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Aging characteristic and mechanical properties of formed Mg-Zn-Al-RE-Ca alloys

I Nyoman Gde Antara

Jurusan Teknik Mesin Universitas Udayana, Kampus Bukit Jimbaran Bali

Abstrak

The present study focused on aging characteristic and mechanical properties of semi solid formed Mg-Zn-Al-RE-Ca alloys. The alloys are divided into Mg-8%Zn-4%Al-0.6%Ca and Mg-6%Zn-3%Al-0.6%Ca based alloys, and rare earth elements were added in the range from 1 to 3 mass% (hereafter ZAE841, ZAE842, ZAE843 and ZAE631, ZAE632, ZAE633). The alloy specimens were strained, press-formed at 580˚C and extracted to prepare specimens for T-6 heat treatment and tensile investigations. The results show that all of the alloys exhibit microstructure that consisting of fine spherical α particles and fine eutectic compounds around the particles. The peak hardness of the alloys was mainly reached when the solution heat treatment is conducted at temperature of 330˚C for 16 hours and aging at 175˚C for 32 hours. The hardness numbers increase with increasing content of the alloying elements. Tensile properties at high temperature of semi-solid formed alloys increase in accordance with increasing the amount of compounds. The amounts of compound increase as the alloying element increase.

Keywords: Mg-Zn-Al-RE-Ca alloys, aging characteristic, mechanical properties, semi-solid formed, hardness, spherical α particle, eutectic compound

Abstract

Penelitian ini dititikberatkan pada karakteristik proses-proses penuaan (aging characteristic) dan sifat-sifat mekanis (mechanical properties) dari paduan-paduan Mg-Zn-Al-RE-Ca yang dibentuk berdasarkan kondisi saat paduan tersebut dalam keadaan setengah padat (semi solid). Paduan-paduan yang dipakai pada dasarnya dapat digolongkan menjadi paduan-paduan dasar (based alloys) Mg-8%Zn-4%Al-0.6%Ca dan Mg-8%Zn-3%Al-0.6%Ca dan logam-logam tanah (rare earth) dipadukan kedalam kedua paduan tersebut dengan prosentase yang berbavariasi dari 1 sampai 3% (sehingga seluruh paduan-paduan tersebut dapat dinotasikan sebagai ZAE841, ZAE842, ZAE843 dan ZAE631, ZAE632, ZAE633). Spesimen dari paduan-paduan tersebut pertama ditekan (negative strain) dan dibentuk dengan kompresi (press-formed) pada temperature 580˚C lalu dipotong-potong untuk membuat spesimen dari uji perlakuan panas menurut T6 (T6 heat traeatment) dan untuk spesimen pengujian tarik (tensile investigation). Data menunjukkan semua paduan-paduan yang diuji tersebut memiliki struktur mikro yang terdiri dari partikel-partikel halus dan bulat dari phase alpha (α) dan dikelilingi oleh senyawa-senyawa eutektik yang halus disekitar partikel-partikel tersebut. Kekerasan tertinggi pada umumnya didapat saat perlakuan panas dilakukan pada temperature 330˚C selama 16 jam yang diikuti oleh proses penuaannya pada temperature 175˚C selama 32 jam. Angka kekerasan meningkat sesuai dengan peningkatan prosentase unsur-unsur paduannya. Kekuatan tarik pada temperatur tinggi dari paduan-paduan yang dibentuk pada kondisi setengah padat tersebut meningkat menurut jumlah dari senyawa-senyawanya. Jumlah senyawa-senyawanya sendiri meningkat menurut peningkatan dari unsur-unsur yang terdapat dalam paduannya.

Kata kunci: Paduan-paduan Mg-Zn-Al-RE-Ca, karakteristik penuaan, sifat-sifat mekanis, pembentukan pada kondisi setengah padat, partikel bulat dari phase α dan senyawa eutectic

1. Introduction

Magnesium alloys are being widely developed in recent years for expanding their applications in the automotive, electronics and aerospace industries. In the automotive industries, owing to their lightness and good recyclability, magnesium alloys have been promising materials in gaining automobile weight savings to maximize fuel economy and to minimize emission of harmful gases. However, the utilization of magnesium alloys in automotive industries for elevated temperature applications is currently limited.

