



AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
Design and Production Engineering

**Effect of Alloying Elements and Processing Techniques on the Properties of
Some Magnesium Alloys**

A Thesis submitted in partial fulfillment of the requirements of the degree of
Master of Science in Mechanical Engineering
(Design and Production Engineering)

By

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Bachelor of Science in Mechanical Engineering
(Manufacturing Engineering and Production Technology)
Modern Academy of Engineering and Technology in Maadi, 2012

Supervised By

Prof. Dr. Nahed El-Mahallawy

Assoc. Prof. Rawia Hammouda

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Statement

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The author carried out the work included in this thesis, and no part of this thesis has been submitted for a degree or qualification at any other scientific entity.

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Thesis Summary

The former two decades have witnessed an obvious rise in the usage of magnesium and its alloys in the fields of automobiles, aerospace, electronics, structural applications, and biomedical implants, (cardiovascular or orthopedic). However, poor mechanical properties, low formability, and severe corrosion susceptibility are the most challenges that claim more research in the field of magnesium development.

Previous studies have worked on new systems of magnesium alloys comprising relatively inexpensive alloying elements (ex: tin, zinc, and manganese). The present study is investigating the mechanical properties and corrosion behavior of Mg-5Sn-xZn alloy prepared by different processing techniques, where x takes the values of 2 and 4 wt.%. These alloys were studied in the as cast, as solution treated, and hot formed (rolled, and extruded) in relation to the commercially pure magnesium. As an intention to enrich the resistance of corrosion, the minor addition of Mn (~0.1%) is included.

A series of advanced techniques were involved in the present study so as to examine the alloy content [inductively coupled plasma spectrometry (ICP)], microstructure [optical microscopy (OM) and scanning electronic microscopy (SEM)], the morphology and dispersal of the precipitates [energy dispersive X-ray spectroscopy (EDS) and X-ray diffraction analysis (XRD)], mechanical properties and corrosion tendency [electrochemical polarization and electrochemical impedance spectroscopy (EIS)].

It could be generally deducted that solution treatment has enhanced the strength of all alloys at the as-cast state without a sensitive influence on the elongation, while the hardness and the corrosion resistance have also increased. Although the rolling at 320 °C has a prime influence on the strength and hardness of the majority of the alloys, but this was at the expense of ductility, and based on that, a subsequent annealing after the last stage of rolling is required to recover the deteriorated elongation. Zn addition is worked as a grain refiner which improved the mechanical properties of the alloys at any production state, while Mn positive effect was obvious only in the alloy Mg-5Sn-2Zn. improving the The maximum tensile properties were obtained by extrusion of alloys Mg-5Sn-2Zn-0.1Mn and Mg-5Sn-4Zn-0.1Mn at 320 °C; these alloys provide both high strength and ductility with an ultimate tensile strength of 223.44 ± 5.44 and 289.44 ± 1.02 MPa and elongation of 22.35 ± 2.4 and $22.02 \pm 4.31\%$, respectively. The Mg-5Sn-2Zn alloy in its rolled state showed the least corrosion rate of about 0.118 mm/year.

Keyword: Magnesium, Tin, Zin Manganese, Casting, Rolling, Extrusion, Heat Treatment, Microstructure, Mechanical properties, Corrosion.

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Table of Contents

ACKNOWLEDGEMENT	I
TABLE OF CONTENTS	I
NOMENCLATURE	IV
LIST OF TABLES.....	VII
LIST OF FIGURES.....	IX
CHAPTER 1.....	1
INTRODUCTION	1
1 .1 Motivation Behind This Thesis	1
1.1.1 Industrial development of magnesium	1
1.1.2 Bio-medical development of magnesium.....	2
1 .2 Development of new Mg alloys	2
1 .3 Thesis aim and objectives	3
CHAPTER 2.....	5
REVIEW OF LITERATURE.....	5
2 .1 Pure magnesium.....	5
2.1.1 Microstructure and mechanical properties of C.P magnesium	6
2.1.2 Corrosion of pure magnesium.....	9
2 .2 Strengthening mechanisms	10
2.2.1 Solid solution strengthening	10
2.2.2 Grain boundary strengthening.....	10
2.2.3 Particle strengthening	11
2.2.4 Texture strengthening	11
2 .3 Restoration Mechanisms after deformation	12
2.3.1 Recrystallization	12
2.3.2 Grain growth.....	13
2 .4 Wrought magnesium alloys.....	13
2.7.1 Rolling	14
2.7.2 Extrusion.....	15
2 .5 Corrosion of magnesium and its alloys	17
2.8.1 Corrosion mechanism	17
2.8.2 Forms of corrosion.....	18
2.8.3 Factors affecting corrosion	21
2.8.4 Corrosion tests and measurement	23

