Kovove Mater. 48 2010 211–216
DOI: 10.4149/km_2010_3_211

Effect of Ce on microstructures and mechanical properties of as-cast Mg-8Li-1Al alloys

M. Zhang, X. Meng, R. Wu*, Ch. Cui, L. Wu

Key Laboratory of Superlight Materials & Surface Technology (Harbin Engineering University), Ministry of Education, Harbin 150001, P. R. China

Received 6 September 2009, received in revised form 10 February 2010, accepted 24 March 2010

Abstract

Microstructures and mechanical properties of Mg-8Li-1Al-xCe alloys are studied. Results show that Mg-8Li-1Al-xCe alloys are composed of α phase (white), β (gray) and AlCe phase. The grains are refined with Ce added in Mg-8Li-1Al alloy. The grains of Mg-8Li-1Al-1.4Ce alloy are refined most obviously. AlCe compound that forms in alloys is favorable for the improvement of strength when the content of Ce is less than 0.6 %. The as-cast Mg-8Li--1Al-0.6Ce alloy possesses the peak values of tensile strength and elongation (173.11 MPa and 21.2 %, respectively). The as-cast Mg-8Li-1Al-1.0Ce alloy possesses the highest Brinell hardness (61.8 HB).

K e y w o r d s: Mg-Li alloy, Ce, microstructures, mechanical properties, Brinell hardness

1. Introduction

Magnesium-lithium alloys possess the lowest density among metallic structural materials [1–3]. Due to their advantages of low density, high specific strength, good machinability and formability, good damping ability and high energetic particle penetration resistance [4–6], Mg-Li alloys have good prospects of applications in the fields of aerospace, electronic industry, military, etc. [7, 8].

When the content of Li is larger than 5.7 %, the microstructures of Mg-Li alloys will be changed from α (hcp) Mg-rich phase to α (hcp) Mg-rich and β (bcc) Li-rich phases [9–11]. The Mg-Li alloys with double phases ($\alpha + \beta$) possess good comprehensive mechanical properties (relatively high tensile strength and high elongation). Mg-8Li alloys are the typical double--phase alloys. Because of the relatively low strength, poor corrosion resistance and thermal stability of Mg-Li binary alloys, some alloying elements should be added into the alloys. Among the alloying elements, Al is one of the most common alloying elements. However, if the addition of Al is too high, the ductility of Mg-Li alloys will be reduced and the density of alloys will be increased. Accordingly, the amount of Al in Mg-Li alloys is always between 1 % and 3 % [12, 13].

Literature reported that the strength was improved and the grains were refined with Ce added in Mg-Li alloys [14–16]. However, the reports about the effects of Ce on the microstructures and mechanical properties of Mg-8Li-1Al alloys are very deficient.

In this paper, Mg-8Li-1Al-xCe alloys were prepared with vacuum melting method under the argon atmosphere. The microstructures and mechanical properties of as-cast alloys were also investigated and discussed.

2. Experimental procedure

Pure magnesium ingot (99.95 %), pure lithium ingot (99.90 %), pure aluminum ingot (99.95 %) and magnesium-cerium master alloy (containing Ce 18.26 %) were used in this experiment. The materials were melted in a vacuum induction-melting furnace under the protection of argon atmosphere. The furnace chamber pressure was pumped to 1×10^{-2} Pa, and then pure argon was input as protective gas before melting. The as-cast alloys were homogenized at 280 ℃ for 24 h.

*Corresponding author: tel.: 86-451-82519696; fax: 86-451-82519696; e-mail adress: Ruizhiwu2006@yahoo.com

Chemical composition of alloys was measured with inductively coupled plasma spectrometer. The results are listed in Table 1.

