



**UniMAP**

**Characterization and In-Vitro Activity of Powder  
Metallurgy Magnesium-Zinc / Bioglass Composite for  
Biomedical Applications**

**By**

**Mohd Amin Farhan bin Zaludin  
(1330410898)**

A thesis submitted in fulfillment of the requirements for the degree of  
Master of Science in Materials Engineering

**School of Materials Engineering  
UNIVERSITI MALAYSIA PERLIS**

2015

## UNIVERSITI MALAYSIA PERLIS

### DECLARATION OF THESIS

Author's full name : MOHD AMIN FARHAN BIN ZALUDIN  
Date of birth : 24 MARCH 1990  
Title : CHARACTERIZATION AND IN-VITRO ACTIVITY OF POWDER  
METALLURGY MAGNESIUM-ZINC / BIOGLASS COMPOSITE  
FOR BIOMEDICAL APPLICATIONS  
Academic Session : 2012 / 2013

I hereby declare that the thesis becomes the property of Universiti Malaysia Perlis (UniMAP) and to be placed at the library of UniMAP. This thesis is classified as :

- CONFIDENTIAL** (Contains confidential information under the Official Secret Act 1972)\*
- RESTRICTED** (Contains restricted information as specified by the organization where research was done)\*
- OPEN ACCESS** I agree that my thesis is to be made immediately available as hard copy or on-line open access (full text)

I, the author, give permission to the UniMAP to reproduce this thesis in whole or in part for the purpose of research or academic exchange only (except during a period of \_\_\_\_ years, if so requested above).

Certified by:

\_\_\_\_\_  
SIGNATURE

\_\_\_\_\_  
SIGNATURE OF SUPERVISOR

900324-09-5055  
\_\_\_\_\_  
(NEW IC NO. / PASSPORT NO.)

PROF. DR. SHAMSUL BAHARIN BIN JAMALUDIN  
\_\_\_\_\_  
NAME OF SUPERVISOR

Date : \_\_\_\_\_

Date : \_\_\_\_\_

NOTES : \* If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization with period and reasons for confidentiality or restriction.

## ACKNOWLEDGEMENT

Assalamualaikum warahmatullahi wabarakatuh...

Alhamdulillah, all praise to Allah S.W.T for bestowing me with health, energy, patience and desire to finish and complete this thesis. All problems, obstacles and difficulties encountered during completing these works could be settled with His consents.

I also wanted to express my deepest appreciation to my supervisor, Prof. Dr. Shamsul Baharin Bin Jamaludin for his great supports and assistances. With his guidance, advises and encouragement, I manage to handle and complete my research works. With his guidance, I have finished my final year project during my degree studies before, and now he helped me finishing my master studies. Thanks you so much Prof.

I also want to thank the following individuals for their dedication, commitment and professionalism in supporting my works and projects: Muhd Faisal Rusli, Mohd Nasir Haji Ibrahim, Ahmad Hadzrul Iqwan, Wan Mohd Arif Wan Ibrahim, Azmi Aziz, Rosmawadi Othman, Che Idrus Omar. Not to be forgotten also all UniMap's School Of Materials staffs that have been helpful during my research works.

Very special thanks and appreciations to my parents Haji Zaludin bin Abdul and Hajjah Naimah binti Jusoh, all of my siblings: Farazilla, Akmal and Azwan for their moral

supports, understanding and loveliness. I also wish to thank my friends and research team: Aishah, Norazimah, Soon Peng, Lutfi, Sze Qing, Wai Hoong, and Kak Hidayah. It has been a pleasure to work with you guys.

The authors also would like to thanks the financial support from the Ministry of Science, Technology & Innovation (MOSTI) under Science Fund grant number 9005-00054.

Thank You. Wassalam...

