

Effect of elements Zn, Sn and In on microstructures and performances of AZ91 alloy

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Abstract: A new magnesium alloy plate added elements Zn, Sn and In was manufactured by twin-roll continuous casting method to improve the precipitation of AZ91 alloy. The effects of elements addition and casting method on microstructure and mechanical properties of the Mg-Zn-In-Sn alloys were investigated by optical microscopy (OM), transmission electron microscopy (TEM), electron probe micro-analysis (EPMA), X-ray diffractometry (XRD) and energy dispersion spectrograph (EDS). The results show that the Mg-Zn-In-Sn alloy has higher tensile strength and better corrosion protection than the AZ91 alloy. The outstanding precipitation strengthening effect of the alloy is attributed to the small grain size and the hard precipitates between the grain boundaries.

Key words: AZ91 alloy; Mg-Zn-In-Sn alloy; twin-roll continuous casting; mechanical property

1 Introduction

Magnesium alloys are considered a potential material for the 21st century, which plays an important role in the mass reduction process because of their characteristics such as low density[1–2], high specific strength and stiffness, good damping characteristics, acceptable weldability, excellent machinability and castability[3]. Magnesium alloys were widely applied in recent years, including gear boxes, seat supports, steering column assemblies, transfer cases, transmission housings, valve covers and wheels, etc[4–5]. However, the poor plastic deformation and strength of magnesium alloys often limit their widespread use[6–7]. In order to enhance the material strength and other mechanical properties, in this work, a new magnesium alloy by adding elements Zn, Sn and In to the AZ91 alloy was developed. And its thin plate was fabricated by the twin-roll continuous casting method[8]. The effects of the elements addition on the microstructure of the Mg-Zn-In-Sn alloy were investigated. The outstanding precipitation strengthening effect of the alloy should be

attributed to the small grain size and the hard precipitates between the grain boundaries[9]. Finally, the corrosion behavior of the AZ91 alloy was compared with that of the developed Mg-Zn-In-Sn alloy on the surface microstructures, which can affect the corrosion protection.

2 Experimental

2.1 Twin rolls continuous casting method

The pure metals of zinc, tin and indium were added into the AZ91 alloy, and then the temperature was increased to 680 °C. When the molten liquid from the tundish was poured into the space formed by two rotating rolls and side dams, the solidification started at the point of first metal-roll contact; the solidified shells would move with rolls, which were cooled by water and became thicker[10]. Finally, the solidified magnesium alloy fell into an oil tank just under the exit of twin roll caster.

2.2 Tensile test

The specimens with stretching region dimensions

were tested using universal testing machine (SHIMATSU AUTOGRAPH AG-300KNG) at the initial strain rates of 3.21×10^{-5} , 1.60×10^{-4} and $1.60 \times 10^{-3} \text{ s}^{-1}$, respectively.

3 Results and discussion

3.1 Tensile properties of Mg-Zn-In-Sn alloy

Fig.1 shows the tensile test strip specimens with stretching region dimensions. Fig.2 shows the effect of initial strain rate on the tensile strength of the Mg-Zn-In-Sn alloy at room temperature. The mechanical properties of the AZ91 alloy and Mg-Zn-In-Sn alloy are summarized in Table 1. The results indicate that the Mg-Zn-In-Sn alloy exhibits better mechanical properties than the AZ91 alloy. The increase of tensile strength of the Mg-Zn-In-Sn alloy is ascribed to the refinement of α -Mg dendrites and the increase of precipitate and eutectic phase[11–12].

