Available online at www.sciencedirect.com
ScienceDirect
Trans. Nonferrous Met. Soc. China 20(2010) s357−s360
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Effects of yttrium on microstructure and mechanical properties of Mg-Zn-Cu-Zr alloys

BAI Yun(白 云), FANG Can-feng(房灿峰), HAO Hai(郝 海),
QI Guo-hong(齐国红), ZHANG Xing-guo(张兴国)

Research Center of Foundry Engineering, Dalian University of Technology, Dalian 116024, China

Received 23 September 2009; accepted 30 January 2010

Abstract: The effects of yttrium addition on microstructure and mechanical properties of as-cast Mg-6Zn-3Cu-0.6Zr-*x*Y (x=0, 0.5, 1.0, 1.5 and 2.0, mass fraction, %) (ZCK630+*x*Y for short in this study) alloys were investigated by means of OM, XRD and SEM. The results show that the average grain size of Mg-Zn-Cu-Zr magnesium alloy is effectively reduced (from 57 μm to 39 μm) by Y addition. The analysis of XRD indicates the existence of I-phase (Mg_3Zn_6Y) and W-phase ($Mg_3Zn_3Y_2$) in ZCK630 alloys with Y addition. The ultimate tensile strength of ZCK630 alloys is significantly deteriorated with increasing Y addition, which is possibly related to the continuous networks of intergranular phases and the increase of W-phase.

Key words: Mg-Zn-Cu-Zr alloy; yttrium; microstructure; mechanical property

1 Introduction

Magnesium alloys will have great potential for the application of structural parts in the near future due to their low density, high specific strength, and good castability, etc[1−3]. It was reported[4−9] that magnesium alloys containing rare earth (RE) element, such as yttrium, exhibit excellent mechanical properties at room temperature. Generally, there are two kinds of ternary equilibrium phases in Mg-Zn-Y and Mg-Zn-Y-Zr systems. They are W-phase ($Mg_3Zn_3Y_2$, cubic structure) and I-phase (Mg_3Zn_6Y, icosahedral quasicrystal structure, quasi-periodically ordered)[6]. Recently, it was reported that as-cast Mg-rich Mg-Zn-Y alloys, which consist of a thermally stable icosahedral quasicrystalline phase (I-phase) formed in situ as a second phase in the α-Mg matrix during solidification, exhibit a significant level of yield stress at room temperature, depending on the volume fraction of the I-phase[10]. It was found[11] that W-phase basically has no strengthening effect on Mg-Zn-Y-Zr system alloys, and the strength of alloys degrades greatly with the increase of W-phase. Furthermore, the experimental results of magnesium alloys reveal that the addition of Zn and Y (or Cu and Y) can form long period ordered structure that leads to the improvement of its strength and plasticity[12−13].

In this study, we present a novel Mg-6Zn-3Cu-0.6Zr (ZCK630 for short in this study) alloy with Y addition. The effects of yttrium on microstructure and mechanical properties of Mg-Zn-Cu-Zr alloys will be studied.

2 Experimental

Magnesium alloys were designed to have a nominal component (mass fraction) of 6% Zn, 3% Cu, 0.6% Zr and x Y (x=0, 0.5%, 1.0%, 1.5% and 2.0%). Commercial pure Mg, Zn and Y stuffs, Mg-25%Zr inter-alloy and Mg-80%Cu inter-alloy were melted in a steel crucible at about 780 ˚C. The melt was stirred in order to make the solutes mix thoroughly, and then cooled and kept at 720 ˚C for about 15 min. Finally, the melt was poured into an iron mould preheated to about 300 ˚C. The whole process was conducted under the cover of protection atmosphere (0.4% SF_6, 50.4% CO_2 and 49.2% Ar, volume fraction).

The chemical compositions of the magnesium alloys were determined by XRF (X-ray fluorescence) analysis.

Foundation item: Project(50875031) supported by the National Natural Science Foundation of China; Project(2009AA03Z525) supported by the National High-tech Research and Development Program of China; Project(20095263005) supported by Aviation Science Foundation of China; Project(2006) supported by the Foundation for the Young Scholars of Dalian University of Technology

Corresponding author: ZHANG Xing-guo; Tel: +86-411-84706183; E-mail: zxgwj@dlut.edu.cn

The results are listed in Table 1. The linear-intercept method was employed to measure the grain size. Microstructures of the as-cast alloys were examined by means of optical microscopy (OM) and scanning electron microscopy (SEM) (JEOL JSM−5600LV). The samples were etched with an etchant of 4 mL nitric acid and 96 mL alcohol. The structural constituent was also analyzed by X-ray diffraction (XRD) on a Shimadzu XRD−6000 diffractometer using Cu K_α radiation. Tensile test was carried out at room temperature and an initial strain rate of 5×10^{-4} s^{-1}, and the tensile specimen had a nominal size of 6 mm in diameter and 30 mm in length.