Several studies have been carried out for improving the high temperature properties of magnesium alloys. These alloys are mainly based on Mg-Al alloy system with addition of zinc, calcium, silicon and rare earth elements in the form of mischmetal. As a result, magnesium alloys having almost same properties as conventional aluminum diecasting alloys used in power train parts have been developed [1,2]. In the present study, rare earth metal are added to Mg-Zn-Al-Ca alloy that was also reported to have attractive properties at elevated temperature [3,5] and furthermore, semi solid processing technique are applied to the alloys because the process can minimize porosity and reduce solidification shrinkage [6,7], resulting in suppression of hot tearing occurred in Mg-Zn-Al-Ca alloys. Aging characteristics and mechanical properties of the semi solid formed samples were investigated in order to evaluate their suitability for elevated temperature applications.

2. Experimental procedure

2.1. Investigated alloys

This research was carried out by using

Korespondensi: Tel./Fax.: 62 361 703321
E-mail: antara@me.unud.ac.id

Mg-Zn-Al-RE-Ca alloys supplied by Chuo Kosan Corporation. The chemical compositions of the alloys are shown in Table 1. They can be mainly divided into two based alloys. The first based alloys, namely ZAE84X, contain about 8% zinc, 4% aluminum and X% rare earth elements (hereafter ZAE841, ZAE842 and ZAE843), while the second, namely ZAE63X, contains 6% zinc, 3% aluminum and X% rare earth elements (hereafter ZAE631, ZAE632 and ZAE633). Both based alloys contain rare earth elements that vary from 1 to 3% in order to investigate the effect of the amount of compounds on the properties of each alloy.

Table 1. Chemical compositions of the investigated alloys

No	*Alloy*	*Zn*	*Al*	*RE*	*Ca*	*Mn*	*Mg*
1	ZAE841	7.8	4.0	0.9	0.60	0.23	Bal.
2	ZAE842	8.1	4.0	1.9	0.57	0.16	Bal.
3	ZAE843	8.0	3.9	3.2	0.60	0.17	Bal.
4	ZAE631	6.1	3.1	1.1	0.61	0.19	Bal.
5	ZAE632	5.9	3.0	1.8	0.60	1.18	Bal.
6	ZAE633	6.0	6.0	2.7	0.64	1.20	Bal.

2.2. Reheating and quenching method

Billet with dimension of 40 mm in diameter and 28.3 mm in height were extracted from ingot. The billets were subjected to a compressive strain of 15% at temperature of 350˚C by using a hydraulic pressure machine. The billets were machined to obtain a dimension of 40 mm in diameter and 23 mm in height. Next, the strained billets were reheated to desired semi solid temperatures using infra-red image furnace. Then the specimens were immediately quenched into water, and microstructure evolution and solid distributions were observed for determining the appropriate temperatures for semi solid forming.

2.3. Semi solid forming process

As described above, after the appropriate semi solid temperature of the each alloy was determined, the billets were reheated to these temperatures in the infrared image furnace. Then the semi-solid specimens were transferred to a squeeze casting machine and semi solid forming is applied. The processing parameters of semi solid forming are plunger pressure of 49 MPa and plunger velocity of 0.05 m/s, die preheating temperature of 300˚C, plunger tip temperature of 200˚C and a holding time of 30 s. The disk shaped semi solid formed specimens obtained in this forming that have a diameter of 55 mm and a height of 12 mm was extracted to prepare samples of the heat treatment and tensile test.

2.4. Microstructure analysis

Microstructures of as-formed and T6-treated test specimens were observed with an optical microscope, Nikon Ephipot TME. Specimens were polished and then etched with acetic glycol.

2.5. Aging response

The heat treatment diagram to evaluate aging response of the ZAE alloys is shown in Fig.1. The specimens are solution treated at 340˚C for 16h in an argon atmosphere with a flow rate of 3.3 x 10^{-5} m^3/s. Solution-treated specimens were immediately quenched in water at room temperature, then were heated to aging temperature at 175˚C for times ranging from 1 to 128h. The aging was carried out by immersing the alloy in a silicon oil bath and the hardness was measured by Vickers hardness tester using a 98N load.

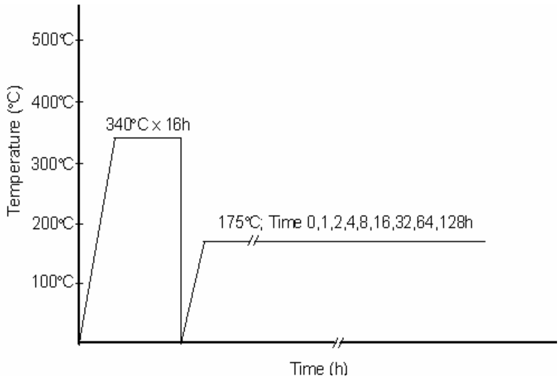

Fig. 1. Heat treatment diagram to evaluate aging response of the ZAE alloys.

