CHAPTER 1

INTRODUCTION

This chapter includes background of magnesium alloys and their needs in different sectors. Additionally, the motivation for this research work is discussed, followed by the organization of the thesis. This research is motivated by the increasing demand for magnesium alloys in various engineering fields by cast route.

1.1 Background

Over the past few years, magnesium alloys have attracted a lot of attention due to their excellent combination of properties like excellent strength to weight ratio, high specific strength (35-260 kNm/kg), stiffness (21-29 MNm/kg), good fatigue and impact strengths, large hydrogen storage capacity, relatively large thermal and electrical conductivities, castability and weldability under controlled atmospheres. It is an outstanding structural material because of above mentioned properties. [1–13] Magnesium alloys are widely employed in engineering design across industries due to their advantageous properties, such as their affordability, low density (1.74 g/cm^3), and excellent machinability. These alloys find applications in automotive, aerospace, electronics, consumer goods, and medical sectors, benefiting from their high strength-to-weight ratio, which provides structural integrity while minimizing overall weight. Notably, magnesium stands out as the lightest structural metal with a specific gravity of 1.74, weighing approximately 0.064 to 0.067 pound per cubic inch (1.74 to 1.85 g/cc). In comparison, aluminum alloys weigh about 0.091 to 0.108 pound (2.5 to 3.0 g/cc), while steel weighs 0.283 pound (7.8 g/cc). These factors collectively contribute to the widespread adoption of magnesium alloys, driven by their excellent strength-to-weight ratios, machinability, and cost-effectiveness. [13–17] Mg is also good substitute for iron and aluminum in applications where damping resistance is important. [18]

According to Globe Newswire, demand for magnesium increased sharply in 2021 at automotive and electronics sectors. Magnesium metal is used specifically in the automotive industry to manufacture components such as steering wheels, transmission cases, seat frames and car bodies. It is also used in electronics for heat dissipation systems, television and computer cases, and other applications. According to OICA, 43,99,112 automobiles were produced in India in 2021, a 30% increase from the 33,94,446 vehicles produced in 2020. In the next 20 years, the Chinese airline corporations intend to invest around USD 1.2 trillion in the purchase of 7,690 new aircraft. The demand for high-strength and light-weight vehicles and aircraft is increasing day by day. Due to all these factors, the metallic magnesium market is expected to expand globally during the forecast period 2022-2027. [19–21]

Presently, cast magnesium alloys and deformed magnesium alloys are the most often utilised magnesium alloys. However, majority of the market is covered by cast products. During casting, refining and purifying steps are most important to get high quality Mg alloys. During these steps, metal and non-metal impurities and gases are removed by fluxing or fluxless process. [22, 23]

1.2 Motivation of Present work

As per the literature, a major challenge for the designer of the 21st century is to design and develop lightweight and energy-efficient materials. Magnesium can substitute steel, aluminum alloys, and plastics. However, molten magnesium is extremely susceptible to oxidation so melt-protection during melting and alloying are necessary. Molten magnesium is protected by the flux process and flux-less process. Both processes have their merits and demerits but due to the environmental and cost factors fluxing technique is still used in many foundries. In the fluxing process, melt loss and the presence of inclusions is the major problem. To overcome this problem, nine magnesium melting and refining fluxes were studied in this research. Dow fluxes compositions were taken as a base to prepare five fluxes and another four fluxes were developed by varying chlorides, fluorides, and oxide content.

Magnesium alloys are used in numerous applications due to their unique characteristics but their poor strength and corrosion resistance property (compare to aluminum alloys) limits their use particularly outdoors. To improve little strength, and corrosion resistance and lower the iron (Fe) impurity in many magnesium alloys, manganese is added as an alloying element. However, its solubility in magnesium is less than 1% at 482 °C and 2.2% at 653°C temperature only. There is not enough literature available to increase the recovery of manganese in magnesium and its alloys. Present research work includes how to increase manganese recovery in pure magnesium metal.