Table 1 Chemical compositions of Mg alloys determined by XRF (mass fraction, %)

Alloy	Zn	Cu	Zr	Y
ZCK630	5.64	2.92	0.42	–
ZCK630+0.5Y	5.40	2.88	0.71	0.48
ZCK630+1.0Y	5.32	2.69	0.52	1.00
ZCK630+1.5Y	5.32	2.77	0.58	1.58
ZCK630+2.0Y	5.74	2.99	0.53	2.09

3 Results and discussion

3.1 Microstructure

The XRD patterns of ZCK630+*x*Y alloys are shown in Fig.1. It can be seen that ZCK630 alloy is composed of *α*-Mg and CuMgZn phase. For ZCK630+0.5Y alloy, there exist I-phase and W-phase in addition to *α*-Mg and CuMgZn phase. For ZCK630+0.5Y, ZCK630+1.0Y and ZCK630+1.5Y alloys, the peak intensities of I-phase and W-phase gradually increase with Y addition increasing. It implies that the contents of I-phase and W-phase gradually increase with Y addition increasing. It is important to point out that the W-phase increases at a far quicker pace than the I-phase.

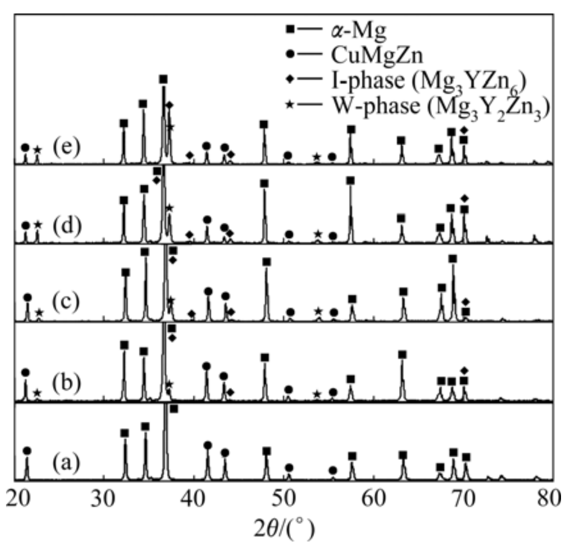

Fig.1 XRD patterns of as-cast ZCK630+*x*Y alloys: (a) ZCK630 alloy; (b) ZCK630+0.5Y alloy; (c) ZCK630+1.0Y alloy; (d) ZCK630+1.5Y alloy; (e) ZCK630+2.0Y alloy

Fig.2 shows the optical microstructures of the as-cast ZCK630 alloys with different Y additions. It can be found that the ZCK630 alloy is comprised of dendrites of magnesium matrix separated by interdendritic phases. With Y addition increasing, the content of interdendritic compound phases increases obviously. According to the XRD analysis (Fig.1), the increased phases should be the W-phase and I-phase. The Y additions to the ZCK630 alloy result in the refinement of *α*-Mg grains, i.e. most of the dendrites disappear and more equiaxed grains are obtained. The linearly intercepted grain sizes of the alloys are 57, 54, 52, 42 and 39 μm, respectively, which means that the grain size of ZCK630 magnesium alloys is effectively reduced by Y addition.

Rare earth elements generally have grain refinement effects on magnesium alloys. The refinement of *α*-Mg grains can be mainly ascribed to the factors as follows: 1) Element Y can effectively refine grains of magnesium alloys because element Y can change the solution degree of element Zn, which decreases the solidus curve, shortens the time for nucleation, and then reduces the grain size[14]; 2) Element Y is a surface active element to Mg and distributes along grain boundaries of *α*-Mg during solidification. The element Y combines with Mg to form compound and concentrates along the grain boundaries to prevent the grain growth [15].

The SEM images of the ZCK630, ZCK630+0.5Y and ZCK630+1.5Y alloys are shown in Fig.3. It can be seen from Fig.3(a) that the intergranular phases (CuMgZn) is semi-continuous network structure. When 0.5% Y is added, W-phase and I-phase emerge in the matrix. The intergranular lamellar eutectics are composed of *α*-Mg and W-phase, as shown in Fig.3(b). The rod-like I-phase mainly exists in the boundaries and the ends of W-phase. As shown in Fig.3(c), the coarsened W-phase is observed in the alloy with 1.5% Y. The volume fraction of the W-phase increases and W-phase tends to form continuous network in the grain boundary. And the grain size of *α*-Mg matrix decreases gradually.