3.2 Microstructure of Mg-Zn-In-Sn alloy

Fig.3 shows the OM microstructures of die casting

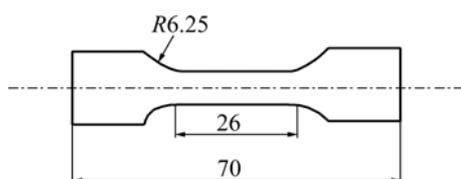


Fig.1 Schematic diagram of tensile specimen (unit: mm)

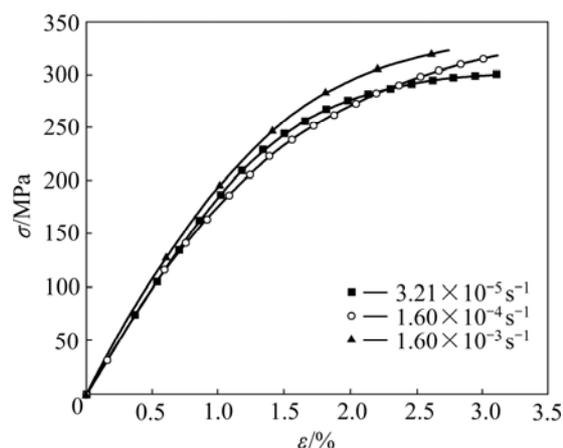


Fig.2 Stress—strain curves of Mg-Zn-In-Sn alloy by twin-roll casting

Table 1 Values of elongation and UTS for magnesium alloys

Alloy	$\dot{\epsilon}/\text{s}^{-1}$	UTS/MPa	Elongation/%
Die casted AZ91	—	230	3.0
Twin roll continuous casted Mg-Zn-In-Sn	3.21×10^{-5}	301	3.1
	1.60×10^{-4}	317	3.1
	1.60×10^{-3}	322	2.8

(DC) and twin-roll continuous casting (CC) specimens. As shown in Fig.3, the mean grain size of the Mg-Zn-In-Sn alloys treated by CC (Figs.3(b) and (d)) is smaller than the total grain size of the Mg-Zn-In-Sn alloys treated

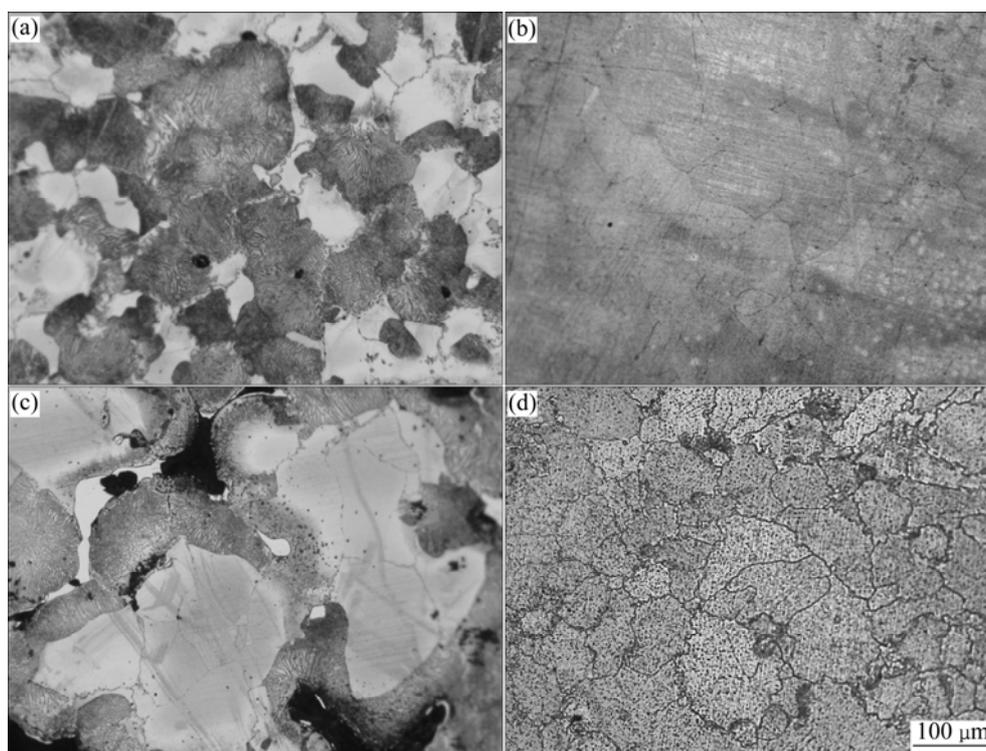


Fig.3 OM microstructures of magnesium alloys treated by different treatments: (a) AZ91 alloy (DC); (b) AZ91 alloy (CC); (c) Mg-Zn-In-Sn alloy (DC); (d) Mg-Zn-In-Sn alloy (CC)