6.2	Previous work.....	27
2.9.1	Mg-Sn binary system	27
2.9.2	Mg-Zn binary system.....	29
2.9.3	Mg-Sn-Zn system	31
2.9.4	Current Research	32
CHAPTER 3.....	41	
MATERIAL AND METHODS	41	
3.1	PLAN OF WORK	41
3.2	MATERIALS SELECTION AND PREPARATION.....	42
3.3	CASTING	43
3.4	PROCESSING	44
2.4.1	Solution Treatment	44
2.4.2	Rolling	45
2.4.3	Extrusion.....	45
3.5	MICROSTRUCTURE CHARACTERIZATION.....	46
3.5.1	Sample preparation	46
3.5.2	Optimal microscopy (OM).....	47
3.5.3	Scanning electron microscopy (SEM)	48
3.5.4	X-ray diffraction (XRD)	48
3.6	MECHANICAL PROPERTIES TESTING	48
3.6.1	Tensile testing	48
3.6.2	Hardness testing.....	49
3.7	CORROSION	50
3.7.1	Linear polarization measurement.....	50
3.7.2	Electrochemical impedance spectroscopy (EIS) measurements.....	51
CHAPTER 4.....	52	
RESULTS AND DISCUSSION.....	52	
4.1.	Evolution of the microstructure of C.P. magnesium and alloyed magnesium processed by different techniques.	52
4.1.1.	Microstructure of commercially C.P. magnesium at different processing techniques.	52
4.2.1.	Evolution of the microstructure of magnesium alloys processed by different techniques.	55
4.2.	Mechanical properties of commercially pure and alloyed magnesium processed by different techniques.....	71
4.2.1	Mechanical properties of C.P. magnesium with different processing techniques.	71
4.2.2	Effect of alloying elements on the mechanical properties of magnesium alloys processed by different techniques.....	76
	Mechanical properties of as cast alloys	76
	Mechanical properties of as Solution treated alloys	78

Mechanical properties of as Rolled alloys	80
Mechanical properties of as extruded alloys.....	82
4.2.3 Effect of alloying elements on the mechanical properties	84
4.2.4 Effect of processing techniques on the mechanical properties	87
Quantitative calculations of the effect of processing on the strengthening mechanisms	91
4.3. Corrosion of pure and alloyed magnesium processed by different techniques	98
CHAPTER 5.....	118
CONCLUSION	118
CHAPTER 6.....	122
FUTURE WORK.....	122
REFERENCES	123

Nomenclature

Acronyms

<u>ASTM</u>	<i>American Society for Testing of Materials</i>
<u>EBS</u>	<i>Electron backscatter diffraction</i>
<u>EDX/EDS</u>	<i>Energy dispersive x-ray spectroscopy</i>
<u>EIS</u>	<i>Electrochemical impedance spectroscopy</i>
<u>FCC</u>	<i>Face centered cubic</i>
<u>HCP</u>	<i>Hexagonal close-packed</i>
<u>HV</u>	<i>Hardness Vickers</i>
<u>ICP</u>	<i>Inductively coupled plasma</i>
<u>OCP</u>	<i>Open circle potential</i>
<u>OM</u>	<i>Optical microscope</i>
<u>RE</u>	<i>Rare Earths</i>
<u>SEM</u>	<i>Scanning electron microscopy</i>
<u>UTS</u>	<i>Ultimate tensile strength</i>
<u>XRD</u>	<i>X-ray diffraction analysis</i>
<u>YS</u>	<i>0.2% Yield strength</i>
<u>SBF</u>	<i>Simulated Body Fluid</i>

Elements and compounds

<u>Ar</u>	<i>Argon</i>
<u>Mg</u>	<i>Magnesium</i>
<u>Zn</u>	<i>Zinc</i>
<u>Sn</u>	<i>tin</i>
<u>Mn</u>	<i>manganese</i>
<u>SF₆</u>	<i>Sulfur hexafluoride</i>