3.2 Mechanical property

The relationship between mechanical properties and Y content in alloys are shown in Fig.4. As shown in Fig.4, the ultimate tensile strength (UTS) reduces from

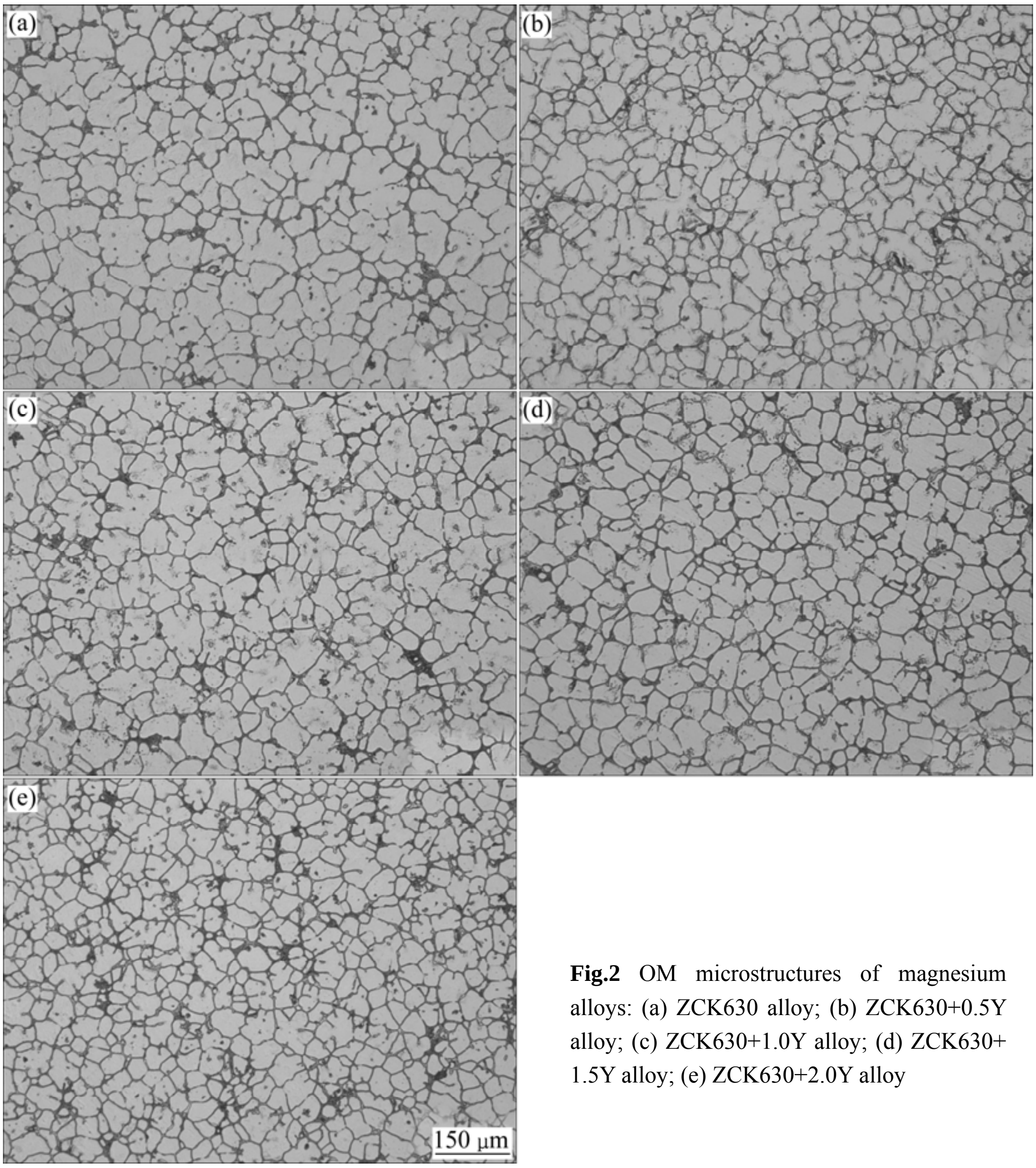

Fig.2 OM microstructures of magnesium alloys: (a) ZCK630 alloy; (b) ZCK630+0.5Y alloy; (c) ZCK630+1.0Y alloy; (d) ZCK630+1.5Y alloy; (e) ZCK630+2.0Y alloy

158 MPa to 126 MPa as the Y content (mass fraction) increases from 0 to 0.5%. However, with the further increase of Y content, the strength of the alloys improves greatly. When the Y content is 1.0%, the UTS of alloy reaches 146 MPa. The further increase of Y content leads to drop trend of UTS.