by DC (Figs.3(a) and (c)). After CC treatment, the band structures disappear and the microstructure becomes uniform. A typical microstructure of the Mg-Zn-In-Sn alloy has well-developed primary β phase along the α -Mg grain boundaries in the form of continuous network[13].

As shown in Fig.4, TEM observation indicates that the dislocations distribute more preferentially in the regions (Figs.4(b) and (d)) next to the grain boundaries and precipitate than in the regions (Figs.4(a) and (c)) of the matrix. The dislocations in different planes cross slip and pile up in the region next to grain boundary to form

dislocation networks. It shows that the dislocations pile up in the matrix next to the precipitates. The precipitates are effective for strengthening. The morphology of α -Mg particles is evolved when the elements Zn, Sn and In are added into the AZ91 alloy. Thus, the tensile strength of the Mg-Zn-In-Sn alloy is higher than that of the AZ91 alloy.

3.3 Phase composition of Mg-Zn-In-Sn alloy

The XRD patterns of the AZ91 alloy and the Mg-Zn-In-Sn alloy are shown in Fig.5. The XRD pattern reveals that $Mg_{17}Al_{12}$ is the main microscopic component

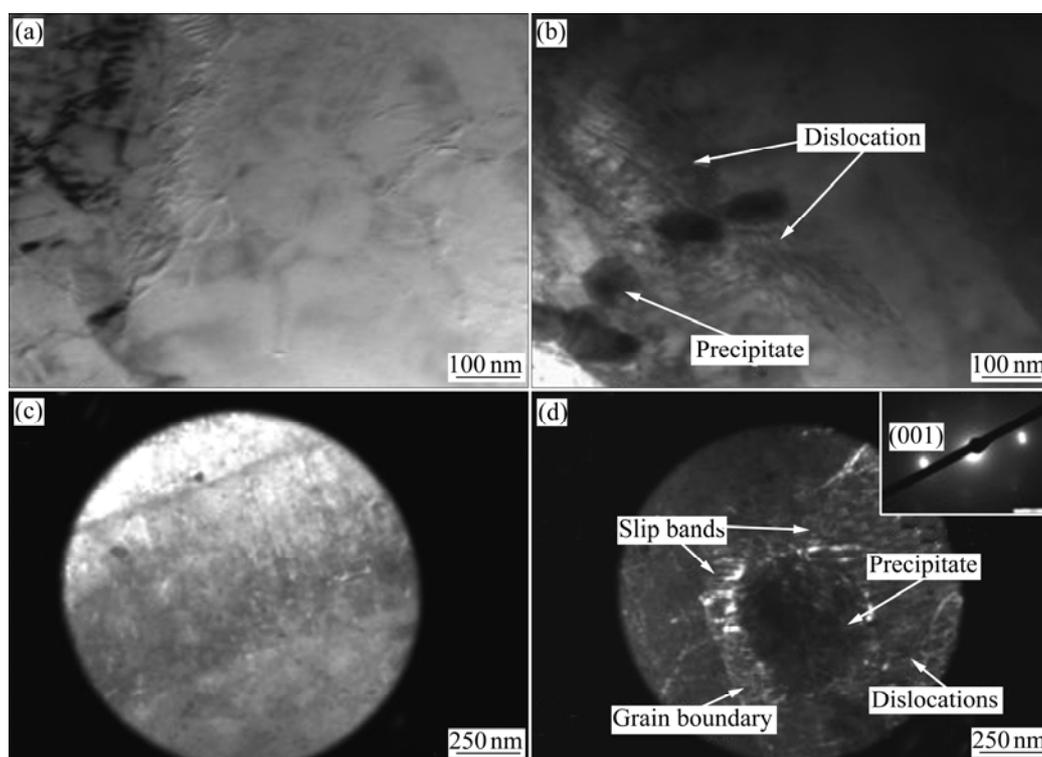


Fig.4 TEM images of Mg-Zn-In-Sn alloys without and with precipitates: (a) Without precipitates, low magnification; (b) With precipitates, low magnification; (c) Without precipitates, high magnification; (d) With precipitates, high magnification

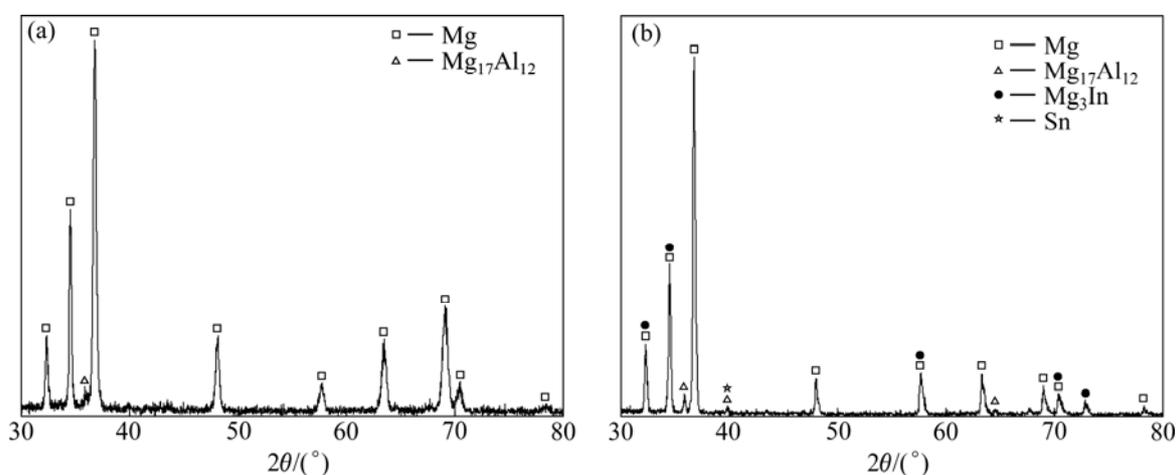


Fig.5 XRD patterns of magnesium alloys: (a) AZ91 alloy; (b) Mg-Zn-In-Sn alloy

of the AZ91 alloy (Fig.5(a)), and Mg_3In , $Mg_{17}Al_{12}$ and Sn are the main microscopic components of the Mg-Zn-In-Sn alloy. It should be noted that the occurrence of Mg-In, Mg-Al and Sn phase in Fig.5(b) affects the mechanical properties and corrosion behaviors of the Mg-Zn-In-Sn alloy.

The EDS patterns of the Mg-Zn-In-Sn alloys without and with precipitates are shown in Figs.6 and 7. And the elemental contents are listed in Tables 2 and 3. The results of TEM with EDS of the Mg-Zn-In-Sn alloys indicate that the precipitate is formed by four elements of Al, Mg, Zn and Sn at grain boundaries.

