CHEMICAL ENGINEERING TRANSACTIONS
VOL. 51, 2016
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Tichun Wang, Hongyang Zhang, Lei Tian

**ISBN** 978-88-95608-43-3; **ISSN** 2283-9216
DOI: 10.3303/CET1651041

# Study on Modification of Novel Magnesium Alloy for Sports Equipment

Shaowei Dong

Harbin University of Science and Technology, China
970766173@qq.com

The novel magnesium alloy for sports equipment is fabricated by adding alloy elements Mo and Y into AZ31 magnesium alloy and is subjected to variable-temperature homogenization treatment. Microstructure, phase composition, wear resistance and corrosion resistance of the novel magnesium alloy are tested and analysed. The result shows that due to the adding of the alloy elements Mo and Y and variable-temperature homogenization treatment, the microstructure of the magnesium alloy is refined significantly, and wear resistance and corrosion resistance of the alloy are improved. Compared with the AZ31 magnesium alloy, the novel magnesium alloy has the advantages that the wear volume is reduced by 59.21% and 67.92% before and after homogenization treatment respectively, and the positive displacement of corrosion potential is 84 mV and 95 mV before and after homogenization treatment respectively.

## 1. Introduction

With the progress of science and technology and people's pursuit of their own health, sports equipment has been developed rapidly, and a new opportunity has been provided for materials for sports equipment accordingly (Dang et al., 2011; Czerwinski, 2011). As magnesium alloy has the characteristics of low weight, high specific strength, good damping and noise reduction performance and outstanding recovery performance, it has attracted widespread attention and is expected to become the main force of a new generation of materials for the sports equipment (Liu, 2010; Aonuma and Nakata, 2012). However, corrosion resistance of the magnesium alloy is poor, so that its application development on sports equipment has been seriously hindered so far. On the premise that the existing advantages of the magnesium alloy are guaranteed, how to improve its corrosion resistance has become an important technical issue in the field of magnesium alloy and is also an urgent technical problem to be solved for the magnesium alloy for sports equipment. The microstructure of the novel magnesium alloy for the sports equipment is refined significantly, and its wear resistance and corrosion resistance are improved as a result of the adding of the alloy elements of Mo and Y and the application of variable-temperature homogenization treatment. In the paper, an alloying and heat treatment combined method is used for studying modification of the novel magnesium alloy for the sports equipment and testing and analysing phase composition, wear resistance and corrosion resistance, so that the foundation has been laid for the practicality of the magnesium alloy for the sports equipment.

## 2. Test materials and methods

### 2.1 Test materials

The novel magnesium alloy with alloy elements of Mo and Y added on the basis of AZ31 magnesium alloy is selected as the test materials. Alloy is molten in a ZG-1.5L cycle type vacuum electric induction furnace at the temperature of 690 degree to 710 degree (He et al., 2009). . The molten alloy samples are analysed in a SPECTRO XEPOS type X-ray fluorescence spectrophotometer, chemical components of the samples are shown in Table 1.
Besides, all the molten alloy samples are subjected to the same variable temperature homogenization process, and the variable temperature homogenization process curve is shown in Figure 1.

*Table 1: Major Chemical Components of the Test Samples*

| Sample number | Al | Zn | Mn | Mo | Y | Other elements | Mg |
|---|---|---|---|---|---|---|---|
| Sample 1(AZ31) | 3.091 | 0.813 | 0.411 | 0 | 0 | <0.045 | Balance |
| Novel magnesium alloy | 3.082 | 0.815 | 0.409 | 0.312 | 0.207 | <0.025 | remain |

