An Executive Summary of the Thesis

STUDY THE EFFECT OF "Mn" IN MAGNESIUM & MAGNESIUM BASED ALLOYS

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By

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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.

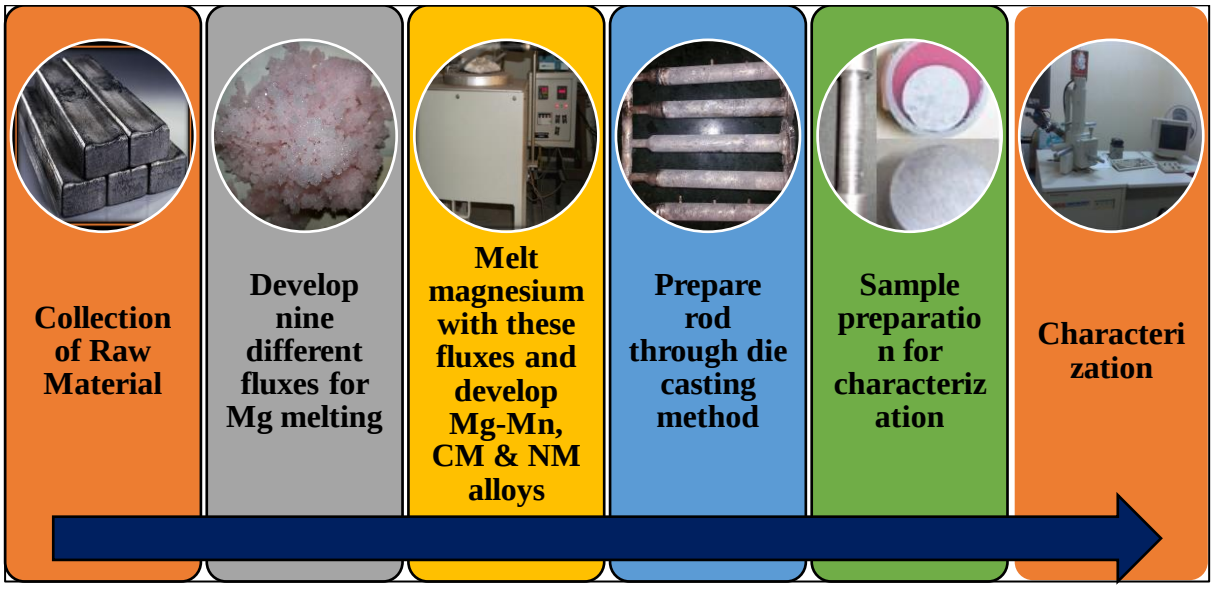
Chapter 3: Experimental Work

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 phases.

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

All the steps and practises followed in above five phases 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 Chapter 4.

Overall experimental work carried out in this research is shown figure 1.



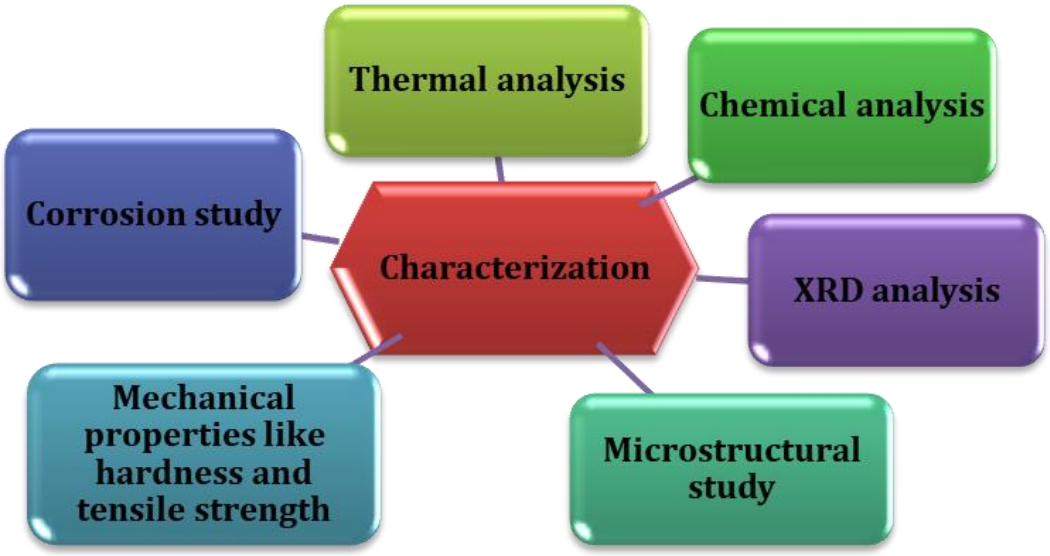


Figure 1 Overall flowchart of experimental work

Chapter 4: Results & Discussion

It includes the results and discussions that follow for all phases. In Phase 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 phases along with important points to be taken into mind for future work's scope.