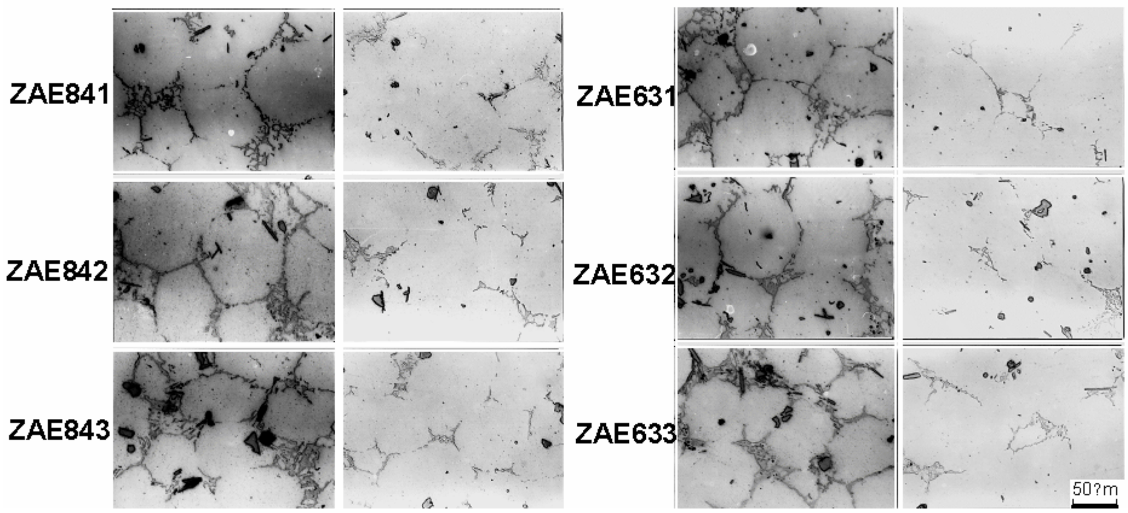

Fig. 2. Change in microstructure of the alloy specimens with solution heat treatment

2.6. Tensile test

Two specimens were extracted from one formed sample and machined to round specimens having a reduced section diameter of 6 mm and a gauge length of 20 mm. The tensile tests were conducted at RT, 100˚C, 150˚C, 175˚C, 200˚C and 250˚C using Instron model 1185, equipped with electrical resistant heater, with 100 kN load cell, under a cross head speed of 0.5 mm/min.

3. Results and discussion

3.1. Aging characteristic

3.1.1. Solid solution treatment

Solution heat treatment was carried out at a temperature of 330˚C for 16h and then aging was conducted at 175˚C [5]. Changes in microstructure of ZAE84 and ZAE63 based alloys specimens with solution heat treatment are shown in Fig. 2. It clearly can be seen that the microstructure of as-formed specimens consisting of eutectic region surrounded the solid particles. The microstructure of heat-treated specimens on the other hand consisted of less eutectic region than before. This due to the part of the eutectic region dissolved into solid α particles during heat treatment, resulting the rise of the area of those particles or reduction number eutectic region.

3.1.2. Aging response

Fig. 3 shows aging curves of semi solid formed specimens. The hardness numbers of the investigated alloys proportionally increase in accordance with increasing amount of alloying elements. The peaks hardness is obtained after aging time of 32h due to the precipitation of the meta-stable β' phase observed in Mg-Zn alloy [5]. When aging time is longer than 32h, the hardness numbers gradually decreases. Therefore, aging for full heat treatment (T6) was conducted at 175˚C for 32 hours.

3.2. Tensile properties

3.2.1. As-formed specimens

Fig. 4 shows tensile properties of as-formed specimens. Maximum tensile strengths of as-formed specimens were reached at temperature 100˚C. At this temperature, the highest tensile strength of 195 MPa is obtained by ZAE843 alloy. It means that from room temperature to 100˚C this alloy improves its tensile properties by 16%. The improvements of tensile strengths are also achieved by other alloys but at a difference level. At higher temperature, ZAE84 based alloys are superior to ZAE63 based alloys, indicating that the alloys containing higher alloying element has better high temperature properties. Generally ZAE84 based alloys are better 0.2% proof stress than ZAE63 based alloys. There is no effect of alloy on elongation.