MOHD AMIN FARHAN BIN ZALUDIN

©This item is protected by original copyright

## TABLE OF CONTENTS

	<b>PAGE</b>
<b>THESIS DECLARATION</b>	i
<b>ACKNOWLEDGMENT</b>	ii
<b>TABLE OF CONTENTS</b>	iv
<b>LIST OF FIGURES</b>	viii
<b>LIST OF TABLES</b>	xii
<b>LIST OF ABBREVIATIONS</b>	xiii
<b>LIST OF SYMBOLS</b>	xvii
<b>ABSTRAK</b>	xix
<b>ABSTRACT</b>	xx
<b>CHAPTER 1 INTRODUCTION</b>	
1.1 Introduction	1
1.2 Problem statement	5
1.3 Objectives	6
1.4 Scope of Study	7
<b>CHAPTER 2 LITERATURE REVIEW</b>	
2.1 Biomaterials	9
2.1.1 Introduction	9
2.1.2 Biomaterials: Brief History	12
2.2 Magnesium	13
2.2.1 Magnesium as Biodegradable Materials	15
2.2.1.1 Corrosion Mechanisms of Magnesium	15
2.2.1.2 Types of Magnesium Alloys Corrosion	17

2.2.1.2.1	Galvanic Corrosion	18
2.2.1.2.2	Localized Corrosion	19
2.2.2	Applications of Magnesium as Biomaterials	20
2.3	Bio-glass	22
2.3.1	Introduction to Bio-glass	22
2.3.2	Bioactivity of 45S5 Bio-glass	23
2.3.3	Mechanisms of Bioactive Bonding with Tissue Cells	27
2.3.4	Applications of 45S5 Bio-glass as Biomaterials	29
2.4	Development of Biocomposites as The Third Generation of Biomaterials	34
2.4.1	Introduction to Composites	34
2.4.2	Emergence of Third Generation of Biomaterials	35
2.4.3	Studies on Biocomposites	37
2.4.3.1	Fabrication Methods of Biocomposites	37
2.4.3.2	Density	40
2.4.3.3	Compressive Strength	42
2.4.3.4	Corrosion Resistance	45
2.4.3.5	Apatite Forming Ability	47

### **CHAPTER 3 METHODOLOGY**

3.1	Introduction	52
3.2	Raw Materials	54
3.3	Fabrication	54
3.3.1	Mixing	54
3.3.2	Uni-axial Powder Compaction	56
3.3.3	Sintering	56
3.4	Experimental Procedure	57
3.4.1	Microstructural Analysis	57
3.4.2	Phase Analysis	58
3.4.3	Density Test	58
3.4.4	Compression Test	59
3.4.5	Corrosion Test	61

3.4.5.1	Preparation of Simulated Body Fluid (SBF)	61
3.4.5.2	Preparation of Cleaning Solution	63
3.4.5.3	Mass Change of Corrosion Test	63
3.4.6	In-Vitro Bioactivity Evaluation	65
3.4.6.1	SEM/EDS	65
3.4.6.2	XRD	66

## **CHAPTER 4 RESULTS AND DISCUSSION**

4.1	Raw Materials Characterizations	67
4.1.1	Scanning Electron Microscope/ Energy Dispersive Spectroscopy (SEM/EDS)	67
4.1.2	X-Ray Diffractions (XRD)	72
4.1.3	Particle Size Analyzer	73
4.2	Characterization of As-Sintered compacts	76
4.2.1	Surface features of the As-Sintered compacts	76
4.2.2	Phase Analysis of the As-Sintered Compacts	85
4.3	Density	88
4.4	Compressive Strength	92
4.5	Immersed Samples Analysis	95
4.5.1	Mass Loss and Corrosion Rates	95
4.5.2	pH Measurement of SBF	101
4.5.3	Phase analysis of Corrosion Products	103
4.5.4	Surface Features of Corrosion Samples	106
4.5.5	In-Vitro Bioactivity	113