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 reported that iron, copper, and nickel are responsible for increasing the corrosion rate of magnesium and its alloys. But, to improve corrosion resistance they should be kept below a threshold value. However, hardly a few researchers worked on the effect of copper and nickel on the mechanical properties of magnesium. So, in this research, the effect of various amounts of copper and nickel on microstructure, mechanical properties, and corrosion behaviour of magnesium alloys were studied which are still unexplored by the researcher.

RESEARCH GAP

The following issue is addressed in the current research:

Research Gap 1

Due to the high oxidation susceptibility of molten magnesium, melt protection is required during melting and alloying. To overcome this problem, fluxless techniques are mainly used by industries. However, method is very costly and gases (SF_6) used in this method are very toxic, creates more pollution in environment. Thus, to protect the melt from the oxidation, development of cost-effective and environment friendly method (fluxing) is necessary.

Research Gap 2

In various magnesium alloys, manganese is added to improve corrosion resistance and creep property with other alloying element. But, as discussed in section 2.4, researcher has a different opinion regarding manganese solubility and recovery in magnesium. The literature on improving manganese recovery in magnesium and related alloys is insufficient. To understand the same different sources of manganese and temperature variations studies are included as a part of the present research work.

Research Gap 3

Copper and nickel addition to magnesium alloys was mostly discussed in past studies. Mostly, researcher had studied the influence of copper on the Mg-Zn, Mg-Zn-Al, ZK60 and Mg-Gd alloy. Few researchers studied damping properties and mechanical properties of Mg-Cu-Mn alloy and Mg-1Mn-Cu. But work on different amount of manganese and its effect on microstructure, mechanical properties and corrosion behaviour on Mg-xCu alloys (x=1,2,3) are still need more attention. Present research work included the same in details. In the case of nickel, mainly researcher had worked on Mg-Ni, Mg-Zn-Ni, Mg-Ni-Cu and Mg-Ni-RE systems. Almost negligible work was done on microstructure, mechanical properties and corrosion behaviour of Mg-Ni-Mn alloy. Present research included all necessary work for the same.

OBJECTIVE OF THE WORK

The present research work has been planned with the following objectives considering the research gap discussed above.

- Synthesis and characterization of magnesium melting fluxes.
- Increase the amount of manganese by addition of various sizes and forms of Mn sources like manganese coarse powder, manganese chloride, manganese oxide, manganese fine powder, and electrolytic manganese flakes and finally studied their behavior in magnesium in terms of microstructure, mechanical properties and corrosion behaviour.
- Develop Mg-Mn alloys by varying temperatures and study their effect on the solubility of manganese in magnesium. Also, study microstructure, mechanical properties and corrosion behaviour of developed alloys.
- Develop Mg-xCu and Mg-xCu-yMn alloy (where x=1,2,3 and y=1,2,2) and study the microstructure, mechanical property, and corrosion behavior of them
- Develop Mg-xNi and Mg-xNi-yMn alloy (where x=1,2 and y=2,2,3) and study the microstructure, mechanical property, and corrosion behavior of them.

OVERALL CONCLUSIONS

1. 23% KCl, 72% $MnCl_2$, 2.5% $BaCl_2$ and 2.5% CaF_2 containing Flux 9 is best for magnesium melting compare to all other fluxes.
2. Maximum manganese recovery found in case of electrolytic flakes forms i.e., 3.46 wt. % at 950°C temperature.
3. Manganese addition refines the grain of pure magnesium and increases hardness and ultimate tensile strength.
4. The corrosion resistance of Mg-Cu alloys is increased by manganese addition.
5. However, in the Mg-Ni system, manganese presence accelerates the corrosion rate so it can't use in this system.