Table 2 Elemental contents of Mg-Zn-In-Sn alloy without precipitate

Element	w/%	x/%	x(Error)/%
Mg	95.19	97.25	±1.10
Al	2.45	2.25	±0.21
Zn	0.75	0.16	±0.11
Sn	1.62	0.34	±0.09

3.4 Distribution of elements in Mg-Zn-In-Sn alloy

The EPMA elements distribution of magnesium alloys is shown in Fig.8. It is confirmed that the precipitates Al-Mn and Al-Zn in the AZ91 alloy (Figs.8(a) and (b)) and Al-Mn, Al-Zn and Zn-Sn in the

Table 3 Elemental contents of Mg-Zn-In-Sn alloy with precipitate

Element	w/%	x/%	x(Error)/%
Mg	57.93	66.73	± 0.42
Al	24.71	25.64	± 0.24
Mn	12.32	6.28	± 0.08
Zn	0.77	0.33	± 0.05
In	1.10	0.27	± 0.04
Sn	3.17	0.75	± 0.07

Mg-Zn-In-Sn alloy (Figs.8(c) and (d)) are divorced. The Al-Mn, Al-Zn and Zn-Sn intermetallic phases distribute in the interdendritic regions, and small intermetallic phase randomly distributes in magnesium matrix. Twin roll continuous cast Mg-Zn-In-Sn alloy produces more highly branched dendrites and traps the eutectic liquid into smaller and more isolated spaces, therefore the divorced island Al-Mn, Al-Zn and Zn-Sn intermetallic phases are concentrated on the interdendritic regions.

3.5 Surface morphology after electrochemical reaction

Fig.9 shows the SEM images revealing the porous surface morphologies of the AZ91 alloy and Mg-Zn-In-Sn alloy. Since Zn, Sn and In are added, the Mg-Zn-In-Sn alloy has smaller pores on the surface than the AZ91 alloy. The small holes can provide corrosion

