friction at 20N there is an increase which goes up to 25%. From the graph it is inferred that the COF values starts from 0% and goes up to 10% from there with some slight variation it moves up to 25% and then then the COF value graph line moves along x axis with rapid and many variations .

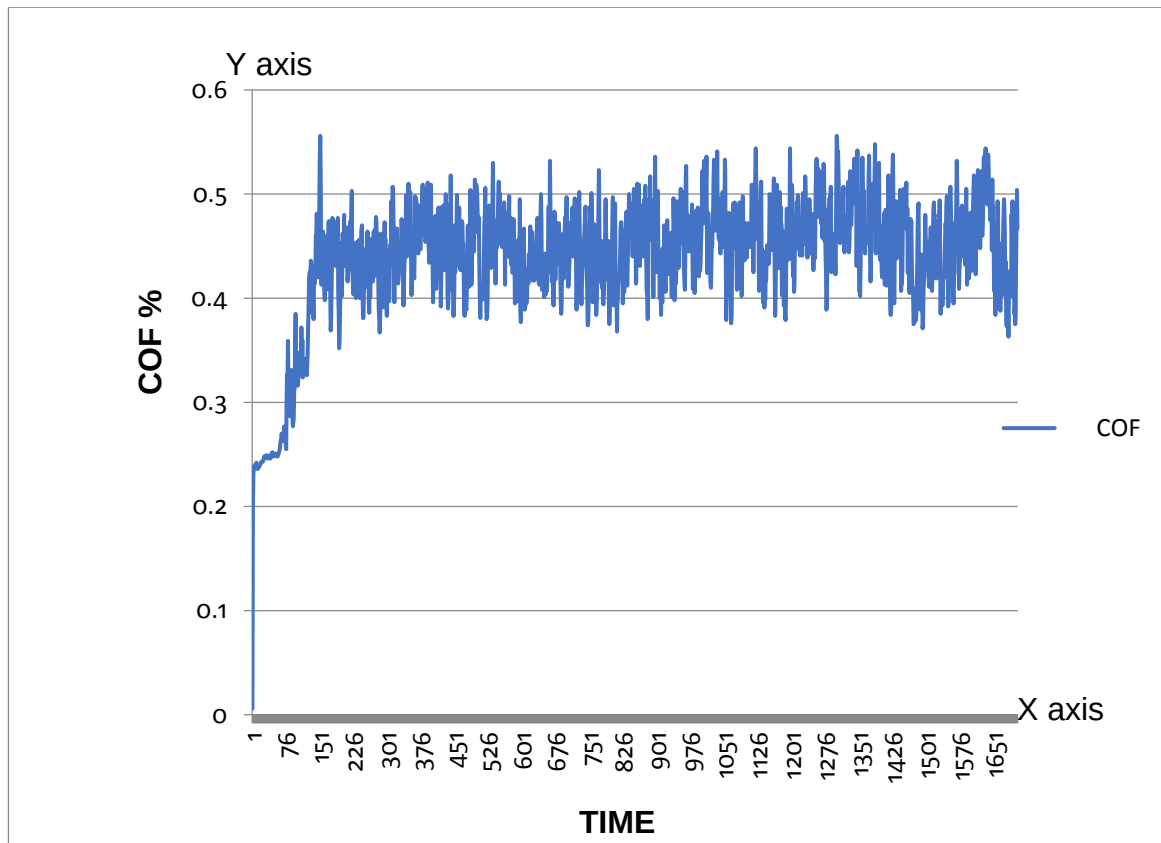


Fig. 5.12: Graph of coefficient rate of friction of Mg-2Sr-8Gd alloy with 40N

The values of coefficient of friction of Mg-2Sr-8Gd alloy with base alloy of Mg-2Sr of wear test with 40N is shown by the graph above.

From the above COF graph it is inferred that the values of coefficient of graph goes up to above 25% and below 30%. When compared to the previous graph of same casted alloy with 20N it said that both the graph are looks same. More over it has some minoe variations still looks both are almost the same.