ORIGINAL CONTRIBUTION BY THE THESIS

The major research contributions are discussed below.

1) Nine magnesium melting fluxes were developed and identified the best flux among them.
2) Using best flux magnesium melting is done and develop various Mg-Mn, Mg-Cu-Mn, and Mg-Ni-Mn alloys.

3) Higher manganese-containing alloys were developed.
4) Refine the microstructure of Mg-Mn, Mg-Cu alloys, and Mg-Ni alloys
5) Increase ultimate tensile strength and hardness of pure magnesium
6) The corrosion rate of Mg-Cu alloys was reduced by adding manganese.
7) Microstructure, mechanical properties, and corrosion behavior of pure magnesium, Mg-Mn, Mg-Cu-Mn, and Mg-Ni-Mn alloys were studied.

FUTURE WORK

This research is a foundation for the future work in the area of Mg-Mn and Mg-Cu-Mn systems. There are several opportunities for study in the following areas.

- The Mg-Mn flakes study can be expanded by studying the corrosion behaviour for various time intervals. Different corrosion rate measurement methods and hydrogen evolution rate can be measured to get more idea regarding corrosion behaviour.
- After corrosion test, detailed microstructural and phase analysis study of Mg-Mn alloys may be important.
- As, manganese improves corrosion resistance of Mg-Cu systems, detailed corrosion study of Mg-Cu-Mn systems give more idea about corrosion behaviour, changes in microstructure and phases.

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LIST OF PUBLICATIONS

1) Paper Published:

1. Sonam M. Patel, Vandana J. Rao, "Study the Influence of MnO_2 and $MnCl_2$ on Microstructure and Mechanical Properties of Pure Magnesium," Proceedings of International Conference on Recent Advances in Metallurgy for Sustainable Development, New Delhi Publishers, ISBN: 978-93-88879-64-4, 2018, pp. 136 – 138.

2. Sonam M. Patel, Vandana J. Rao, "Effect of Various Forms of Manganese and Its Recovery in Pure Magnesium Metal," Current Advances in Mechanical Engineering, Lecture Notes in Mechanical Engineering, Springer Proceeding, ISBN: 978-981-33-4794-6, 2021 pp. 929-938. DOI: https://doi.org/10.1007/978-981-33-4795-3

3. Sonam M. Patel, Mehul M. Patel, Vandana J. Rao, "Synthesis and characterization of magnesium melting fluxes," Materials Research Express, IOP Publishing Ltd, 116503, Volume 8, Number 11, 2021, pp.1-11. DOI: https://doi.org/10.1088/2053-1591/ac30b2

4. Sonam M. Patel, Vandana J. Rao, "Effect of Mn on microstructure, mechanical properties, and corrosion behaviour of Mg-Ni alloys," Engineering Research Express, IOP Publishing Ltd, 045035, Number 4, 2022 pp. 1-9. DOI: https://doi.org/10.1088/2631-8695/aca9a8

2) Paper Presented:

1. Sonam M. Patel, Vandana J. Rao, "Study the Effect of Different Types of Fluxes Used for Magnesium Melting," National Seminar on Recent Scenario in science and technology, RSST – 2016, Organized by FTE, The M.S. U. of Baroda on 27th February 2016. Got best paper presentation award for this paper.

2. Sonam M. Patel, Vandana J. Rao, "Study the Influence of MnO_2 and $MnCl_2$ on Microstructure and Mechanical Properties of Pure Magnesium", IC-RAMSD 2018, Organized by The M. S. University of Baroda, Vadodara, on 1st to 3rd February 2018.

3. Sonam M. Patel, Vandana J. Rao, "Effect of Various Forms of Manganese and Its Recovery in Pure Magnesium Metal," International Conference on Recent Advances in Mechanical Engineering Research and Development (ICRAMERD_2020), Organized by Department of Mechanical Engineering, Institute of Technical Education & Research, Siksha 'O' Anusandhan on 24th to 25th July 2020.

3) Paper in Process:

1. Sonam Patel, Vandana Rao, "Microstructure, Mechanical Properties and Corrosion Behaviour of Mg-Cu and Mg-Cu-Mn Alloys" This paper is in process.

2. Sonam Patel, Vandana Rao, "Study the recovery of manganese at various temperatures and its influence on microstructure and properties of pure magnesium" This paper is in process.