Akreditasi Dikti Nomor : 26/DIKTI/Kep/2005

ISSN 1410 - 8577

JURNAL TEKNOLOGI

DITERBITKAN OLEH :
PUSAT PENELITIAN DAN PENGABDIAN MASYARAKAT
SEKOLAH TINGGI TEKNOLOGI JAKARTA

Jurnal Teknologi	Vol. 9	No. 2	Halaman 97-201	Jakarta, Desember 2006	ISSN 1410 - 8577

LEMBAR PENGESAHAN

Judul	: Emerging Tent In The Application Of Magnesium Alloys : From Mechanical to Bio - Engineering
Penulis	: 1. Irza Sukmana (NIP 197008122001121001)
Instansi	: Fakultas Teknik, Universitas Lampung
Publikasi	: Journal Teknologi.
	ISSN : 1410 - 8577
	Vol. 9 , No. 2 , Halaman 97 - 102, Bulan Desember , Tahun 2006.
Penerbit	: Journal Teknologi.

Bandar Lampung, 4 April 2017

Mengetahui,
Dekan Fakultas Teknik

Prof. Dr. Suharno, M.Sc., Ph.D.
NIP. 196207171987031002

Penulis,

Irza Sukmana, S.T, M.T., Ph.D.
NIP. 197008122001121001

Menyetujui:
Ketua LPPM
Universitas Lampung

Ir. Warsono, Ph.D.
NIP. 196302161987031003

UNIVERSITAS LAMPUNG

TGL	10 - mei 2017
NO INVEN	0013/1/A/N/FT/2017
JENIS	Jurnal
PARAF	4

JURNAL TEKNOLOGI

Volume [illegible], Nomor 2, Desember 2006 ISSN 1410 – 8577

Terakreditasi dengan Nilai C Nomor 26/Dikti/Kep/2005

Diterbitkan Oleh (Published by) : Pusat Penelitian dan Pengabdian Masyarakat
Sekolah Tinggi Teknologi Jakarta

Penanggung Jawab: Kepala Pusat Penelitian dan Pengabdian Masyarakat; **Ketua Editor (Chief Editor):** Jarman Sudimo; **Dewan Editor (Editorial Board Members):** Togar Harapan Pangaribuan, Mangasi Alion Marpaung, Sudi Ariyanto; **Editor Pelaksana (Managing Editors):** Ety Widayati; **Sirkulasi (Distribution):** [illegible] Yatno Milkhan

Alamat Editor (Editorial Address)
Sekolah Tinggi Teknologi Jakarta (STTJ)
Jl. Jatiwaringin Raya 278 Pondok Gede 17411
Telp (021) 8462316 – 8463692, Fax (021) 8463692
E-mail : sttj@cbn.net.id & jurnal_sttj@yahoo.co.id

Percetakan : Lipit Mandiri
Harga langganan satu tahun (Terbit Juni dan Desember)
Pelanggan (Subscriber) : Rp. 60.000,- ; Institusi/Perpustakaan Rp. 120.000,-

UCAPAN TERIMA KASIH

Ucapan terima kasih dan penghargaan diberikan kepada para pakar yang telah diundang sebagai penelaah oleh Jurnal Teknologi dalam volume 9. Berikut ini adalah daftar nama pakar yang berpartisipasi

Harsono Wiryomarto, Profesor (Emeritus) Teknik Mesin ITB
Sasi Kirono, B2TKS, BPPT Jakarta
Budiono Mismail, Fakultas Teknik Universsitas Brawijaya Malang
Hiskia, Puslit Elektronika dan Telekomunikasi LIPI Bandung
Imran Idris, Pusat Mikroelektronika ITB
Sarinanto, Koordinator Bidang Teknologi Informasi, Komunikasi & Komputasi BPPT Jakarta

Jurnal Teknologi, Des 2006, hlm. 98-102
ISSN 1410-8577 Vol. 9, No. 2

Emerging Trend in the Application of Magnesium Alloys: From Mechanical to Bio-Engineering