5.4 EXPERIMENTAL RESULTS OF XRD ANALYSIS OF Mg-2Sr-2Gd WITH THE BASE ALLOY OF Mg-2Sr

A81 (Coupled TwoTheta/Theta)

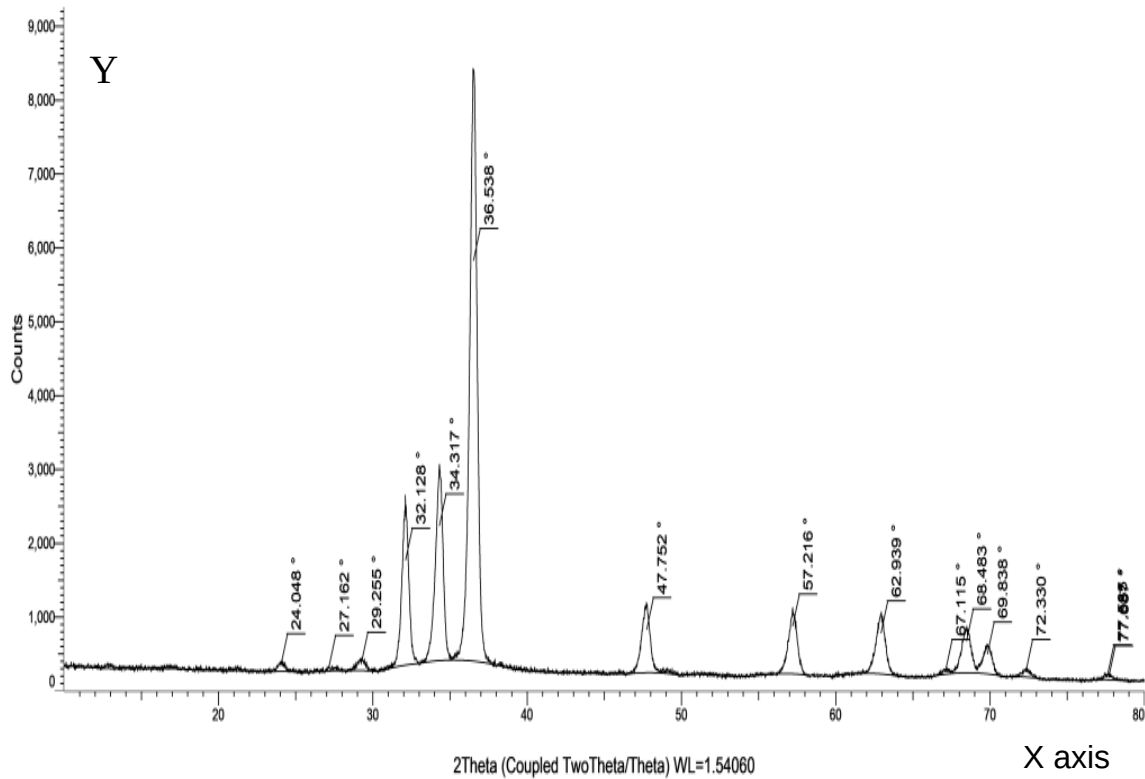


Fig. 5.13: Graph of XRD analysis of Mg-2Sr-2Gd alloy

The sample Mg-2Sr-2Gd have been tested by the XRD analyzer by considering 10.002° to 80.010° as a angle range. Which has been investigated under room temperature. 5432.28 are the observed maximum intensity at the 36.538° and 34.0288 are the minimum intensity observed at the angle of 77.687°. From the XRD graph at the high intensity point the crystalline nature is observed and at the low intensity point the amorphous nature in found.

5.5 EXPERIMENTAL RESULTS OF XRD ANALYSIS OF Mg-2Sr-5Gd WITH THE BASE ALLOY OF Mg-2Sr

A85 (Coupled TwoTheta/Theta)