## **CHAPTER 5 CONCLUSION**

5.1	Summary	122
5.2	Recommendation for Future Project	125

**REFERENCES**

127

**APPENDICES**

**LIST OF PUBLICATIONS**

©This item is protected by original copyright



## LIST OF FIGURES

NO.		PAGE
2.1	Classification of biomaterials according to their response in physiological environment (a) bioinert, (b) bioactive, (c) surface active, and (d) biodegradable.	10
2.2	Types of galvanic corrosion: (a) Macrogalvanic and (b) Microgalvanic.	19
2.3	Pitting corrosion of AM60 immersed in 3,5% NaCl solution.	20
2.4	Absorbable Metal Stent.	21
2.5	MagnIM Magnesium screw implant.	22
2.6	Bioactivity spectrum for several types of bio-ceramic implants.	24
2.7	Ternary diagram which correlates compositional fractions with bioactivity of the $\text{Na}_2\text{O}$ - $\text{CaO}$ - $\text{P}_2\text{O}_5$ - $\text{SiO}_2$ glass systems.	26
2.8	Reactions of bone formations between bone and bio-glass.	29
2.9	Applications of various types of bioceramics and composites as biomaterials.	33
2.10	Classification of composite materials.	35
2.11	Structure of bones.	36
2.12	Corrosion rate of AZ91/FAp composites immersed inside SBF.	47
2.13	SEM micrograph of Titanium/CaP surface after immersion in SBF for 7 days showing (a) cloudy growth and (b) cotton ball like growth.	48
2.14	SEM images of the Co-base alloy/15 wt% FA after soaking in SBF solution for (a) 1 day, (b) 14 days and (c) 28 days.	49

2.15	SEM image of F-75/HAp after immersion in PBS for 18 days (a) 0 HAp, (b) 2 wt.% HAp, (c) 6 wt. % HAp, and (d) 10 wt. % HAp.	50
3.1	Flow Chart of the project.	53
3.2	Sintering profile for the composites.	57
3.3	Examples of compression test samples.	60
3.4	Sample configuration during compression test.	60
3.5	Ultrasonic cleaning of the composites inside ethanol.	64
3.6	Samples configuration inside SBF solution for corrosion analysis.	64
3.7	Samples configuration inside SBF solution for bioactivity evaluation.	65
4.1	(a) - (d) SEM images of magnesium powders (e), (f) EDS image and spectrum of Mg powders.	69
4.2	(a) - (d) SEM images of zinc powders (e), (f) EDS image and spectrum of Zn powders.	70
4.3	(a) - (d) SEM images of bio-glass powders (e), (f) EDS image and spectrum of bio-glass powders.	71
4.4	Diffraction patterns for (a) bio-glass, (b) Zn, and (c) Mg powders.	73
4.5	Particles Size of as received (a) Magnesium, (b) Zinc, (c) Zinc after 3 hours of ball mill, and (d) Bio-glass.	75
4.6	Optical micrographs of (a) Mg-5Zn, (b) composite 1, (c) composite 2, (d) composite 3, (e) composite 4, (f) composite 5 and (g) composite 6.	79
4.7	SEM-EDS of Mg-5Zn.	80
4.8	SEM-EDS of composite 1.	81
4.9	SEM-EDS of composite 2.	81
4.10	SEM-EDS of composite 3.	82
4.11	SEM-EDS of composite 4.	82
4.12	SEM-EDS of composite 5.	83

4.13	SEM-EDS of composite 6.	83
4.14	SEM-EDS showing diffusion of Mg and Zn (Composite 3).	84
4.15	SEM with EDS at point 018 showing compositions inside the pore (Composite 5).	85
4.16	Diffraction patterns for all samples.	87
4.17	Diffraction patterns of Mg-5Zn and composite 6.	88
4.18	Densities of the composites.	89
4.19	Graph of relative density vs. total porosity of the composites.	92
4.20	Compressive strength of the composites with different bio-glass percentage.	93
4.21	Graph of Mass Loss VS. Immersion Time for the composites immersed in SBF.	99
4.22	Graph of Corrosion Rate VS. Immersion Time for the composites.	100
4.23	Graph of pH of SBF VS. Immersion Time.	103
4.24	Phase analysis of the corrosion products.	104
4.25	Eye inspection of the composites (a) Mg- 5Zn, (b) composite 1, (c) composite 2, (d) composite 3, (e) composite 4, (f) composite 5, and (g) composite 6 after immersion at different time intervals (24, 72, 120, and 168 hours).	107
4.26	Pitting microstructure of Mg-5Zn after immersion in SBF (a) 24 hours, (b) 72 hours.	108
4.27	Pitting microstructure of composite 1 after immersion in SBF (a) 24 hours, (b) 72 hours, (c) 120 hours and (d) 168 hours.	108
4.28	Pitting microstructure of composite 2 after immersion in SBF (a) 24 hours, (b) 72 hours, (c) 120 hours and (d) 168 hours.	109
4.29	Pitting microstructure of composite 3 after immersion in SBF (a) 24 hours, (b) 72 hours, (c) 120 hours and (d) 168 hours.	110
4.30	Pitting microstructure of composite 4 after immersion in SBF (a) 24 hours, (b) 72 hours, (c) 120 hours and (d) 168 hours.	111