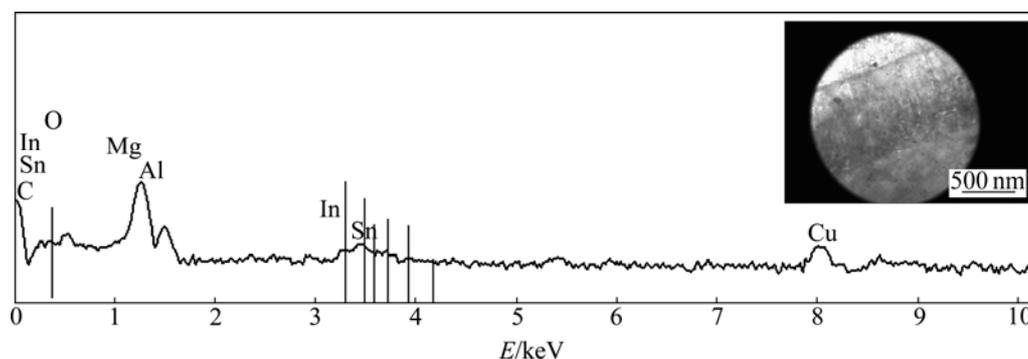


Fig.6 EDS pattern of location without precipitate in Mg-Zn-In-Sn alloy

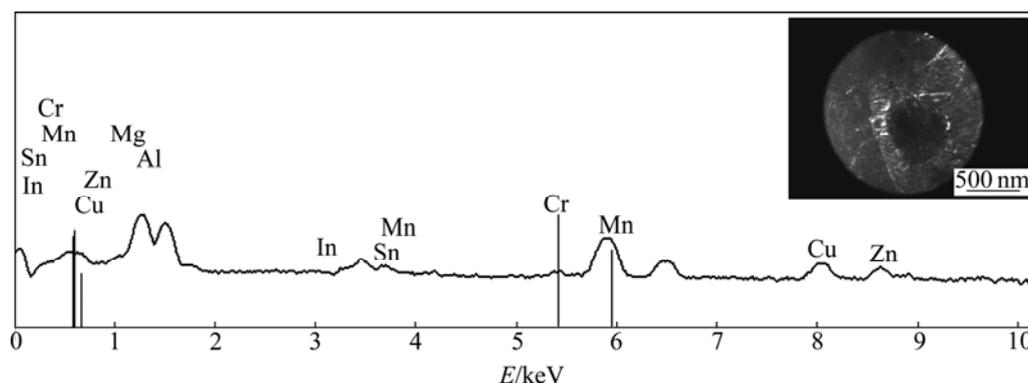


Fig.7 EDS pattern of location with precipitate in Mg-Zn-In-Sn alloy

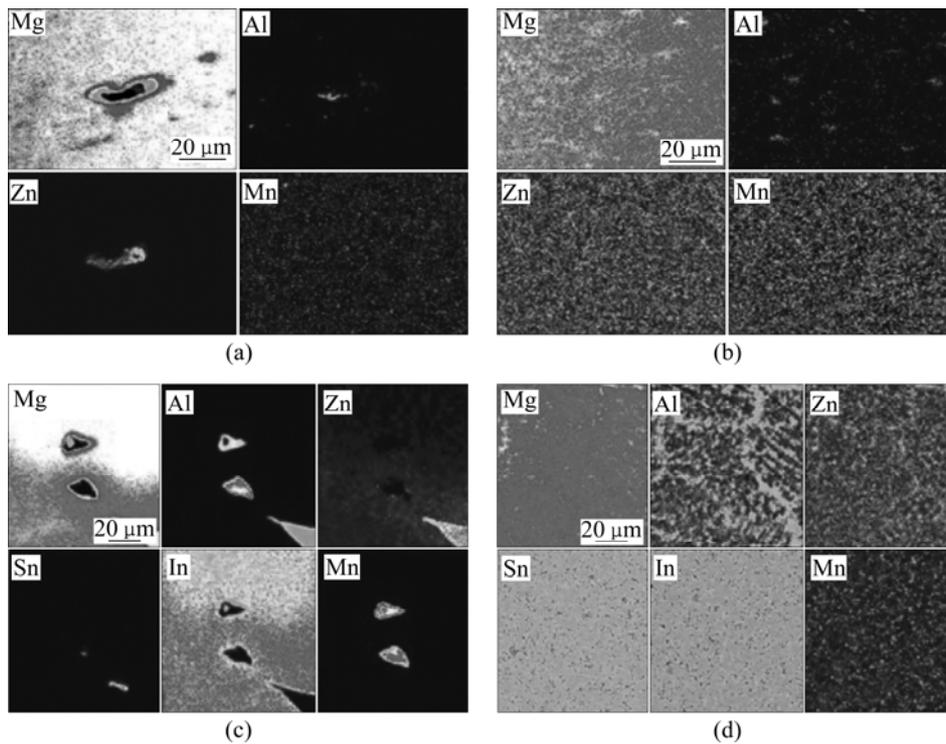


Fig.8 EPMA elements distribution of magnesium alloys: (a) AZ91 alloy (DC); (b) AZ91 alloy (CC); (c) Mg-Zn-In-Sn alloy (DC); (d) Mg-Zn-In-Sn alloy (CC)

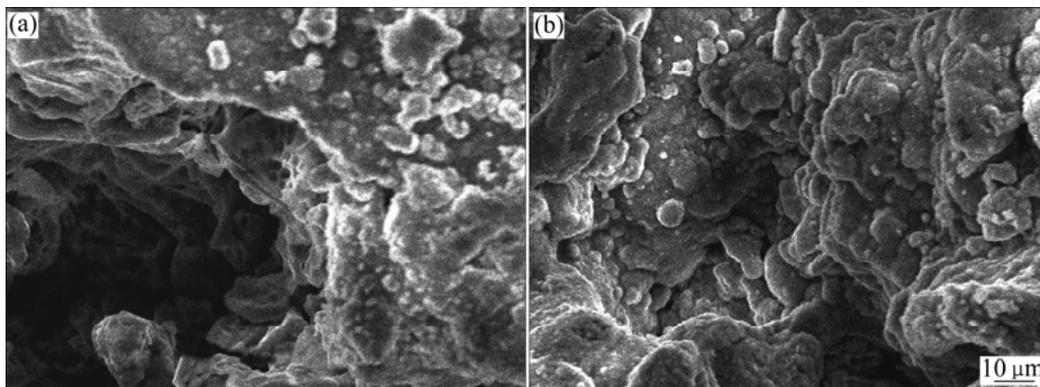


Fig.9 SEM images of magnesium alloys: (a) AZ91 alloy; (b) Mg-Zn-In-Sn alloy

protection because this type of structure can block corrosive media from contacting the substrate[14–15].