Microstructures were observed with optical microscope (OM). The samples were etched with an etchant of 3 vol.% nital. Phase composition of alloys was measured with X-ray diffraction (XRD). Micro-zone elemental analysis was measured with SEM and EDS. The mechanical properties of these alloys were meas-

Table 1. Chemical composition of alloys (mass %)

Nominal composition	Actual composition
Mg-8Li-1Al	Mg-8.2Li-1.12Al
Mg-8Li-1Al-0.2Ce	Mg-8.35Li-1.02Al-0.25Ce
Mg-8Li-1Al-0.6Ce	Mg-8.30Li-1.17Al-0.67Ce
Mg-8Li-1Al-1.0Ce	Mg-8.26Li-1.11Al-1.2Ce
Mg-8Li-1Al-1.4Ce	Mg-8.40Li-1.12Al-1.50Ce

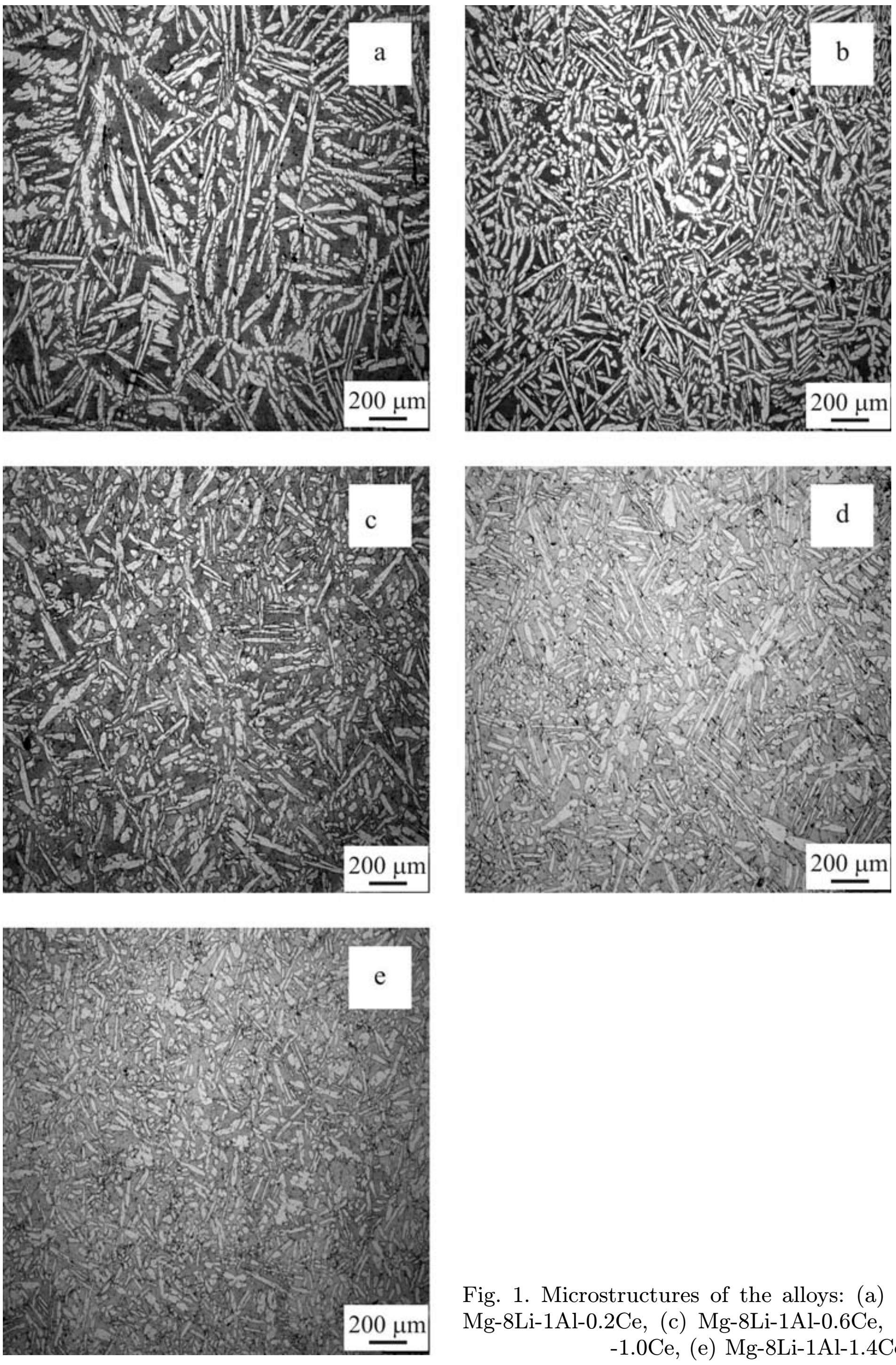

Fig. 1. Microstructures of the alloys: (a) Mg-8Li-1Al, (b) Mg-8Li-1Al-0.2Ce, (c) Mg-8Li-1Al-0.6Ce, (d) Mg-8Li-1Al--1.0Ce, (e) Mg-8Li-1Al-1.4Ce.