4.31	Pitting microstructure of composite 5 after immersion in SBF (a) 24 hours, (b) 72 hours, (c) 120 hours and (d) 168 hours.	112
4.32	Pitting microstructure of composite 6 after immersion in SBF (a) 24 hours, (b) 72 hours, (c) 120 hours and (d) 168 hours.	113
4.33	SEM/EDS of Mg-5Zn after immersion for 12 hours.	115
4.34	SEM/EDS of composite 4 after immersion for 12 hours.	116
4.35	SEM/EDS of composite 6 after immersion for 12 hours.	117
4.36	SEM/EDS of composite 4 after immersion for 24 hours.	120
4.37	SEM/EDS of composite 6 after immersion for 24 hours.	121

©This item is protected by original copyright

## LIST OF TABLES

NO.		PAGE
2.1	Properties comparison of several types of biomaterials.	14
2.2	Summary of effect of processing parameter on fabrication of composite via powder metallurgy.	39
2.3	Comparison of compressive strength of biocomposites.	45
3.1	Composition of the samples.	55
3.2	Reagents to prepare SBF.	62

©This item is protected by original copyright

## LIST OF ABBREVIATIONS

$((\text{HOCH}_2)_3\text{CNH}_2)$ (Tris)	Tris- Hydroxymethyl Aminomethane
$(\text{Ca})_{10}(\text{PO}_4)_6(\text{OH})_2$	Apatite
45S5 Bio-glass	A type of bio-glass
A.D	Anno Domini/ Before Christ (B.C)
Al	Aluminum
$\text{Al}_2\text{O}_3$	Aluminum Oxide/ Alumina
AM60	Magnesium- Aluminum (6%) - Manganese (0.35%) Alloy
AMS	Absorbable Metal Stent
aq	Aqueous
AZ63	Magnesium- Aluminum (6%) - Zinc (3%) Alloy
BG	Bio-glass
$\text{Ca}^{2+}$	Calcium Ions
$\text{Ca}_3\text{Mg}_3(\text{PO}_4)_4$	Calcium Magnesium Phosphate
$\text{Ca}_5(\text{PO}_4)_3\text{X}$	Stoichiometry of Calcium Phosphate materials
$\text{CaCl}_2$	Calcium Chloride
$\text{CaCO}_3$	Calcium Carbonate
$\text{CaO}$	Calcium Oxide
$\text{Cl}^-$	Chloride Ions
$\text{CO}_3^{2-}$	Carbonate Ions

Co-Cr	Cobalt Chromium
Co-Cr-Mo	Cobalt Chromium Molybdenum
DI	Deionized Water
e <sup>-</sup>	Electron
EDS	Energy Dispersive Spectroscopy
ERMI ®	Endosseous Ridge Maintenance Implant
F <sup>-</sup>	Fluoride Ions
F-75	Cobalt- Chromium (30%) - Molybdenum (7%) Alloy
FAp	Fluoroapatite
H <sub>2</sub>	Hydrogen Gas
H <sub>2</sub> O	Water
HAp	Hydroxyapatite
HCA	Hydroxycarbonate Apatite
HCl	Hydrochloric Acid
I <sub>B</sub>	Bioactivity Index
K <sub>2</sub> HPO <sub>4</sub> ·3H <sub>2</sub> O	di- Potassium Hydrogen Phosphate Anhydrous
KCl	Potassium Chloride
l	Liquid
LTI	Low Temperature Isotropic Carbon
MEP ®	Middle Ear Protheses
Mg	Magnesium
Mg(OH) <sub>2</sub>	Magnesium Hydroxide
Mg <sup>2+</sup>	Magnesium Ions
MgCl <sub>2</sub>	Magnesium Chloride