3.2.2. T6-treated specimens

Fig. 5 shows tensile properties of T6 treated specimens. The maximum tensile strength of the alloys was reached at 100˚C. The highest strength of about 220 MPa at this temperature is exhibited by ZAE843. At higher temperatures, the tensile strengths significantly fall down and they are about 130 MPa at 200˚C. At almost all the test temperatures, ZAE84 based alloys have relatively higher tensile strength and 0.2% proof stress than ZAE63 based alloys. Among these alloys, the alloys that contains 3% rare earth element has the highest tensile strength and in 0.2% proof stress compared to the alloys that contain 1% or 2%.

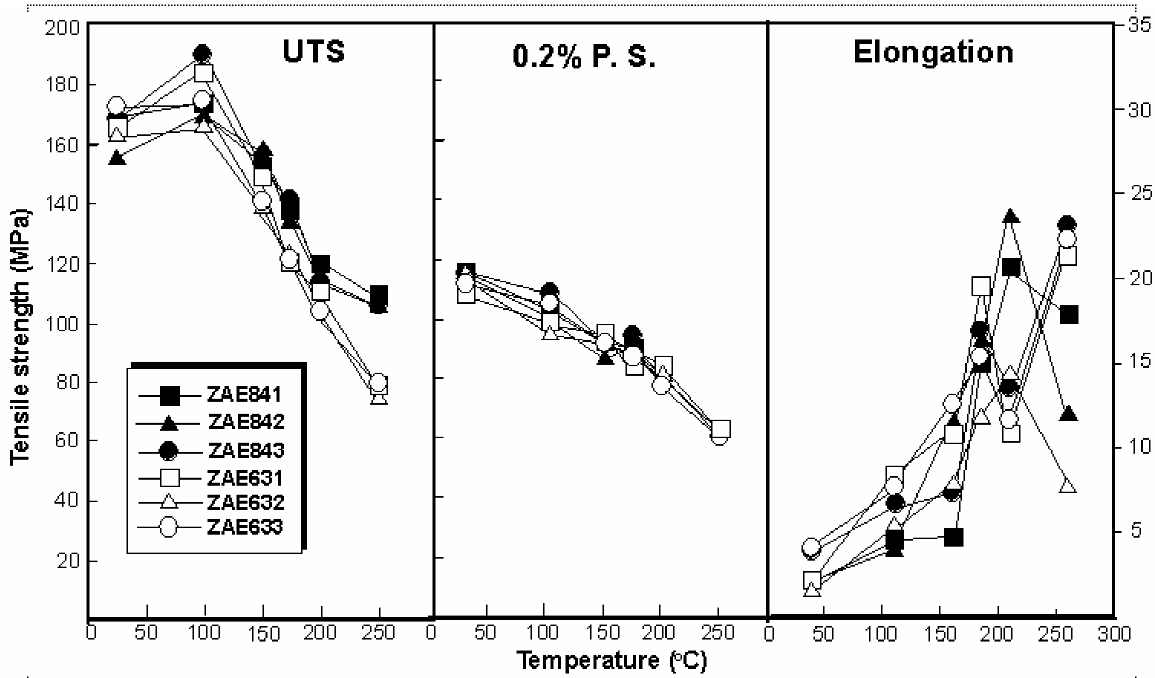

Fig. 4. Tensile properties of as-formed alloy specimens

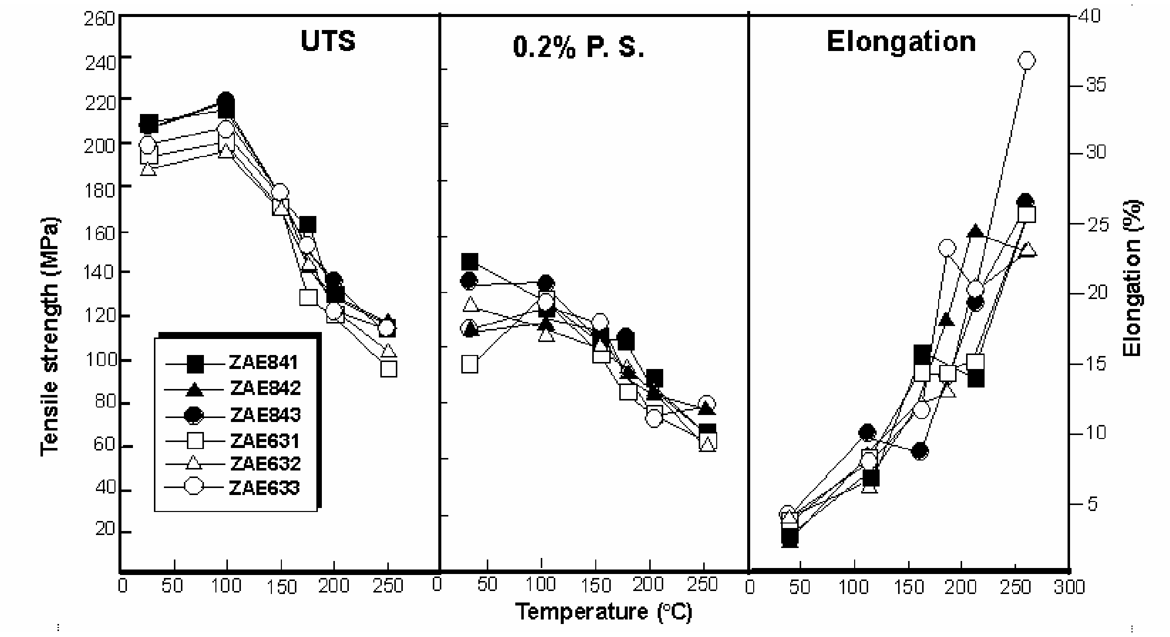

Fig. 5. Tensile properties of T-6 treated alloy specimens

Generally, elongation increases with test temperature. However, no significant effect of content of alloying elements associated with the ductility is observed. For instance, at 100˚C, ZAE843, which contains the highest amount of alloying element exhibits the highest elongation of about 10%. However, at temperatures higher than 100^{o}C, the elongation as it is below those of other alloys with lower content of alloying elements.

4. Conclusions

When strained-introduced specimens were press-formed at their semi-solid temperature of 580˚C the microstructure of all alloys exhibit microstructure that consisting of fine spherical particle and fine eutectic compound around the particle. The result can be summarized as follows;

1. The peak hardness of the alloys was mainly reached when the solution heat treatment is conducted at temperature of 330˚C for 16 hours and aging at 175˚C for 32 hours. The hardness number increase with an increase in content of the alloying elements. The highest hardness number is contributed by Mg-8%Zn-4%Al-0.6Ca with 3% rare earth, due to larger amount of remained compounds.