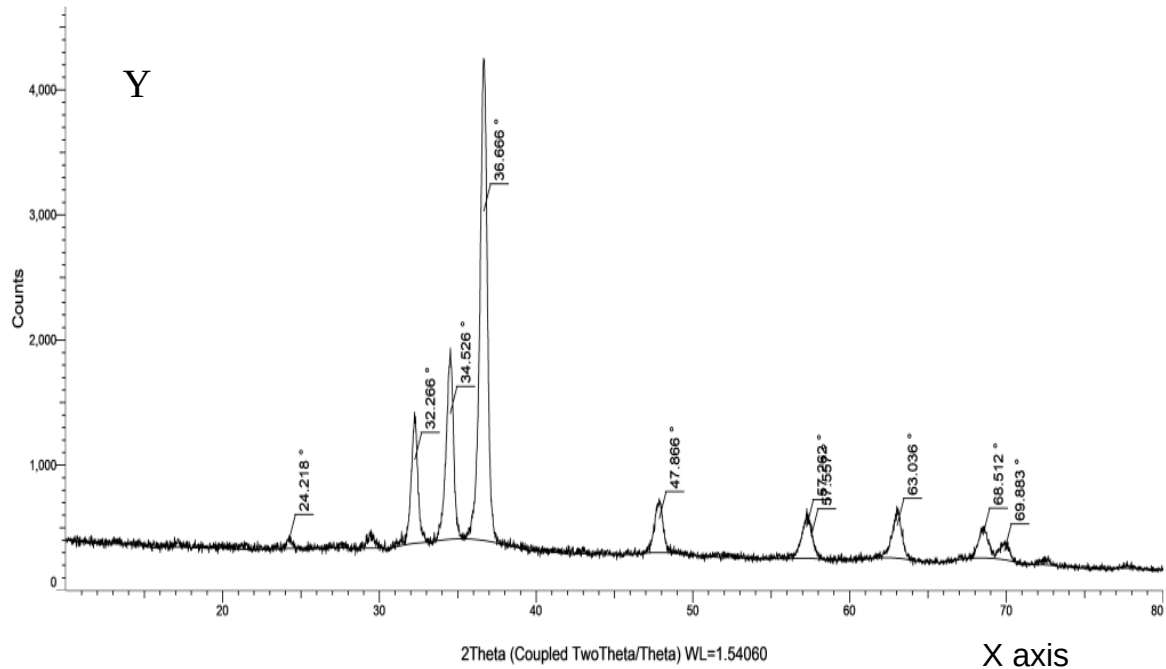


Fig. 5.14: Graph of XRD analysis of Mg-2Sr-5Gd alloy

Under the room temperature the sample Mg-2Sr-5Gd sample is tested by the XRD analyze. At the 36.666° the samples maximum intensity is observed and at the 69.883° the samples minimum intensity is observed.

For our naked eye the graph may appear similar but there will be small amount of deviations in the angle and the peak movements. The high intensity peak indicates the crystalline nature and low intensity peak indicates the amorphous nature.