MgCl <sub>2</sub> .6H <sub>2</sub> O	Magnesium Chloride 6-hydrate
MgF <sub>2</sub>	Magnesium Fluoride
MgZn	Magnesium Zinc Alloy
Na <sup>+</sup>	Sodium Ions
Na <sub>2</sub> O	Sodium Oxide
Na <sub>2</sub> SO <sub>4</sub>	Sodium Sulfate Anhydrous
NaCl	Sodium Chloride
NaHCO <sub>3</sub>	Sodium Hydrogen Bicarbonate
OH <sup>-</sup>	Hydroxide Ions
OM	Optical Microscope
P <sub>2</sub> O <sub>5</sub>	Phosphorus Pentoxide
PBS	Phosphate Buffered Saline Solution
pH	pH Values
PO <sub>4</sub> <sup>3-</sup>	Phosphate Ions
PSR	Particle Size Ratio
RE	Rare Earth Elements
rpm	Rotation per Minute
s	Solid
SBF	Simulated Body Fluid
SEM	Scanning Electron Microscopy
SiO <sub>2</sub>	Silicon Dioxide
SiO <sub>4</sub> <sup>4-</sup>	Silicate
t <sub>0.5bb</sub>	Time taken for bioactive material to bind at the bone surface so that it covers more than of 50% of the bone surface



TCP	Tricalcium Phosphate
Ti	Titanium
XRD	X-Ray Diffraction
Zn	Zinc
ZrO <sub>2</sub>	Zirconium Oxide/ Zirconia

©This item is protected by original copyright

## LIST OF SYMBOLS

%	Percentage
°/min	Degree per Minute
°C	Degree Celsius
°C/min	Degree Celsius per Minute
Å	Angstrom
$f_i$	Mass Mole Fraction of Composite Constituent
g	Grams
$\text{g/cm}^3$	Grams per Cubic Centimeter
g/l	Grams per Liter
$\text{gm}^{-2}/24\text{hr}$	Grams per Meter Square per 24 hours
GPa	Giga Pascal
M	Molar
$\text{mg/cm}^2 \cdot \text{hr}$	Milligram per Centimeter Square Hours
MHz	Mega Hertz
mL	Milliliter
mm	Millimeter
MPa	Mega Pascal
$\text{MPam}^{1/2}$	Mega Pascal per Meter Square
N/A	Not Available
wt. %	Weight Percentage

$\Theta$	Theta
$\lambda$	Lambda
$\mu\text{m}$	Micrometer
$\rho_{\text{Bulk}}$	Bulk Density
$\rho_i$	Theoretical Density of Composite Constituent
$\rho_{\text{Relative}}$	Relative Density
$\rho_{\text{Theory}}$	Theoretical Density
$\rho_{\text{True}}$	True Density

©This item is protected by original copyright

## **Pencirian dan Aktiviti In-Vitro Komposit Magnesium-Zink/Bioglas Secara Metalurgi Serbuk Untuk Aplikasi Bioperubatan**