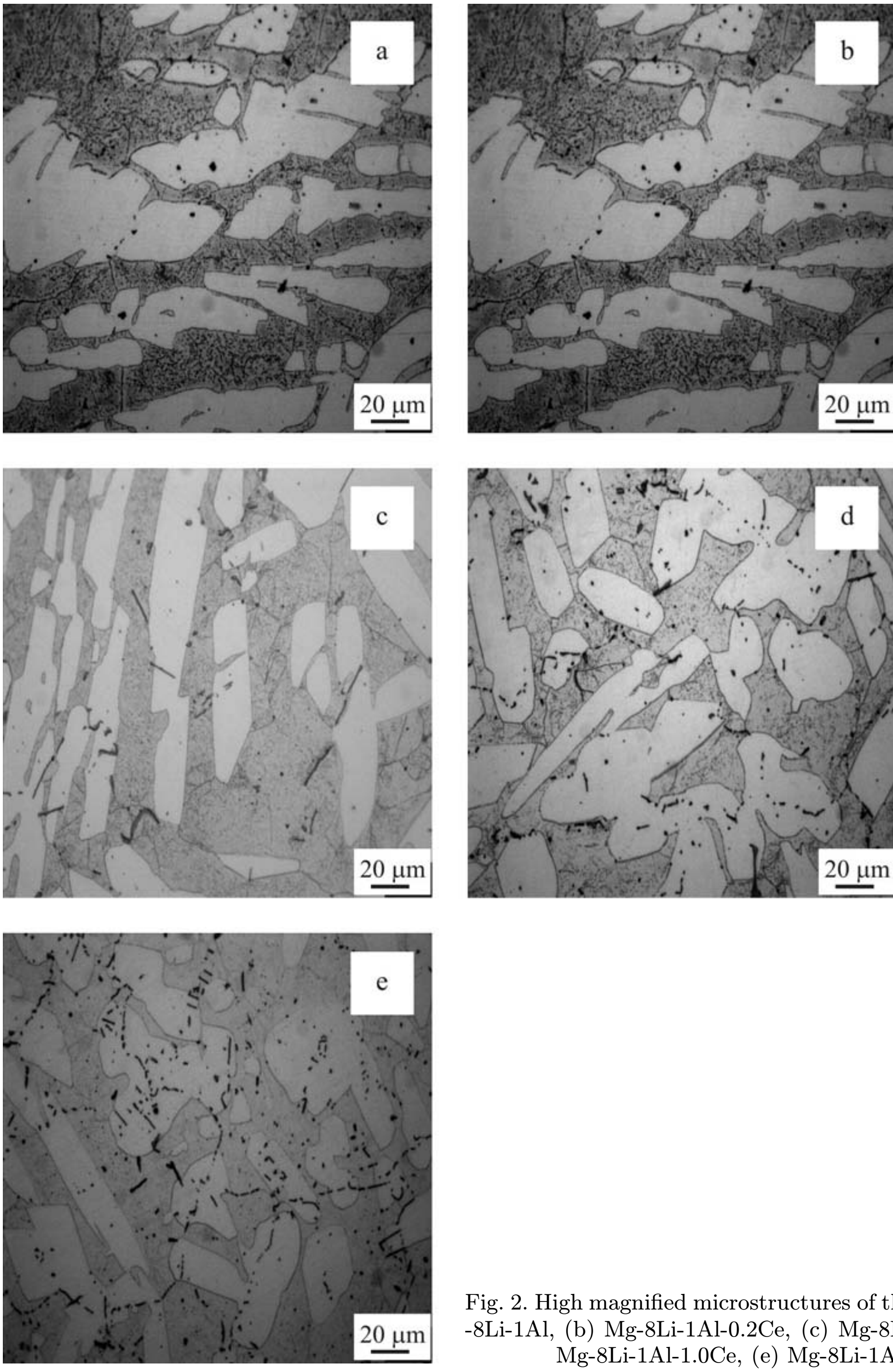

Fig. 2. High magnified microstructures of the alloys: (a) Mg-8Li-1Al, (b) Mg-8Li-1Al-0.2Ce, (c) Mg-8Li-1Al-0.6Ce, (d) Mg-8Li-1Al-1.0Ce, (e) Mg-8Li-1Al-1.4Ce.

ured with a tensile tester (2 mm min^{-1} of the tensile speed).