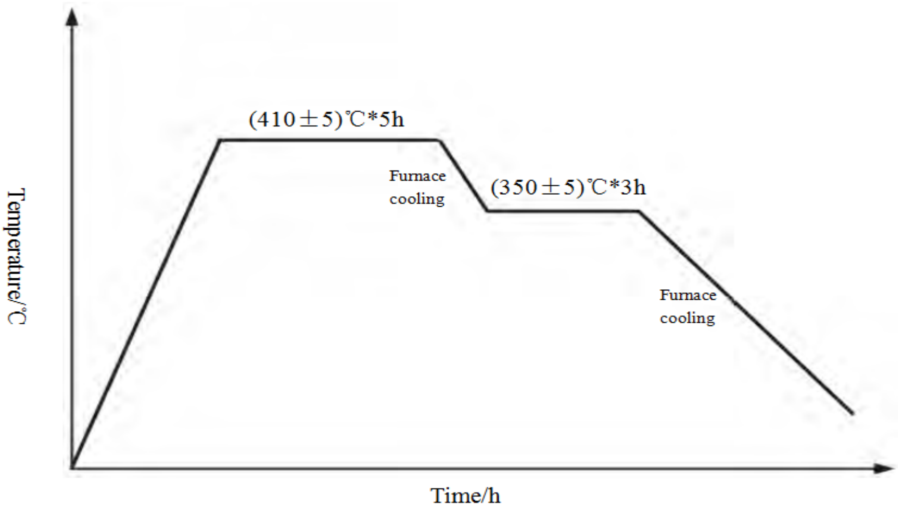



*Figure 1: Curve of variable-temperature homogenization process*

**2.2 Test Methods**

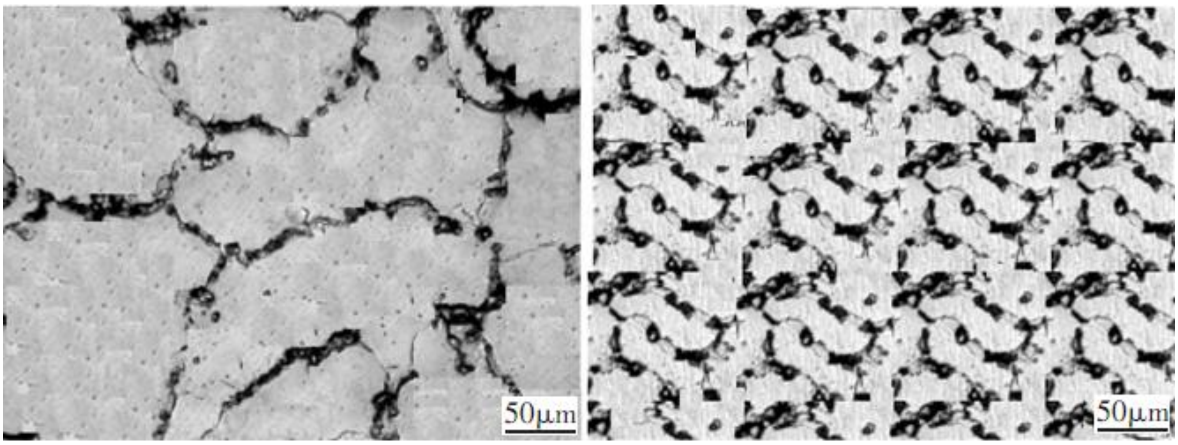
Microstructure and phase composition analysis: the microstructure of each test sample is analysed through a DM12000M metallographic microscope, and the phase composition of the samples is analysed through a D8 ADVANCE X-ray diffractometer. Wear resistance test: the wear resistance performance of the samples are tested through an MRS-10A friction and wear testing machine at the room temperature under the condition that the spindle speed is 2300 r/min , total revolutions of the spindle is 23, 000 r, the load is 300 N and the relative sliding velocity is 100 mm/min. The wear resistance of the samples is represented in the Table of Wear Volume (Belov, 2010). Corrosion resistance test: corrosion resistance of each test sample is subjected to electrochemical test in a CHI660B electrochemical workstation through a tri-electrode system. That is, a calomel electrode is used as the reference electrode, a platinum black electrode is used as an auxiliary electrode, and electrodes fabricated by the samples are used as the working electrode. When the working electrodes are fabricated, first of all, a surface of a cut test block is selected as a test surface to be ground flat and polished; then, copper wires are welded on the surface opposite to the test surface of the test block; lastly, all the surfaces except the test surface are sealed with resin. The test is performed with a 5% sodium chloride aqueous solution serving as the electrolyte, at the room temperature, at the scanning speed of 0.005 V/s. Tafel curves of the samples is tested. The test surface of each sample is polarized for 180 s under constant potential of -1.0 V l before test so as to prevent influences of oxides on the surface of the sample on test results. It is showed that the corrosion potential before homogenization treatment is moved from -0.868 V to -0.784 V and is moved positively by 84 mV. The corrosion potential after homogenization treatment is moved positively to-0.742V from -0.837 V and is moved positively by 95 mV. In addition, as can be seen from the Ref. 4 in the reference part below, for the same alloy sample , the corrosion potential after homogenization treatment is moved towards the positive direction significantly than the corrosion potential before homogenization treatment. As is known to all, on the premise that other conditions are consistent, the more positive the corrosion potential is, the higher the corrosion resistance of materials will be.