### **ABSTRAK**

Dalam kajian ini, serbuk 45S5 bio-kaca telah ditambah ke dalam campuran serbuk Mg-Zn untuk menghasilkan biokomposit menggunakan kaedah metalurgi serbuk untuk aplikasi bioperubatan. Komposisi bio-kaca diubah daripada 0, 5, 10, 15, 20, 25, 30 wt. %. Objektif kajian ini adalah untuk mengkaji kesan penambahan bio-kaca ke dalam bio-bahan berasaskan Mg-Zn dari segi sifat fizikal, mekanikal, rintangan kakisan dan bioaktiviti. Mikroskop optik, Mikroskop Imbasan Elektron-Tenaga serakan Spektroskopi (SEM-EDS) dan pembelauan sinar-X (XRD) telah digunakan untuk mencirikan mikrostruktur dan fasa yang terdapat di dalam komposit. Keputusan mikrostruktur menunjukkan bahawa bio-kaca telah diedarkan dalam matriks Mg-Zn itu. Keputusan EDS menunjukkan bahawa Zn tidak meresap sepenuhnya ke dalam matriks Mg yang disebabkan oleh kesan parameter pemrosesan. Tidak ada bukti bio-kaca resapan ke dalam matriks. Corak pembelauan sinar-X sampel tersinter menunjukkan puncak Mg jangkaan dalam semua sampel. Sifat-sifat seperti ketumpatan dan kekuatan mampatan masing-masing telah ditentukan dengan menggunakan piknometer dan mesin Instron. Ketumpatan komposit telah dibandingkan dengan nilai teori dan trend terhasil menunjukkan bahawa ketumpatan meningkat seiring dengan peningkatan jumlah bio-kaca. Trend adalah sah untuk ketumpatan sebenar, teori, dan pukal. Kenaikan nilai ketumpatan boleh dikaitkan dengan pengisian bio-kaca pada ruang interpartikel. Walau bagaimanapun, jumlah keliangan juga meningkat kerana peningkatan jumlah bio-kaca. Ia boleh dikaitkan dengan pengasingan zarah bio-kaca. Oleh kerana jumlah bio-kaca meningkat, lebih bio-kaca terasing dan membawa kepada saiz masukan bio-kaca yang lebih besar di dalam komposit. Oleh kerana tiada tindak balas antara magnesium dan bio-kaca, semakin besar saiz masukan bio-kaca, lebih besar lompong yang terbentuk di antara muka magnesium dan bio-kaca, yang akhirnya akan memberikan meningkatkan kepada jumlah hasil keliangan. Kekuatan mampatan menunjukkan bahawa jumlah bio-kaca meningkat, kekuatan mampatan bagi komposit menurun. Ini juga boleh dikaitkan dengan lompong yang ditinggalkan di antara muka bio-kaca dan matriks yang bertindak sebagai pemula retak. Ujian in-vitro telah dijalankan, di mana sampel direndam dalam Bendalir simulasi Badan (SBF) untuk menentukan kadar hakisan dan bioaktiviti bagi komposit. Hasil kajian menunjukkan bahawa kadar kakisan sampel berkurangan dengan pertambahan kandungan bio-kaca. Pengumpulan produk kakisan, bersama-sama dengan pembentukan lapisan apatit membantut proses kakisan. Lapisan apatit yang digunakan untuk menunjukkan bioaktiviti itu juga dikesan di permukaan komposit. Lapisan apatit terbentuk mempunyai nilai yang lebih rendah daripada nisbah Ca / P berbanding hydroxyapatite kristal yang ideal, namun ia masih mematuhi keperluan bahan bio.

## **Characterization and In-Vitro Activity of Powder Metallurgy Magnesium-Zinc/Bioglass Composite for Biomedical Applications**

### **ABSTRACT**

In this study, bio-glass 45S5 powder was added into the mixture of Mg-Zn powders to produce biocomposite using powder metallurgy method for biomedical applications. The bio-glass composition was varied from 0, 5, 10, 15, 20, 25, to 30 wt. %. The objective of this work is to study the effect of bio-glass addition into Mg-Zn based biomaterials in terms of physical, mechanical, corrosion resistance and bioactivity properties. Optical microscope, Scanning Electron Microscope-Energy Dispersive Spectroscopy (SEM-EDS) and X-Ray Diffraction (XRD) were used to characterize the microstructure and phases present in the composites. Microstructure result shows that bio-glass was distributed in the matrix Mg-Zn. EDS results show that Zn has not completely diffuse into the Mg matrix due to the effect of processing parameter. There is no evidence of bio-glass diffusion into the matrix. XRD diffraction patterns of as sintered samples show expected peak of Mg in all samples. Properties such as density and compressive strength were determined using the pycnometer and Instron machine respectively. Density of the composite was compared with the theoretical value and the result trends indicated that the density has increased as the amount of bio-glass increased. The trends are valid for the true, theoretical, and bulk densities. Increment of densities value could be subjected to the filling of interparticles spacing by bio-glass. However, the total porosity also increased as the bio-glass amount increased. It could be attributed to the segregation of bio-glass particles. As the amount of bio-glass increase, more bio-glass segregate and leads to bigger size of bio-glass inclusion size inside the composite. Since no reaction between magnesium and bio-glass, the bigger the size of bio-glass inclusions, the larger the voids form at the interface, which will eventually give raise to total porosity results. The compressive strength shows that as the amount of bio-glass increased, the compressive strength of the composites decreased. This also could be attributed to the voids left at the interface of bio-glass and matrix which acts as crack initiators. In vitro test was conducted, in which samples were immersed in Simulated Body Fluid (SBF) to determine the corrosion rate and bioactivity of the composites. The results showed that corrosion rate of the samples decreases with increasing content of bio-glass. The accumulation of corrosion products, alongside with the formation of apatite layer retarded the corrosion process. The apatite layer that used to indicate the bioactivity was also traced on the surface of composites. The apatite layer formed has a lower value of Ca/P ratio compared to the ideal crystalline hydroxyapatite, however it is still compliant with biomaterials requirement.