3. Results and discussion

3.1. Microstructures and phases analysis

Microstructures of Mg-8Li-1Al-xCe alloys are shown in Fig. 1. The microstructures of Mg-8Li-1Al alloy are composed of α phase (white) and β phase (gray). The microstructures of Mg-8Li-1Al-(0.2∼1.4)Ce alloys are composed of α phase (white), β phase (gray) and compounds. The shapes of α phase are virgulate-like and spherical-like. Phases and compounds are refined with Ce added in alloys. When the content of Ce is 1.4 %, the refinement of α phase is mostly obvious. Additionally, the shape of α phase changes from virgulate to spherical with Ce added in alloys.

To observe the microstructures of the alloys more clearly, the high-magnified microstructures are shown in Fig. 2. With Ce added in alloys, some compounds exist in matrix. The amount of AlCe phases increases with the Ce content.

To know the compounds in Mg-8Li-1Al-xCe alloys, specimens were analyzed with XRD and EDS. Figure 3 shows the XRD patterns of Mg-8Li-1Al-xCe alloys. It is known that the Mg-8Li-1Al alloy is composed of α (Mg) and β (Li). The AlCe phase exists in alloys with Ce addition. The diffraction strength of the AlCe phase increases with increasing content of Ce.

The EDS results are shown in Fig. 4. The compound at point A is composed of Mg, Al and Ce elements. Elements composition of point A is listed in Table 2. The atomic ratio of Al to Ce is about 1. Based on the electronegativity difference between elements, the trend to form compounds can be valued. The electronegativity difference between Ce and Al is larger than that between Ce and Mg [13]. Therefore, Al is easier than Mg to react with Ce to form compounds. Combined with the XRD patterns, it can be concluded that the compound is AlCe.

3.2. Mechanical properties

Figure 5 shows the effect of Ce on the mechanical properties of alloys. Both strength and elongation of the alloys increase with increasing content of Ce. The alloy possesses peak tensile strength and elongation (173.11 MPa and 21.2 %, respectively), when the content of Ce is 0.6 %. The stress-displacement curve of Mg-8Li-1Al-0.6Ce alloy is shown in Fig. 6.

There are two aspects for the increase of strength and elongation of alloys. Firstly, α phase of alloys is refined with the Ce added in alloys. It brings about the mechanical properties of alloys are improved [11]. Secondly, during tensile testing, the AlCe phase exists at the grain boundary that can restrain the grain boundary slip. This is also a favorable factor for the mechanical properties of alloys are improved.

The amount of AlCe compounds increases with increasing content of Ce. The stress concentration is produced on the tips of AlCe compounds while suffered from external force. Under the external force, the tips of AlCe compounds are the cracking sources, which may lead to the reduction of the elongation of as-rolled alloy.

The strength and elongation of alloys is influenced with the size and the shape of phases, compounds and grains. When the influence of the refinement of grains and phases is greater than that of cracking sources, the strength of alloys is increased. Reversibly, the strength of alloys is reduced. Therefore, the strength and elongation of alloys are reduced when the content of Ce is larger than 0.6 %.