In most of the literature, it is commonly reported that the presence of iron, copper, and nickel in magnesium and its alloys tends to increase the corrosion rate. To improve corrosion resistance, it is crucial to keep the concentrations of these elements below a specific threshold. Among these elements, copper has a particularly negative influence on corrosion resistance as it exhibits less solid solubility in magnesium. When copper combines with magnesium, it forms an intermetallic compound known as Mg_2Cu. Similarly, the solid solubility of nickel in magnesium is also limited. When nickel is incorporated into magnesium, it leads to the formation of the intermetallic compound Mg_2Ni. It has been observed that exceeding certain concentrations of copper and nickel can have detrimental effects on both corrosion resistance and ductility. Specifically, if the copper concentration exceeds 0.05 wt. % and the nickel concentration goes above 0.004 wt. %, it significantly reduces both corrosion resistance and ductility of magnesium alloys.

However, there have been relatively few studies that have specifically investigated the impact of copper and nickel on the mechanical properties of magnesium alloys. To address this research gap, the present study aims to explore the effects of varying amounts of copper and nickel on the microstructure, mechanical properties, and corrosion behaviour of magnesium alloys. Considering the known influence of copper on high-temperature strength and overall mechanical properties, as well as the potential impact of nickel on yield strength and ultimate tensile strength, investigating their effects in combination with manganese becomes particularly relevant.

1.3 Problem Statements

The present research work addresses the following problems:

1. **Fluxing Process Optimization:** The fluxing process used in magnesium melting and alloying leads to significant melt loss and the presence of inclusions. Therefore, the research focus on developing improved flux compositions that effectively minimize melt loss and improve the overall quality of magnesium alloys.

2. **Manganese Recovery in Magnesium Alloys:** The solubility of manganese in magnesium is limited, affecting the strength, corrosion resistance, and iron impurity levels in magnesium alloys. The objective is to explore methods that can effectively increase the recovery of manganese in pure magnesium metal, aiming to improve the alloy's properties.

3. **Effect of Manganese on Mg-Cu and Mg-Ni Alloys:** Limited research has been conducted on the specific effects of manganese on the microstructure, mechanical properties, and corrosion behavior of Mg-Cu and Mg-Ni alloy. Therefore, the objective

of this study is to address this research gap by exploring the influence of manganese in combination with copper and nickel on the aspects of these alloys.

1.4 Thesis Outline

The main objective of the present study is to develop the best magnesium melting flux and use this flux to develop various Mg-Mn, Mg-Cu-Mn and Mg-Ni-Mn alloys and study their microstructure, mechanical properties and corrosion behaviour. This research work is divided into the following chapters of the dissertation.

Chapter 1: Introduction

It includes the background of magnesium alloys and their needs in different sectors. Additionally, the motivation for this research work and organization of the thesis are discussed.

Chapter 2: Literature Survey

This chapter contains an introduction to magnesium, the development of its alloys, and the impact of alloying elements on the characteristics of magnesium alloys. Fluxless and fluxing techniques for melting magnesium are covered in this chapter. Additionally, thorough investigations on Mg-Mn alloys, Mg-Cu alloys, and Mg-Ni alloys have been also added. Furthermore, based on the literature review, the study's objectives and research gap are explained.

Chapter 3: Experimental Work

The experimental work used in the current research is included in this chapter. It includes an experimental work plan, details of developed fluxes, alloys and experimental set-up used. This research work is divided into five parts.

Part I: Develop the magnesium melting fluxes and identify the best among them
Part II: Effect of addition of various manganese sources on magnesium metal
Part III: Effect of temperature on solubility of manganese in magnesium
Part IV: Develop and study the Mg-Cu and Mg-Cu-Mn (CM) alloys
Part V: Develop and study the Mg-Ni and Mg-Ni-Mn (NM) alloys

All the steps and practises followed in above five parts are covered. At the end, characterization include microstructure, mechanical properties, and corrosion behaviour of developed alloys. Based on the objectives of the research work, the experimental results and their discussion are given in Chapters 4.

Chapter 4: Results & Discussion

It includes the results and discussions that follow for all parts. In Part 1, TG/DTA analysis of all fluxes, macro, and micro-observation of surface layer of magnesium, effect of fluxes on mechanical properties of magnesium were studied and their results are discussed. Results of manganese recovery by varying manganese sources and temperature is also discussed here. Effect of manganese, copper and nickel on microstructure, mechanical properties and corrosion behaviour of magnesium were also studied. All the results and comparative studies of Mg-Mn, Mg-Cu, Mg-Cu-Mn, Mg-Ni, Mg-Ni-Mn systems are included in this chapter.

Chapter 5: Conclusions & Future Work

It highlights the result summary of all parts along with important points to be taken into mind for future work's scope.