## CHAPTER 1

### INTRODUCTION

#### 1.1 Introduction

Biomaterials are defined as materials intended or any substance (other than drug), whether synthetic or natural, used to interface with biological systems and can be used as a system or part of a system that treat, augments, or replaces any tissue, organ, or the function of the body (William, 1999; Pirhonen, 2006).

Biomaterials are the results obtained as the population ages. It is intended to help human to have more quality life. The research and development progress of biomaterials have had a significant effect on the production of medical implant and devices over the last 40 years (Holzapfel et. al., 2013). However, the use of biomaterials has started from since ancient times. According to historical records, there is a finding that the dental implants were used by the Mayan people in 600 A.D. Besides, there are also finding that proving the metal dental implants were used back in 200 A.D by discoveries of corpses in Europe (Ratner et. al., 2004).

The rapid development of biomaterials field, however came after the World War II. During World War II, many soldiers injured and this has put the attention of researchers to

develop implants that can be implanted in the human body and must be able to adapt to its new environment which is biological environment (William, 1999). Materials that originally applied as machinery or vehicles were implemented as materials for medical devices. Since then, the research and studies, innovation and development, and industrial productivity of biomaterials have developed sustainably. Nowadays, biomaterials representing market size about over \$9 billion per year in the United States (US) only (Temenoff & Mikos, 2008).

Biomaterials could be classified into three types of materials, which are metals, ceramics, and polymers. Metals and ceramics are inorganic materials which have different types of bonding. Metals have metallic bonding with the high mobility of electrons while ceramics possessed ionic bonding. Metals are generally strong and offers a high degree of design complexity and suitable for orthopedic applications. Ceramics, however are generally hard and brittle materials, but are more corrosive resistant than metals. Polymers are organic materials that made up from long chains of covalent bonding elements. Due to its properties such as elasticity and high water content, polymers are suitable to be implemented in cardiovascular and soft tissue applications. Composite is another class of materials which combines any of the three materials to fulfill the requirement of the biomaterials (Temenoff & Mikos, 2008).

In present times, researchers are attracted towards studies on magnesium alloys as a potential biodegradable bone implant materials. Magnesium and its alloys is a lightweight metals ( $1.74 - 2.0 \text{ g/cm}^3$  in density) and biocompatible because of its biodegradable properties (Gu & Zheng, 2010). Biodegradable materials are defined as resorbable,

degrades materials at the same rate at which the host tissue regenerates. The developed interest of magnesium is due to their properties such as biodegradability in bioenvironments, mechanical properties such as elastic modulus which may decrease the shielding effect problems. Shielding effect is defined as bone remodeling by starving the new tissue of the fluctuating loads that are necessary to stimulate strong and healthy tissue formation (Parsons et. al., 2010).

Magnesium alloys have shown its excellent degradation properties inside in- vitro experiment conducted in earlier research. This degradation properties rate is fast and caused by electrochemical reaction or corrosion. The products of this reaction are  $Mg(OH)_2$  and  $H_2$  (Liu et. al., 2007; Witte et. al, 2008; Kirkland et. al, 2012). So, there is a need to study the new process to slow down the corrosion rate and perhaps, new alloying elements to be added with magnesium. This is important since the corrosion or degradation rate may affect the structure integrity of the implants and the alloying elements added may have a negative effect in human body (Kirkland et. al., 2012).

Although magnesium is known to be one candidate of biodegradable and biocompatible materials, it also has its own weakness, which is, its bioactivity. The key element for a biomaterial to perform well its functions, especially for bone regeneration or orthopedics applications is the formation of apatite layers. Since the discoveries of bio-glass, the apatite layer formation has been used as an indicator of bioactivity of a biomaterial. Apatite is one of a subgroup originates from phosphate minerals. It is one component of bone minerals. Apatite exhibits a miscellaneous structure with assorted lattice and morphologies. This mineral stoichiometry may be written as  $Ca_5(PO_4)_3X$ , where