2. Tensile properties at high temperature of semi-solid formed alloys increase in accordance with increasing the amount of compounds. The amounts of compound increase as the alloying element increase. Therefore, it is noticeable that compounds play a significant role in improving the high temperature strength of the alloys but no particular influence in elongation occurs.

References

[1] J. F. King: ***Proc. Int. Conf. on Magnesium Alloys and their Applications,* ed.** by K. U. Kainer (WILEY-VCH, Germany, 2000) pp.14-22.

[2] H. Haferkamp, M. Niemeyer, R. Boehm, U. Holzkamp, C. Jachik and V. Kaese: Mater. Sci. Forum, 350-351 (2000), 31-41.

[3] S. Kamado, N. Ikeya, R. S. Rudi, T. Araki and Y. Kojima: ***Proc. Int. Conf. on Magnesium Alloys and their Applications,* ed**. by K. U. Kainer (WILEY-VCH, Germany, 2000) pp.14-22.

[4] S. Kamado, N. Ikeya, R. S. Rudi, T. Araki and Y. Kojima: Mater. Sci. Forum, 350-351 (2000), 205-213.

[5] R. S. Rudy: ***Application of semi solid forming to high performance Aluminum and Magnesium alloys,*** Doctoral dissertation, Nagaoka University of Technology, Japan , 2000) pp.173-178.

[6] A. Kaye and A. Street: ***Die Casting Metallurgy*** (Butterworth) Scienctific, London, (1982), pp.239-241.

[7] S. Kamado and Y. Kojima: ***Proc. 3rd Intern. Magnesium Conf.*** (The Institute of Material, 1997) pp.123-136.

[8] I. Ohnaka: ***Introduction to Heat Transfer and Solidification Analyses by Computer*** (Maruzen, Tokyo, 1995) pp.197-200.

[9] I. J. Polmear: ***Light Alloys,*** third edition, (Arnold, London, 1995), pp.223-227.

[10] N. G. Antara, T. Kayuta, S. Kamado and Y. Kojima: ***Proc.4th Pacific Rim Int. Conf. on Advanced Materials and Processing (PRICM4),*** **ed**. by S. Hanada, Z. Zhong, S. W. Nam and R. N. Wright. (The Japan Institute of Metal pp.1247-1250.