## 3. Test results and discussion

### 3.1 Microstructure and Phase Composition

Magnesium alloys are among the lightest metallic materials for structural applications. Due to high specific strength and rigidness, as well as good machinability and recyclability, magnesium alloy has been known as the 21st century ’green’ engineering material. In recent years, with the rapid progress of automotive and electronic industries, a number of magnesium alloy components have been manufactured to replace those made from plastics, aluminium alloy and steel ones. It can be expected that magnesium alloys will become the most important structural materials in commercial metal materials. Wrought magnesium alloys can exhibit the higher strength and better plasticity than cast magnesium alloys, and show the more significant potential in further applications of magnesium based materials. As structural materials in service, magnesium alloys are usually subjected to repeated reverse loading, and therefore the cyclic deformation behaviour of these materials needs to be studied in detail for safety reasons. However, many investigations were based on the macroscopic fatigue properties, neglecting the deformation characteristics of magnesium alloys. Due to hcp crystal lattice, twinning and slip are important to deformation of magnesium alloys. And in some cases, twinning may be the main deformation mechanism. As such, it is important to understand the role of twinning in fatigue process. So in this dissertation, the widely used AZ31 wrought magnesium alloy is chosen as model material to understand the role of twinning. In fact, some factors influence the behaviour of twinning, such as texture, strain rate, grain size and initial twins. According to the initial texture of the extruded AZ31 plate investigated by X-ray diffraction, samples were cut along different directions to discriminate the role of twinning and slip in fatigue process. Under different frequencies, the degree of twinning is different and its effect on fatigue properties was analysed. Magnesium alloy can be fined by equal channel angular pressing (ECAP), which suppress the activation of twinning. And the fatigue properties of untrained AZ31 can be understood. Initial twins can alter the deformation mechanism under fatigue process, and the influence of initial twins on fatigue properties can be acquired by pre-deformation.

Met allographs of the microstructure of the sample 1 (AZ31 magnesium alloy) and the sample 2 (novel magnesium alloy) after variable-temperature homogenization treatment are shown in figure 2. It can be seen that compared with the sample 1 of the AZ31 magnesium alloy, the microstructure of the sample 2 of the novel magnesium alloy with alloy elements of Mo and Y added is refined remarkably.




*(a) Sample 1* *(b) Sample 2*

*Figure 2: Microstructure of the Samples after Homogenization Processing*

The XRD spectrum of the sample 1 and sample 2 is shown in figure 3.

It can be seen that after the same variable temperature homogenization treatment, the sample 2 and the sample 1 are each composed of a large amount of Mg and a small amount of $Mg_{17}Al_{12}$,but magnesium compounds containing Mo and Y are not found in the sample 2 of the novel magnesium alloy with alloy elements of Mo and Y added, which is mainly caused by the fact that only a small content of Mo or Y is added into the magnesium alloy, and stable compounds are difficult to form in the alloy so that the compound phases have not been found in the XRD spectrum.

