CHAPTER 5
CONCLUSIONS

5.1 Conclusions

From the above research work, the following conclusions can be drawn for different parts of experiments.

For Part I:

1. Decomposition of all fluxes is started between 450 to 635°C, and it protects the molten magnesium from oxidation.
2. The presence of calcium fluoride reduces the decomposition temperature range and protects magnesium before melting by generating a thin and brittle layer at the magnesium surface.
3. The addition of magnesium oxide in the flux controls the refining and the presence of inclusion in the metal.
4. The combination of chloride and fluoride helps to protect the surface of magnesium metal before melting but flux 9 offers a brittle, thin, and uniform layer which ultimately gives the highest metal recovery i.e., 94 %.

For Part II:

1. Electrolytic manganese flakes are the best source of manganese to prepare Mg-Mn alloys.
2. The highest Manganese recovery is achieved in the case of electrolytic manganese flakes which are 2.66 wt. % from 5wt. % addition at 850 °C with 60% recovery.
3. The coarse grain of pure magnesium can be refined by manganese addition.
4. The hardness and ultimate tensile strength value of the manganese-containing system are more compared to the original pure magnesium. It is nearly 30 to 40% more compared to pure magnesium.
5. Electrolytic Manganese flakes containing system has a maximum hardness and ultimate tensile strength compared to others, which is 58 HV and 140 MPa respectively.
6. % Elongation is also improved by manganese (up to 1% Mn) but as tensile strength increases ductility decreases from 12% to 6% in the case of electrolytic manganese flakes. The highest 12% elongation is obtained in the Mg-$MnCl_2$ system.

7. Mg-Mn flakes systems shows excellent corrosion resistance compare to Mg-Mn sources systems.

For Part III:

1. The highest Manganese recovery is achieved at 950°C temperature.
2. Manganese presence (up to 2.66 wt.%) refines the coarse grain of pure magnesium.
3. Maximum hardness and ultimate tensile strength are achieved in Mg-2.66%Mn alloy (at 850°C).
4. A higher amount of manganese decreases the % elongation of magnesium alloy.
5. Corrosion resistance of more than 1 % Mn shows excellent corrosion resisatnce.

For Part IV:

1. The addition of Cu and Mn has a significant effect on the microstructure of magnesium. The Mg_2Cu phase is formed along the grain boundaries. The amount of this eutectic phase increases by increasing Cu content and due to that grain size of the CM30 alloy is small compared to CM10 and CM20 alloy. Compare to Mg-Cu alloys, Mg-Cu-Mn system have reduction in grain size observed.
2. The less amount of copper addition (1 wt. %) increases the ultimate tensile strength of magnesium i.e. 157 MPa in CM10 alloy. However, more amount of Cu addition decreases the UTS.
3. 2 wt. % Manganese addition is more effective to improve UTS and hardness of Mg-Cu alloys. Maximum UTS and hardness are achieved in CM32 alloy i.e. 179 MPa and 55 HV respectively.
4. Manganese plays important role in Mg-Cu alloy and reduces the detrimental effect of copper and reduces the corrosion rate. The corrosion rate of Mg-Cu-Mn alloy is very less compared to Mg-Cu alloy.

For Part V:

1. Nickel and manganese presence refine the grain size of pure magnesium. The Mg_2Ni phase is formed along the grain boundaries in these alloys. The amount of this eutectic phase increases by increasing nickel content.
2. The ultimate tensile strength and hardness of all developed alloys are more compared to pure magnesium. Maximum UTS is found in more than 1 % Ni-containing alloy i.e. around 160 MPa.

3. Mg-2.3Ni-1.96Mn alloy has achieved maximum hardness i.e. 59 HV. There is negligible change in % Elongation observed.
4. The presence of nickel and manganese shows a vigorous corrosion reaction. The maximum corrosion rate was found in Mg-1.4Ni alloy i.e. 3.22×10^5 mpy after 1.5 hr immersion. Manganese doesn't show much difference in mechanical and corrosion properties in Mg-Ni alloys. Therefore, it is not appropriate to use it as an alloying element.

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.

5.2 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.