Symbol

<u>a</u>	<i>Unit cell dimension of an HCP lattice cell</i>
<u>α</u>	<i>Pro-eutectic and primary eutectic phase of HCP magnesium matrix</i>

β	<i>Secondary eutectic phase</i>
β_A	<i>Anodic Tafel slope</i>
β_C	<i>Cathodic Tafel slope</i>
c	<i>Unit height of an HCP lattice cell</i>
C	<i>Double layer Capacitance</i>
c/a	<i>Characteristic ratio of the HCP lattice</i>
d	<i>Average grain diameter</i>
e^-	<i>Electron</i>
E	<i>Electrochemical potential</i>
E_f	<i>Elongation</i>
EC	<i>Equivalent circuit</i>
E_{corr}	<i>Open circuit corrosion potential</i>
ε	<i>Stress</i>
$\dot{\varepsilon}$	<i>Strain rate</i>
i	<i>Current density, number of weeks submerged</i>
i_{corr}	<i>Open circuit corrosion current density</i>
l	<i>Specimen length after fracture</i>
l_0	<i>Gauge Length</i>
mm	<i>Millimeter</i>
MPa	<i>Mega pascal</i>
μm	<i>Micrometer</i>
P_i	<i>Corrosion rate measured electrochemically by tafel extrapolation</i>
$P_{i,EIS}$	<i>Corrosion rate measured by electrochemical impedance spectroscopy</i>
P_w	<i>Corrosion rate measured by weight loss</i>
P_H	<i>Corrosion rate measured by hydrogen evolution</i>
R_{ct}	<i>Charge transfer resistance</i>
R_p	<i>Polarization resistance</i>
R_s	<i>Solution resistance</i>
ρ	<i>Density</i>
V	<i>Applied potential</i>
V_f	<i>Volume fraction of precipitates</i>

<u>wt. %</u>	<i>weight percent</i>
<u>Z</u>	<i>Impedance</i>
<u>Z'</u>	<i>Real impedance</i>
<u>Z''</u>	<i>Imaginary impedance</i>

List of tables

Table 1. Comparing some of magnesium properties with aluminum, titanium, and iron [8]....	6
Table 2. Mechanical process of pure magnesium at different processing techniques.	8
Table 3. Literature data of the magnesium alloys where Sn, Zn and Mn are the major alloying elements.	35
Table 4. Chemical composition (wt. %) of the experimented alloys.	43
Table 5. Solution treatment applied to the alloys of study.	44
Table 6. Parameters used to evaluate precipitation strengthening of the Mg-5Sn-4Zn-0.1Mn alloy.....	92
Table 7. Effect of rolling and extrusion on the strengthening of C.P. magnesium.....	94
Table 8. Results of the SEM showing elements' content in the α -Mg solid solution of as cast and as solution treated Mg-5Sn-4Zn-0.1Mn alloy.	95
Table 9. Effect of solution treatment on the strengthening of as cast Mg-5Sn-4Zn-0.1Mn alloy.....	95
Table 10. Results of the SEM showing elements' content in the α -Mg solid solution of as the as rolled Mg-5Sn-4Zn-0.1Mn alloy.	96
Table 11. Results of the SEM showing elements' content in the α -Mg solid solution of the as extruded Mg-5Sn-4Zn-0.1Mn alloy.	97
Table 12. Effect of rolling and extrusion on the strengthening of as solution treated Mg-5Sn-4Zn-0.1Mn alloy.	97
Table 13. Results of the of polarization curves and electrochemical impedance of the commercially pure magnesium processed by different techniques in 3.5wt.% NaCl solution.....	100
Table 14. Results of the of polarization curves and electrochemical impedance of the Mg-alloys at their as cast state in 3.5wt.% NaCl solution.	102
Table 15. Results of the of polarization curves and electrochemical impedance of the Mg-alloys at their as solution-treated state in 3.5wt.% NaCl solution.	105
Table 16. Results of the of polarization curves and electrochemical impedance of the Mg-alloys at their as rolled state in 3.5wt.% NaCl solution.	109
Table 17. Results of the of polarization curves and electrochemical impedance of the Mg-alloys at their as extruded state in 3.5wt.% NaCl solution.	111