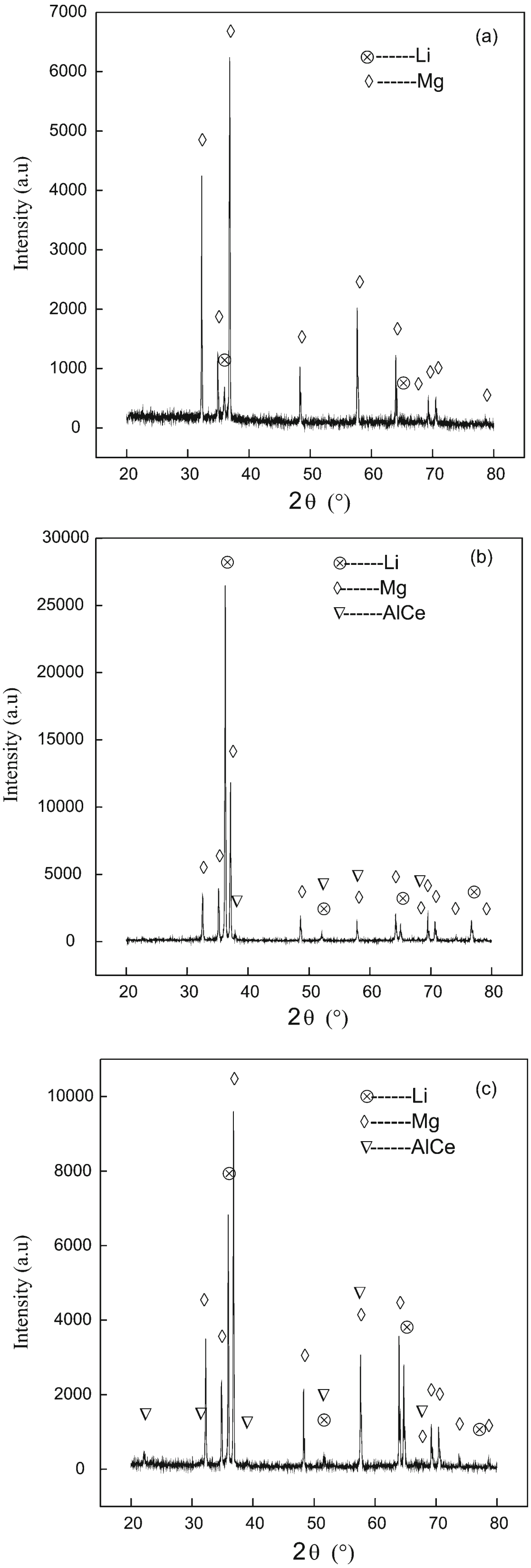

Fig. 3. XRD pattern of as-cast alloys: (a) Mg-8Li-1Al, (b) Mg-8Li-1Al-0.2Ce, (c) Mg-8Li-1Al-1.4Ce.

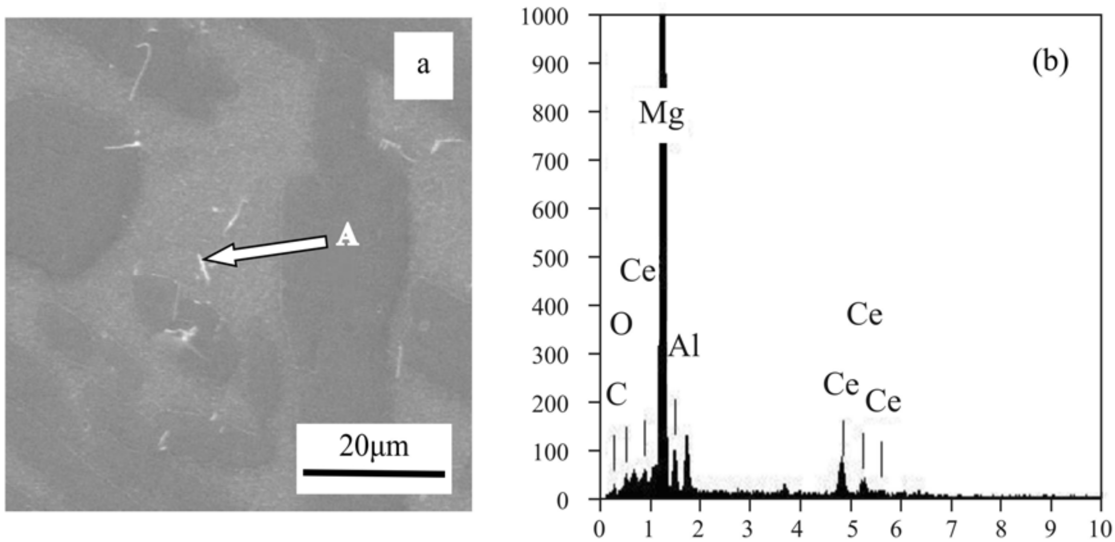

Fig. 4. SEM image (a) and EDS pattern (b) of Mg-8Li-1Al-0.2Ce alloy.