5.6 EXPERIMENTAL RESULTS OF XRD ANALYSIS OF Mg-2Sr-8Gd WITH THE BASE ALLOY OF Mg-2Sr

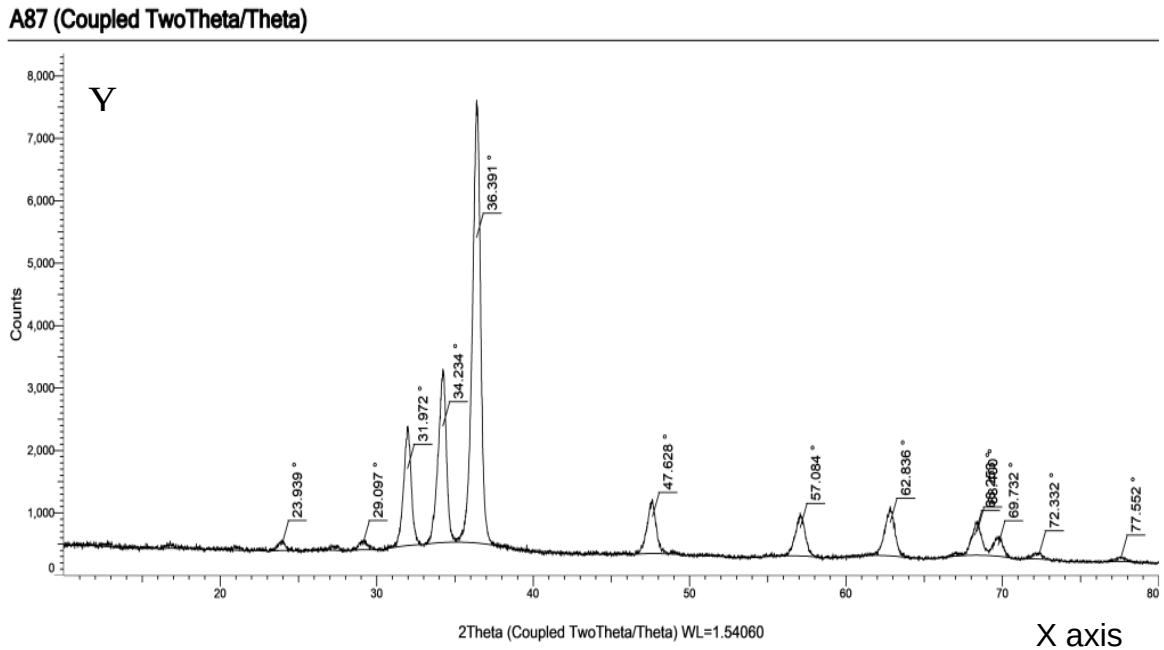


Fig. 5.15: Graph of XRD analysis of Mg-2Sr-8Gd alloy

The sample Mg-2Sr-8Gd alloy was tested with XRD analyzer with the angle range of 10.002° to 80.010° which was conducted under room temperature. At 36.391° the maximum intensity is observed and at 77.552° minimum intensity is observed. More over the results may look same but there will be small amount of deviation is occurred due to addition of specific amount of Gadolinium. The high intensity peak refers the crystal nature and the low intensity peak refers the amorphous nature.

CHAPTER 6

SUMMARY AND CONCLUSION

- With the addition of gadolinium to the base alloy of Mg-2Sr the wear resistance percentage increases significantly. From the results and graph we can infer that, under 20N loads the Mg-2Sr-8Gd has the 75% increase in wear resistance with respect to the base alloy of Mg-2Sr. However, at 40 N load there is only 52% increase in wear resistance. Under 20 N, 40 N loads, Mg-2Sr-8Gd has the highest wear resistance which confirms that when higher wt. The wear resistance increases by adding of gadolinium to the base alloy of Mg-2sr. due to the thick layer formation at the top surface the wear resistance increases.
- The size of grain refinement of Mg-Sr-Gd REE alloy it is related to the wear reduction. The refinement and altering of grain size is done by adding strontium. At the worn surface the dominant mechanism at the higher load was confirmed. This is due to a mixed abrasion and delamination wear mechanism. The adhesion wear occurs at the 20N load and 40N at it occurs in higher, for wear mechanism the plastic deformation is a contributing factor. As a result in increase of micro hardness and grain refinement which leads to improve the tribological properties due to addition of strontium which observed the inter metallic phase.
- Due to thick hardening layer which forms on the top of the surface the wear resistance is improved. Due to the addition of strontium which results in increase of micro hardness and grain refinement where inter metallic phase is observed. By decreasing the wear rate the addition of Gadolinium increases the wear resistance. The wear property of base

alloy Mg-2Sr is improved significantly by adding the gadolinium increases from 2% to 8%.

- In XRD analysis at the angle 36.593° where the maximum intensity peak is formed where the crystal structure of hexagonal packed Mg is observed. In the XRD peak patterns it is observed that in Mg-2Sr-2Gd there is no existence of second phase. The reduction of intensity of alpha Mg peaks due to the addition, which leads to the betterment of the metallurgical properties and mechanical properties.
- The Mg-2Sr-2Gd alloy has low crystalline nature when compared to Mg-2Sr alloy. The d spacing of Mg-2Sr-2Gd alloy is 2.45729 and the d spacing of Mg-Sr alloy is 2.45368. It is observed that there is relationship between d value and grain size due to the increase of d space value and decrease in grain size. The grain size of pure alpha Mg is 35 ± 10 nm. The grain size is reduced to 23.9 ± 8.3 nm by the addition of strontium. The grain size is furtherly reduced to 20.5 ± 7 nm by adding gadolinium to the Mg-2Sr to create Mg-2Sr-2Gd.

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