IRZA SUKMANA*

Mechanical Engineering Dept. Engineering Faculty, University of Lampung
Jl. Prof. Sumantri Brojonegoro No. 1 Bandar Lampung 35143

Abstract

Magnesium alloys as a new light-weight structural metal will form the basis of key technologies in the coming decades. Its applications not only in the field of mechanical engineering, electronics, and aerospace technology, but also in the field of medical engineering as biomaterial implant. In general there are two potential sectors on the application of Magnesium alloys: mechanical engineering (including aeronautics) and medical engineering. This article will review the potentiality and drawback on the application of Magnesium alloys on those two sectors in the side view of types of alloys, physical and mechanical properties, also the corrosion performance and its protection technology.

Keywords: magnesium alloys, mechanical properties, corrosion, and biomaterial implant

INTRODUCTION

Nowadays, Magnesium and its alloys are the attractive materials for several engineering applications, such as: for aircraft and missile components, material-handling equipment, portable power tools, ladders, luggage, bicycles, sporting goods, case of computer and electronic products, and general lightweight component. Primarily because of its light-weight, about 36% lighter per unit volume than Aluminum (Al) alloys and about 78% lighter than iron (Fe) alloys.

Magnesium element was first isolated in 1808 by the English scientist Davy, but it was not until 1852 that Bunsen demonstrated that magnesium metal could be isolated by electrolysis of fused anhydrous magnesium chloride, magnesium being released at the cathode and chlorine at the anode of the cell. The commercial possibilities of the electrolytic method of production were first exploited in 1909 by a German company, *Chemische Fabrik Griesheim: Magnesium Elektron*. By the 1920's, the electrolytic process had been worked out on an industrial scale and the metal became available in commercial quantities to justify its use as a structural material. [1]

When alloyed, Mg has the highest strength-to-weight ratio of any structural metal and since the first oil crisis in the 1970's, there has been an economic and legislated move to cars lighter by a combination f down-sizing, new design and shifts to lighter materials, so engineers are keen to use as much magnesium as possible in their vehicles. The most striking material shift from iron to high strength steel (HSS), and from iron to Al and plastics, but now Mg offers even greater potential to reduce weight. [2]

Magnesium (Mg) is abundant metallic element, since sea water, the main source of supply, contain about 13-14% Mg, which virtually unlimited supply. Magnesium is extracted from ores of Carnallite ($MgCl.KCl.6H_2O$), Dolomite ($MgCO_3.CaCO_3$), and Magnesite ($MgCO_3$) or from sea water. The extraction process involves processing the ore or brine to make $MgCl_2$, which is split by electrolysis to give pure magnesium.[3]

CONSIDERING ON USING MAGNESIUM ALLOYS

Today, world production of magnesium totals about 415,000 tons per annum and the figure is increasing annually with averaging almost 20% per annum worldwide. Figure 1 shows the five biggest producer of magnesium alloy during 2001-2002, and it indicated the increasing of world magnesium production about 6%. [4]

* Penulis untuk korespondensi, Telp./Fax.: 0721-704947 ; email: isukmana@yahoo.com

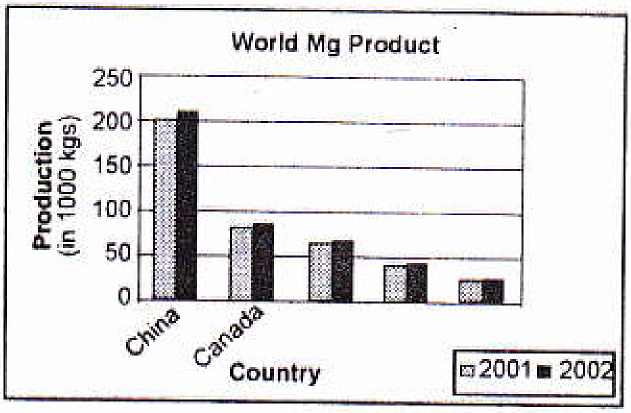


Figure 1. World Production of Magnesium

Event its low density, Mg has some drawback and the most important factor is the materials physical properties, as shown on Table 1. Comparing to the steel fabrication, since its crystal structure is *hcp*, Mg fabrication must be done at elevated temperature of 200-315C and thus can't use the large and very capital-intensive machinery. (2)