4 Conclusions

1) The morphology of α -Mg particles is evolved when the Zn, Sn, In are added into the AZ91 alloy. And the grain size becomes smaller in the Mg-Zn-In-Sn alloy by the twin rolls continuous casting. The Mg-Zn-In-Sn alloy shows higher tensile strength than the AZ91 alloy.

2) The Mg_3In , $Mg_{17}Al_{12}$ and Sn are the main components of the Mg-Zn-In-Sn alloy.

3) The Mg-Zn-In-Sn alloy has smaller pores on the surface than the AZ91 alloy. The holes can provide

corrosion protection because this type of structure can block corrosive media from contacting the substrate.

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References

- [1] HORST E F, MORDIKE B L. Magnesium technology, metallurgy, design data, application [M]. Berlin, Heidelberg: Springer-Verlag, 2006.
- [2] ABBAS G, LI L, GHAZANFAR U, LIU Z. Effect of high power

- diode laser surface melting on wear resistance of magnesium alloys [J]. *Wear*, 2006, 260: 175–180.
- [3] BACHA F W, RODMANB M. High quality magnesium sheets for automotive applications [J]. *Advanced Materials Research*, 2005, 6/7/8: 665–672.
- [4] CARPENTER A J. Automotive Mg research and development in North America [J]. *Materials Science Forum*, 2007, 546/547/548/549: 11–24.
- [5] SCHUNMANN S. The paths and strategies for increase magnesium application in vehicles [J]. *Materials Science Forum*, 2005, 488/489: 1–8.
- [6] SCHUNMANN S, FRIENDICH H. Current and future use of magnesium in the automobile industry [J]. *Materials Science Forum*, 2003, 419/420/421/422: 51–56.
- [7] KANEKO T, SUZUKI M. Automotive applications of magnesium alloys [J]. *Materials Science Forum*, 2003, 419/420/421/422: 67–72.
- [8] WALLENTOWITZ H, LEYERS J, PARR T. Materials for future automotive body structures [R]//*Business Briefing: Global Automotive Manufacturing and Technology*, 2003: 1–4.
- [9] WATARIA H. Trend of research and development for magnesium alloys—Reducing the weight of structural materials in motor vehicles [J]. *Quarter Review*, 2006, 18: 84–97.
- [10] JU D Y, HU X D, ZHAO H Y. Experimental study of in-line heat treatment for twin roll casting of magnesium alloy AZ31 [J]. *Advanced Materials Research*, 2007, 15/16/17: 513–518.
- [11] LI S B, WU K, ZHENG M Y. The effect of extrusion on the mechanical properties of cast AZ91 magnesium alloy [J]. *Material Engineering*, 2006, 12: 54–57.
- [12] DONG G Z. Research on microstructure and properties of highly strengthened wrought magnesium alloys [D]. Chongqing: Chongqing University, 2005.
- [13] BETTLES C J, GIBSON M A, VENKATESAN K. Enhanced age-hardening behaviors in Mg-4%Zn micro-alloyed with Ca [J]. *Scripta Mater*, 2004, 51: 193–197.
- [14] ZHANG Y, YAN C, WANG F, LOU H, CAO C. Study on the environmentally friendly anodizing of AZ91D alloy magnesium alloy [J]. *Surf Coat Tech*, 2002, 161: 36–43.
- [15] BARCHICHE C E, ROOCCA E, HAZAN J. Corrosion behavior of Sn-containing oxide layer on AZ91D alloy formed by plasma electrolytic oxide [J]. *Surf Coat Tech*, 2008, 202: 4145–4152.

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