According to the grain size, the UTS of ZCK630+2.0Y alloys (with the smallest grain size) should be the highest. However, the results show that the UTS of ZCK630+1.5Y and ZCK630+2.0Y alloys are lower than that of ZCK630+1.0Y alloy. Therefore, to explain this abnormal phenomenon, the influence of W-phase on the mechanical properties of the alloys must be investigated, which will be discussed as follows.

When 0.5%Y is added to the ZCK630 alloys, the refinement of grain size is very small (from 57 μm to 54 μm). Thus the influence of grain size on the mechanical properties is very slight. On the other hand, the W-phase begins to emerge in the ZCK630 alloys. The degradation of mechanical properties attributes to the W-phase that is easily cracked during the tensile process[10]. When Y content is up to 1.0%, the improved strength is regarded as the strengthening effect of the smaller grain size (52 μm). When Y content reaches 1.5%, the coarsened W-phase increases obviously. In addition, as shown in Fig.3(c), the primary α-Mg gains are almost surrounded completely by the continuous networks of interdendritic eutectic phase, which significantly deteriorates the ultimate strength.

Certainly, the increase of I-phase can improve the mechanical properties of ZCK630 alloys. However, as shown in Fig.1 and Fig.3, the quantity of rod-like I-phase is tiny. Therefore, the influence of I-phase on the mechanical properties can be omitted.

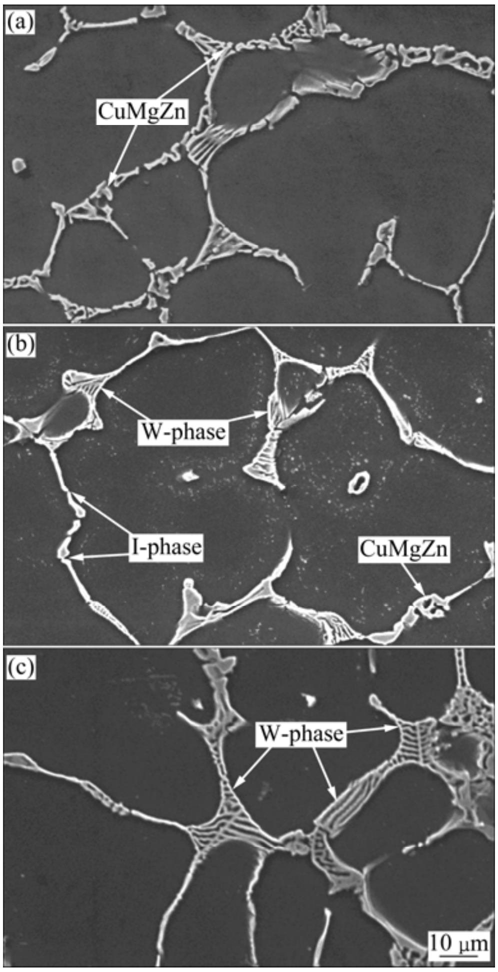

Fig.3 SEM images of as-cast Mg-Zn-Y alloys with different Y contents: (a) ZCK630 alloy; (b) ZCK630+0.5Y alloy; (c) ZCK630+1.5Y alloy

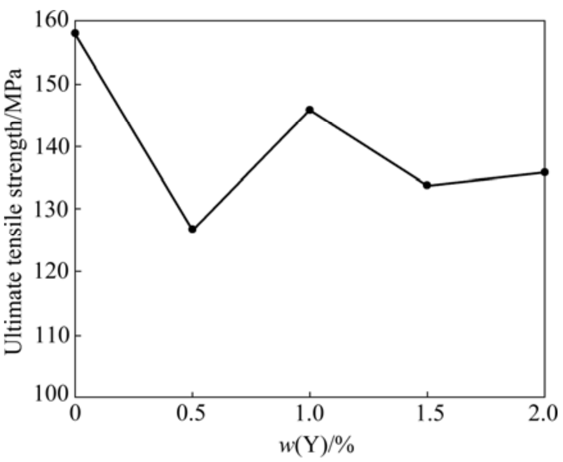

Fig.4 Relationship between mechanical properties and Y content of ZCK630 alloys

4 Conclusions

1) I-phase and W-phase emerge in the microstructures as a result of the Y addition in the ZCK630 alloys. The W-phase increases gradually with increasing Y content.