Table 2. Elements composition of point A

Element	wt.%	at.%
Mg	78.35	74.58
Al	2.99	2.74
Ce	13.18	2.32

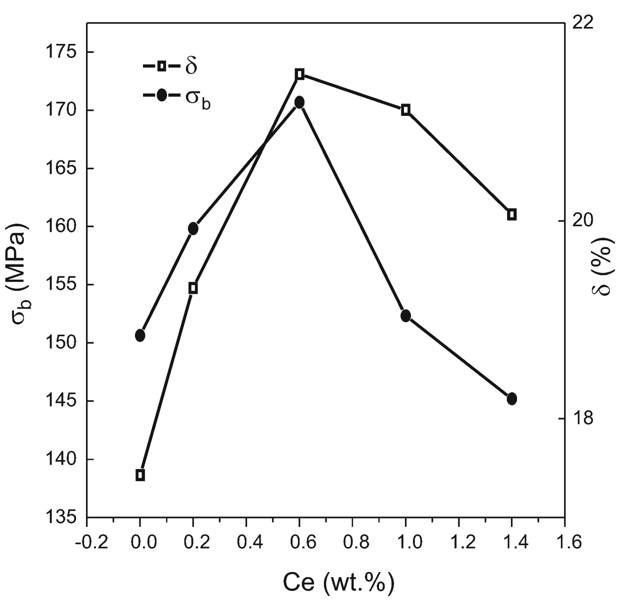

Fig. 5. Relationship between mechanical properties of alloys and Ce content in Mg-8Li-1Al.

The influence of Ce on the hardness of alloys is shown in Fig. 7. The hardness of alloys increases with Ce added in alloys. The Mg-8Li-1Al-1Ce alloy possesses peak hardness (61.8 HB). The hardness of alloy is decreased when the content of Ce is more than 1.0 %.

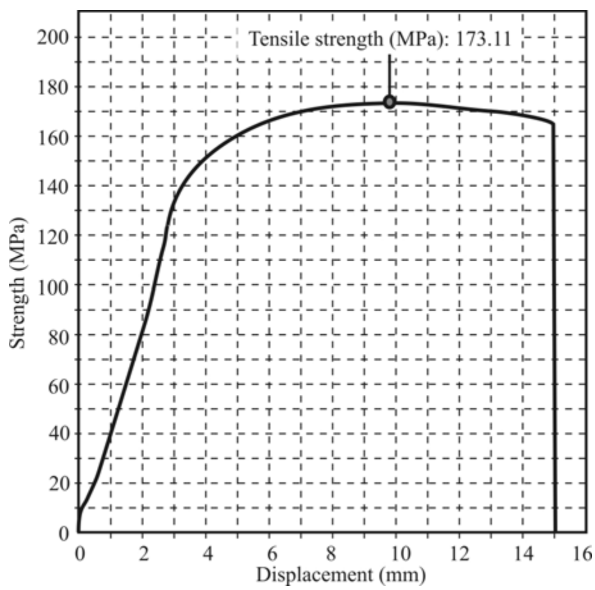

Fig. 6. The stress-displacement curve of Mg-8Li-1Al-0.6Ce alloy.

The AlCe compound is a hard phase. Therefore, the hardness of alloys increases with increasing amount of AlCe compound. When excess AlCe compounds exist in the matrix, the amount of Al dissolved in matrix is decreased. Therefore, the effect of solid solution strengthening is decreased.

4. Conclusions

1. The α phase of the alloys is refined with Ce

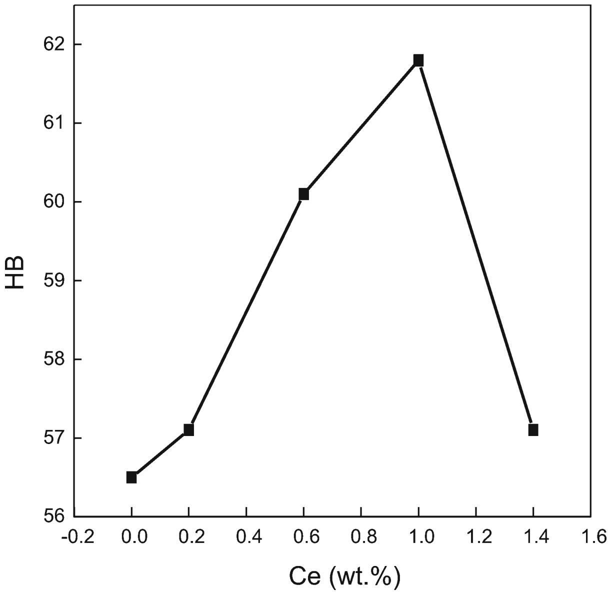

Fig. 7. Relationship between hardness of alloys and Ce content.

added in alloys. When the content of Ce is 1.4 %, α phase is refined most obviously. The AlCe compounds form in matrix when the Ce is added in alloys.