Table 1. Comparison of Material Properties

Property	Magnesium	Aluminum	Iron
Crystal Structure	*hcp*	*fcc*	*bcc*
Density at 20C (g/cc)	1.74	2.70	7.86
Coefficient of Thermal Expansion, 20-100C ($x10^6$/C)	25.2	23.6	11.7
Elastic Modulus (10^6 psi)	6.4	10	30
Melting Point (C)	650	660	1,536

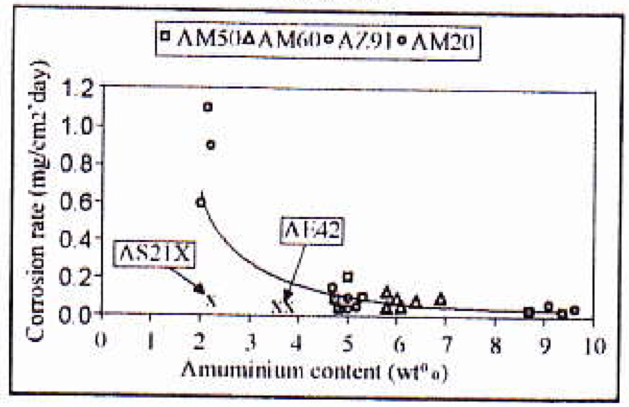
The corrosion performance of most of magnesium alloys is also not satisfactory in practical application and its becoming a major issue which limits their application. Currently, the use of magnesium alloys is mainly limited to the components in mild service.(5)

Concerning with corrosion properties, Mg alloys can be generally divided into two groups: 1) those containing aluminum as the primary alloying element; and 2) those free of aluminum and containing a small amount of zirconium (Zr) for the purpose of grain-refinement.

The first group of Mg alloys is based on the M-Al system and Mg-Al-Zn system, and with codification of AM and AZ alloy. These alloys have been developed for good room temperature, strength and ductility but not exhibit good creep resistance. (6)

The addition of a certain amount of aluminum can introduce a secondary phase (β -$Mg_{17}Al_{12}$ in inter-metallic) and α -Mg solid solution phase into the magnesium alloys. The secondary phase can improve corrosion resistance on the matrix phase and the corrosion resistance of α phase can vary, based on the amount of aluminum contents on the alloy. In general, the corrosion resistance of the first group of Mg alloys decreased with decreasing aluminum content, as illustrated on Figure 2. (7)

Figure 2. Corrosion rates as a function of aluminum content in



The second group of Mg alloys is based on Mg-Zn-Zr and Mg-Zn-Zr-RE (RE=Rare Earth element) system, that has been developed to improved elevated-temperature and corrosion performance of the alloys.

The additional of Zirconium element is not only as a powerful grain refiner of the matrix, but also a very effective purifier for magnesium alloys. RE elements added to improve creep resistance, since its will form precipitation at the grain boundaries and hold them in place. (6)

Another key factor that inhibits the massive use of magnesium alloy is the highly and unstable price of magnesium alloy. On a per-pound basis, magnesium cost 3,5 - 6 times as much as steel and 1,7-2,8 as much as aluminum.(2) Figure 3 show the price of aluminum and magnesium alloys during 1996-2000. (3)

However, the use of magnesium alloys becoming more attractive because of several factors, such as:

a R&D process could significantly reduce the cost of magnesium production. Figure 3 indicated that the price of magnesium decreased where on