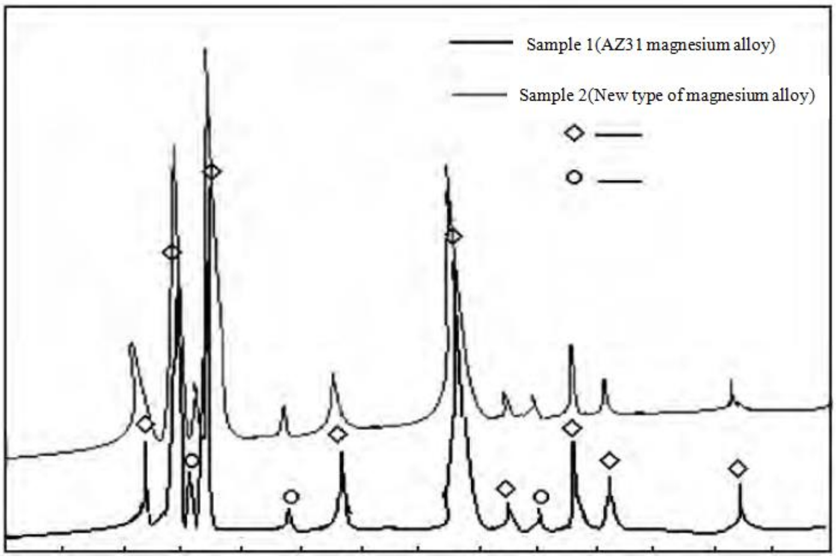



*Figure 3: XRD spectrum of the samples*

**3.2 Wear Resistance Performance**

Results of the wear test of the sample 1 and the sample 2 at the room temperature before and after variable-temperature homogenization treatment are shown in figure 4. It can be seen that whether before or after homogenization treatment, the wear volume of the sample 2of the novel magnesium alloy with alloy elements of Mo and Y  added is smaller than the sample 1 of the AZ31 magnesium alloy. Before homogenization treatment, the wear volume is reduced from 76*10-3 mm3 to 31*10-3 mm3 and is reduced by 59.21%, After variable-temperature homogenization treatment, the wear volume is reduced from 53*10-3 mm3 reduced to 17*10-3 mm3 and is reduced by 67.92%. In addition, as can be seen from the figure 3, for the same alloy sample, the wear volume after variable-temperature homogenization treatment is significantly smaller than that before variable-temperature homogenization treatment. is the main reason for these changes is that  the uniformity of the structure inside the alloy is effectively improved through variable temperature homogenization treatment, so that the alloy elements in the magnesium alloy are distributed in the matrix more evenly, and wear resistance of the magnesium alloy is effectively enhanced(Huang et al., 2013). Therefore, it can be considered that wear resistance of the novel magnesium alloy for the sports equipment is remarkably improved by the adding of the alloy elements of Mo and Y and the application of variable-temperature homogenization treatment.

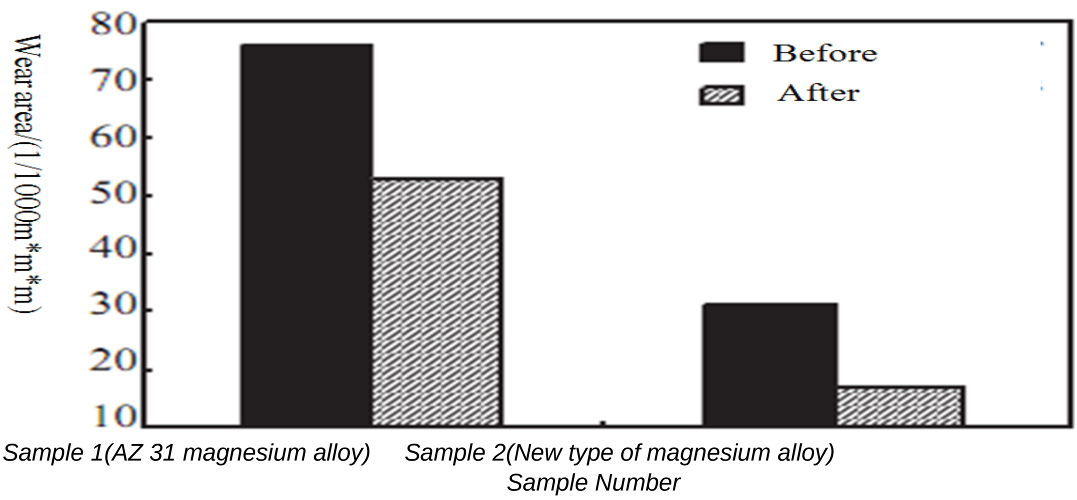



*Figure 4: Results of Wear Test of the Samples at the Room Temperature*

### 3.3 Electrochemical Corrosion Test

The sample 1 and the sample 2 are corroded in the 5% sodium chloride aqueous solution at the scanning speed of 0.005 V/s, to test Tafel curves of the samples, and results are shown in Figure 5.

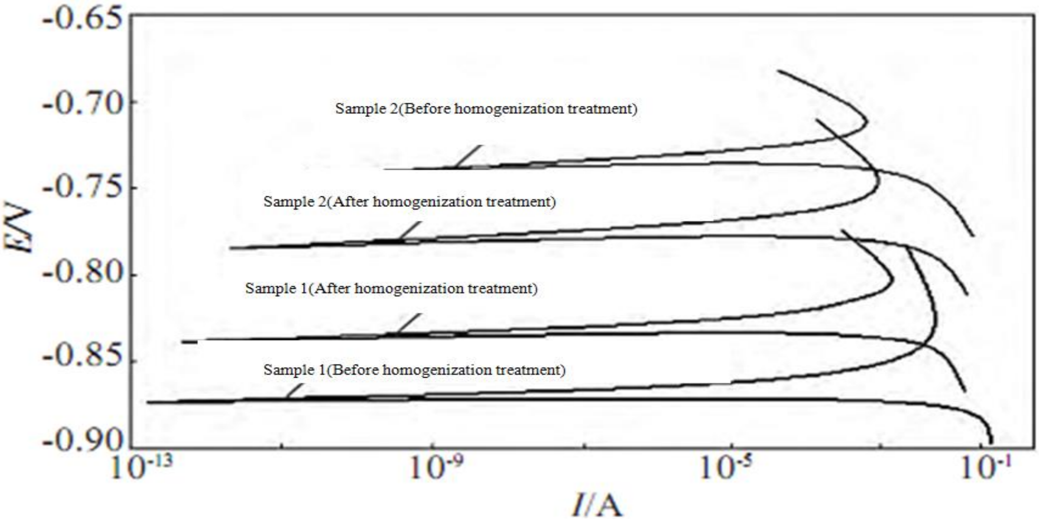



*Figure 5: Tafel Curves of the Samples at the Room Temperature When the Scanning Speed is 0.005V/s*