2. The strength and elongation of alloys are increased with the increasing content of Ce. The alloy possesses peak tensile strength and elongation (173.11 MPa and 21.2 %, respectively) when content of Ce is 0.6 %. The strength and elongation of alloys are decreased with the content of Ce being increased further.

3. The strength and elongation of alloys are influenced by the size and the shape of phases, compounds and grains. The mechanical properties of alloys would be improved by refinement and spheroidization of phases.

4. The hardness of alloys increases with Ce added in alloys. The alloy possesses peak hardness (61.8 HB) when the content of Ce is 1.0 %. The hardness of alloys decreases when the content of Ce is more than 1.0 %.

Acknowledgements

This work was supported by the National Natural Science Foundation of China (No. 50871033), the Key Project of Science and Technology of Harbin City (2008AA4CH044, 2009AA1AG065, 2010AA4BE031), the Key Project of Chinese Ministry of Education (NO 208181) and the Fundamental Research funds for the Central Universities.

References

[1] TROJANOVA, Z.—LUKAC, P.: Kovove Mater., *45*, 2007, p. 75.
[2] TROJANOVA, Z.—DROZD, P.—CHMELIK, F.: Mater. Sci. Engn. A., *410*, 2005, p. 148. doi:10.1016/j.msea.2005.08.088
[3] TROJANOVA, Z.—DROZD, P.—KUDELA, S.—SZARAZ, Z. et al.: Compos. Sci. Technol., *67*, 2007, p. 1965.
[4] HAFERKAMP, H.—NIEMEYER, M.—BOEHEM, R.: Mater. Sci. Forum, *350*, 2000, p. 31. doi:10.4028/www.scientific.net/MSF.350-351.31
[5] XIANG, Q.—WU, R. Z.—ZHANG, M. L.: J. Alloys Compd., *477*, 2009, p. 832. doi:10.1016/j.jallcom.2008.10.166
[6] WU, R. Z.—ZHANG, M. L.: Mater. Sci. Eng. A., *520*, 2009, p. 36. doi:10.1016/j.msea.2009.05.008
[7] BYRER, T. G.—WHITE, E. L.—FROST, P. D.: The Development of Magnesium-Lithium Alloys for Structural Applications. NASA Contractor Report. Columbus, OH, Battelle Memorial Institute 1963.
[8] WU, R.—WANG, C.—ZHANG, M.: Kovove Mater., *47*, 2009, p. 169.
[9] CHIU, C. H.—WU, H. Y.—WANG, J. Y. et al.: J. Alloys Compd., *460*, 2008, p. 246. doi:10.1016/j.jallcom.2007.05.106
[10] YU, K.—LEE, W. X.—LEE, S. R. et al.: Nonferrous Alloy. China, *1*, 2001, p. 41.
[11] WEI, L. Y.—DUNLOP, G. L.—WESTENGEN, H.: Mater. Sci. Technol., *12*, 1996, p. 741.
[12] YU, H. S.—MING, G. H.: Rare Metal Materials and Engineering. China, *25*, 1996, p. 1.
[13] WU, R. Z.—QIU, Z. K.—ZHANG, M. L.: Mater. Sci. Eng. A., *516*, 2009, p. 96. doi:10.1016/j.msea.2009.04.025
[14] WANG, T.—ZHANG, M. L.—WU, R. Z.: Mater. Lett., *62*, 2008, p. 1846. doi:10.1016/j.matlet.2007.10.017
[15] ZHANG, M. L.—WU, R. Z.—WANG, T. et al.: Trans. Nonferrous Met. Soc. China, *17*, 2007, p. 381.
[16] ZHANG, M. L.—WU, R. Z.—WANG, T.: J. Mater. Sci., *44*, 2009, p. 1237. PMid:19184371. doi:10.1007/s10853-009-3254-9