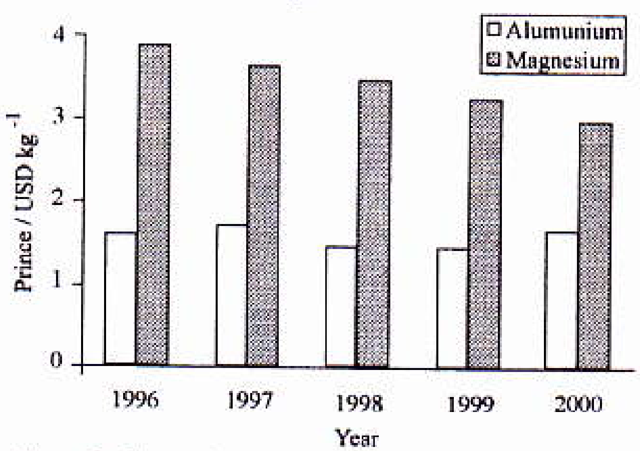


Figure 3. Comparing price of aluminum magnesium alloys

the other hand aluminum is increasing.

b Total cost of magnesium alloy will vary based on the alloying element. In order to reduce the total cost of the alloy, the magnesium producer can strictly control the amount of alloying element. Table 2 comparing the total material cost if two types of Mg alloys.

and engine block, and was estimated to have a lifetime energy consumption less than 60% that of a conventional car. [2]

The European Union also directive that cars should produce less than 120 g of CO_2 per kilometres by 2005, and are approaching this problem by attempting to reduce the weight of their cars. "Concept cars" produced in recent years have been lightweight, for example, the Ford P2000 which weighs only 544.3 kg.

Table 2. The cost of magnesium alloying elements and the total material cost

		AZ91D		AE42	
Alloying element	Cost ($/kg)	Weight of element in alloy (kg)	Cost ($/kg)	Weight of element in alloy (kg)	Cost ($/kg)
Mg	3.64	0.918	3.342	0.959	3.491
Zn	1.32	0.010	0.013		
Al	1.54	0.092	0.142	0.041	0.063
Rate Earth Element	15.43			0.033	0.509
	Total Materials cost ($kg)		3.497		4.63

APPLICATION IN MECHANICAL ENGENEERING

The two most extensive uses of magnesium alloys in ME are in the automobile and aerospace industry. Since the impetus for light weighing automobile and aero-passenger body is to save gasoline, it is important to make sure that there is a net energy savings over the lifecycle of vehicle. For example, Volvo's concept car used several lightweights materials, including about 50 Kg of magnesium for the wheels, chassis, The potential for weight saving by using magnesium is about 6%: 77kg for a medium sized car.

There are some common applications of magnesium alloy in automobile and aerospace industry as shown on Table 3 and Table 4. Then, to explore the possibility on the application of magnesium alloy in mechanical engineering, Gaines categorized the three major system or component groups are: the body, the power train, and the chassis. The major system and sub-systems each made primarily of only a few of materials are shown on Table 5. [2]

Table 3. Magnesium components currently used by car manufacturer

Mg Alloys	Components	Manufacturer
AZ91D	Transmission casing	VW, Passat, Audi
AM50A and	Intake manifolds, cylinder head covers, steering	VW, BMW, Ford, Jaguar
AM 50B	wheels cover	Formula-1 mobiles
WE43	Gearboxes	Mazda
AS21	Transmission and engine parts	Nissan, GM
AE42	Engine parts (creep resistance properties)	

Table 4. Magnesium application in Aerospace industry

Mg Alloys	Applications	Magnesium Producer	Aerospace Brand
AZ91E	Transmission casing	DOW & AMAX	
WE43	Gearboxes	Magnesium Elektron	F16, F119 and F22
EA55B	High strength-room temperature components	Allied-Signal	Eurocopter EC120 and
RZ5	Transmission casing	Magnesium Elektron	Sikorsky 592
EQ21	Aero engine and missile components for high temperature and good creep resistance	Magnesium Elektron	American Satelite Ind.

