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

Alia Ahmed Diaa Eldeen

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

Supervised By

Prof. Dr. Nahed El-Mahallawy

Assoc. Prof. Rawia Hammouda

Cairo - (2017)

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Date:

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Statement

This thesis is submitted in partial fulfillment of Master of Science degree in mechanical engineering, Faculty of Engineering, Ain Shams University.

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 ^{O}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 ^{O}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±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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This thesis would not have been remotely possible without the guidance and support of my supervisor, Professor Nahed el. Magallay, mentorship allowed me to grow as a researcher and made my masters studies a fully enjoyable experience.

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My Mother who spent effort while I am making my experiment, I remember that she was carrying the large cylinder of SF6+ Argon we are in the bus, from the factory to university.

I would like to thank my sister and brother, and to thank my fiancée.

Finally, thanks to my father, may allah bless him. He drew the route which we are following.

Table of Contents

Nomenclature

Acronyms

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

Elements and compounds

Ar	*Argon*
Mg	*Magnesium*
Zn	*Zinc*
Sn	*tin*
Mn	*manganese*
SF_6	*Sulfur hexafluoride*

Symbol

a	*Unit cell dimension of an HCP lattice cell*
α	*Pro-eutectic and primary eutectic phase of HCP magnesium matrix*

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

wt.%	*weight percent*
Z	*Impedance*
Z'	*Real impedance*
Z''	*Imaginary impedance*

List of tables