2) The grain size of Mg-Zn-Cu-Zr magnesium alloy is effectively reduced when element Y is added into the ZCK630 alloys.

3) With the Y addition, the increased W-phase and the continuous networks of intergranular phases significantly deteriorate the mechanical properties.

References

[1] KOJIMA Y, AIZAWA T, KAMADO S, HIGASHI K. Progressive steps in the platform science and technology for advanced magnesium alloys [J]. Materials Science Forum, 2003, 419/420/421/422: 3−20.

[2] MORDIKE B L, EBERT T. Magnesium: Properties–applications–potential [J]. Materials Science and Engineering A, 2001, 302(1): 37−45.

[3] MENG Fan-gui, LIU Hua-shan, LIU Li-bin, JIN Zhan-peng. Thermodynamic optimization of Mg-Nd system [J]. Transactions of Nonferrous Metals Society of China, 2007, 17(1): 77−81.

[4] ZHANG Ya, ZENG Xiao-qin, LIU Liu-fa, LU Chen, ZHOU Han-tao, LI Qiang, ZHU Yan-ping. Effects of yttrium on microstructure and mechanical properties of hot-extruded Mg-Zn-Y-Zr alloys [J]. Materials Science and Engineering A , 2004, 373(1/2): 320−327.

[5] XIE Jian-chang, LI Quan-an, WANG Xiao-qiang, LI Jian-hong. Microstructure and mechanical properties of AZ81 magnesium alloy with Y and Nd elements [J]. Transactions of Nonferrous Metals Society of China, 2008, 18(2): 303−308.

[6] XU D K, TANG W N, LIU L, XU Y B, HAN E H, Effect of Y concentration on the microstructure and mechanical properties of as-cast Mg-Zn-Y-Zr alloys [J]. Journal of Alloys and Compounds, 2007, 432(1/2): 129−134.

[7] ZOU Hong-hui, ZENG Xiao-qin, ZHAI Chun-quan, DING Wen-jiang. The effects of yttrium element on microstructure and mechanical properties of Mg-5wt.%Zn-2wt.%Al alloy [J]. Materials Science and Engineering A, 2005, 402(1/2): 142−148.

[8] SINGH A, TSAI A P. On the cubic W phase and its relationship to the icosahedral phase in Mg-Zn-Y alloys [J]. Scripta Materialia. 2003, 49(2): 143−148.

[9] XIAO Wen-long, WANG Jun, YANG Jie, JIA Shu-sheng, WANG Li-min. Microstructure and mechanical properties of Mg-12.3Zn-5.8Y-1.4Al alloy [J]. Materials Science and Engineering A, 2008, 485(1/2): 55−60.

[10] BAE D H, LEE M H, KIM K T, KIM W T, KIM D H. Application of quasicrystalline particles as a strengthening phase in Mg-Zn-Y alloys [J]. Journal of Alloys and Compounds, 2002, 342(1/2): 445−450.

[11] XU D K, LIU L, XU Y B, HAN E H. Effect of microstructure and texture on the mechanical properties of the as-extruded Mg-Zn-Y-Zr alloys [J]. Materials Science and Engineering A, 2007, 443(1/2): 248−256.

[12] CHINO Y, MABUCHI M, HAGIWARA S, IWASAKI H, YAMAMOTO A, TSUBAKINO H. Novel equilibrium two phase Mg alloy with the long-period ordered structure [J]. Scripta Materialia, 2004, 51(7): 711−714.

[13] KAWAMURA Y, KASAHARA T, IZUMI S, YAMASAKI M. Elevated temperature $Mg_{97}Y_2Cu_1$ alloy with long period ordered structure [J]. Scripta Materialia, 2006, 55(5): 453−456.

[14] MA Chun-jiang, LIU Man-ping, WU Guo-hua, DING Wen-jiang, ZHU Yan-ping. Tensile properties of extruded ZK60-RE alloys [J]. Materials Science and Engineering A, 2003, 349(1/2): 207−212.

[15] PENG Q M, WU Y M, FANG D Q, MENG J, WANG L M. Microstructures and properties of Mg-7Gd alloy containing Y [J]. Journal of Alloys and Compounds, 2007, 430(1/2): 252−256.

(Edited by HE Xue-feng)