Table 5. Components in the three major auto systems

Body	Power train	Chassis
- Body and closures - Glass - Hardware exterior and interior - Trim - Body electrical - Seats - Passenger restrains instruments and controls	- Engine & accessories - Engine electrical - Engine controls - Engine cooling system - Transmission or transaxle - Clutch - Drive line (near wheel drive) - Differential gear - Transfer case	- Suspension steering system - Bumper system - Brake system - Sub frames - Fuel storage system - Chassis - Exhaust system - Wheels and tires

The body is the largest group of total mass, about 40% and mostly steel are the first choice for structural components. The best opportunity on magnesium alloy applications are space frames (using wrought magnesium), seat frame (magnesium casting), and body panels (magnesium casting with hot forming).

In the components of power train group, magnesium alloy casting has been extensively used and replacing iron and aluminum casting. However, the application in some housing and covers for engine block and cylinder head can be done for the magnesium alloy with high creep resistance properties, such as: Mg-Zn-Zr and Mg-Zn-Zr-RE alloys.

The chassis components highly diverse, but iron and steel still play a major role. But wheels were one of the first applications for magnesium, since experimental Ford synthesis has been process the possibility on using magnesium on the suspension links, especially in the rear. (2)

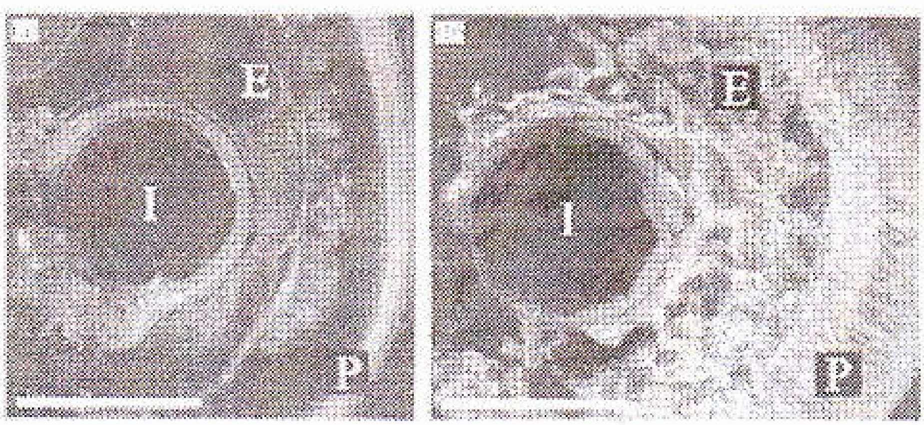
APPLICATION IN BIO-ENGINEERING

Metallic materials now play an essential role as biomaterial implant and replace the bone tissue that has become damaged. Metals are more suitable for load-bearing applications compared with ceramics or polymeric materials due to their combination of high mechanical strength and fracture toughness. Currently approved and commonly used metallic biomaterials include stainless steels, titanium, and cobalt-chromium based alloys.

The application of magnesium alloys in bio-engineering field, especially as biomaterial implant also becoming more popular since it is a light weight metal with mechanical properties similar to natural bone. In vivo degradation via corrosion in the electrolytic environment of the body, magnesium-based implants have a potential to serve as bio-compatible, osteo-conductive, and degradable implants for load-bearing application. (8)

Magnesium based materials were first introduce as orthopedic biomaterials in 1907 when Lambotte utilized a plate of pure magnesium with gold-plated steel nails to secure a fracture involving the bones of the lower leg, future in vivo works have investigated for various magnesium alloys.

Recently, Witte explored the in vivo degradation of magnesium based alloys, comparing two alloys containing only aluminum and zinc and other two alloys containing rare earth element combination. The first two alloys are AZ31 (3 wt% aluminum and 1 wt% zinc) and AZ91 (9 wt% aluminum and 1 wt% zinc) and the other two are WE43 (4 wt% yttrium and 3 wt% RE) and LAE 442 (4 wt% lanthanum, 4 wt% aluminum, and 2 wt% RE). Those materials formed as implants that consisted of rods 1,5mm in diameter and 20mm in length, and then inserted into the femur



Both specimens were harvested 18 weeks postoperatively. In vivo staining of newly formed bone by calcein green. Bar=1.5 mm; I=implant residual; P=periosteal bone formation; E=endosteal bone formation

Figure 4. Fluoroscopic images of cross-sections of a degradable polymer (a) and a magnesium rod (b) performed 10 mm below the trochanter major in a guinea pig femur

magnesium implants. The slowest corrosion rate was noted for LAE 442, while AS31, AZ91, and WE43 degraded at similar rate. The RE elements were shown to be localized in the corrosion layer and were not detected in the surrounding bone. X-ray diffraction suggest that a high level of calcium and phosphorous. Those alloys showed direct contact with newly formed bone, which prove its biological compatibility.[10]

While magnesium is a prevalent ion in the body, and magnesium based implants have been used in vivo without adverse reaction, more information still required to confirm its safety use. The future investigation of the potentiality on the magnesium alloys application as biomaterial implants are addressed in the non-toxicity, bio-compatibility, mechanical integrity with original body structure, and the optimization of in vivo degradation process.

CONCLUSIONS

As a first step, it is clear that the corrosion rate of magnesium-based materials is not satisfactory for some practical applications. An appropriate alloying composition of magnesium can improve the corrosion resistance, mechanical properties, and the easy of the manufacturing process. Magnesium alloy has becoming a competitive and applicable material in the mechanical engineering, including aerospace industry, and the possibility of its application in bio-engineering, as biomaterial implants, is widely open. The toxicity of magnesium alloys as biomaterial implants and more corrosion variations must be more evaluated.

Acknowledgement

The Author would like to express a thank you for PT Semen Baturaja for their financial support.

REFERENCES

1. International Magnesium Association. 2004. http://intlmag.org/db-mechanical.html, Mg Mechanical Database.
2. Gaines, L., Cuenca, R., Stodolsky, F., and Wu, S., 1996, Potential Automotive Uses of Wrought Magnesium Alloys, Conference Paper of Automotive Technology Development. Detroit. USA.
3. Longworth, S., 2001, Bolting of Magnesium Components, Master of Philosophy Thesis, University of Cambridge, Cambridge, UK.
4. Kramer, DA., 2003, Summaries of US Geological Survey, New York, USA.
5. Song, G., 1999, Investigation on Corrosion of Magnesium and its Alloys, Journal of Corrosion Science and Engineering, Vol. 6, Paper C104.
6. Pekguleryuz, MO., 1996, High Temperature Magnesium Alloy Development, Publication Report of Noranda Inc. Technology Centre, Quebec, Canada.
7. Skar, J.I., Albright,D., 2002, Emerging Trends in Corrosion Protection of Magnesium Die-Casting, Journal of The Materials, Metals and Material Society, Michigan, USA.
8. Staiger,M.P., et. al., 2005, Magnesium and its Alloys as Orthopedic Bio Materials: A Review, Journal of Biomaterials, Paper No. 10.1016.
9. Witte, F., et. al., 2005, In Vivo Corrosion of Four Magnesium Alloys and the Associated Bone Response, Journal of Biomaterials, 26(17): 3557-63
10. Witte, F., et. al., 2006, In vitro and Vivo Corrosion Measurements of Magnesium Alloys, Journal of Biomaterials, 27(2006): 1013-1018.
11. Sukmana,I., 2004, Magnesium Alloys as a New Trend in Material Development and Its Corrosion Behavior, Paper of International Collaboration Workshop: Keio Univ-Brawijaya University, Malang.
12. Joneses, D.A. 1992, Principles and Prevention of Corrosion, Macmillan Publishing, New York.
13. Ulrich, K., Dietzel, W., 2002, Official Publication of Corrosion Department, GKSS Research Center, Hamburg.
14. ASM International, 1987, Metal Handbook 9^{th} Edition, Volume 13: Corrosion, Ohio, USA.
ASM International, 1990, Metal Handbook 10^{th} Edition, Volume 2: Properties and Selection of Materials, Ohio, USA.