Corrosion resistance of each test sample is subjected to electrochemical test in a CHI660B electrochemical workstation through a tri-electrode system. That is, a calomel electrode is used as the reference electrode, a platinum black electrode is used as an auxiliary electrode, and electrodes fabricated by the samples are used as the working electrode. When the working electrodes are fabricated, first of all, a surface of a cut test block is selected as a test surface to be ground flat and polished; then, copper wires are welded on the surface opposite to the test surface of the test block; lastly, all the surfaces except the test surface are sealed with resin. The test is performed with a 5% sodium chloride aqueous solution serving as the electrolyte, at the room temperature, at the scanning speed of 0.005 V/s. Tafel curves of the samples is tested. The test surface of each sample is polarized for 180 s under constant potential of -1.0 V l before test so as to prevent influences of oxides on the surface of the sample on test results. Whether before or after homogenization treatment, all of the corrosion potential of the sample 2, the novel magnesium alloy with alloy elements of Mo and Y added moves towards the positive direction., the corrosion potential before homogenization treatment is moved from -0.868 V to -0.784 V and is moved positively by 84 mV. The corrosion potential after homogenization treatment is moved positively to-0.742V from -0.837 V and is moved positively by 95 mV. In addition, as can be seen from the Figure 5, for the same alloy sample, the corrosion potential after homogenization treatment is moved towards the positive direction significantly than the corrosion potential before homogenization treatment. As is known to all, on the premise that other conditions are consistent, the more positive the corrosion potential is, the higher the corrosion resistance of materials will be [5]. Therefore, the corrosion resistance of the novel magnesium alloy with the alloy elements of Mo and Y added is obviously higher than that of the AZ31 magnesium alloy, and after variable homogenization treatment, its corrosion resistance can be further improved.

The low-cycle tension-tension fatigue properties of extruded Mg-3%Al-1%Zn alloy plate have significantly different features in twinning-dominated samples and dislocation-dominated samples. The twinning-dominated samples show more pronounced cyclic hardening and longer fatigue life than those of the slip-dominated samples. The elongated lifetime of the twinning-dominated samples may be due to the roughness-induced crack closure, according to the calculated reverse plastic zone size. A number of uniaxial stress-controlled cyclic loading experiments were conducted on extruded AZ31 magnesium alloy, in order to investigate the influence of tension-compression asymmetry on fatigue properties. The results show that the systems are loops exhibit asymmetry during initial fatigue cycles, but this asymmetry vanishes after 200 cycles. The peak compressive strain gradually decreases, and at about 200 cycles, it reverses to tensile strain. Fatigue crack initiates at the twin bands in the surface, and the crack propagates along with specific twin boundaries. Due to texture and deformation mechanism, twining and detaining behaviours are often observed in the fatigue process, which leads to the hysteresis loop asymmetry.

Fully reversed strain-controlled tension-compression fatigue tests were carried out at frequencies of 1Hz and 10Hz in ambient air to investigate the frequency effect. When the strain amplitude was lower than 0.2%, the fatigue life exhibited a positive correlation with loading frequency, and the activity of twinning was increased at 10Hz. When the strain amplitude was higher than 0.2%, significant twinning was observed both at both frequencies and the fatigue life was found to be independent of frequency. The possible reasons for this frequency-related fatigue lifetime may be due to the dependence of twinning upon loading frequency and strain amplitude. The low-cycle tension-compression fatigue tests were performed at ambient temperature on ultrafine grained AZ31 magnesium alloy processed by equal channel angular pressing. All samples exhibited cyclic softening, and the softening effect increased with increasing total strain amplitude, which may be due to the instability of microstructure. Observations by optical microscope revealed that pronounced recrystallization occurred, and the direction of larger axis of recrystallized grains was nearly 45°with respect to the loading axis. A model is proposed to account for the recrystallization, based on the characteristic distribution of defects introduced by equal channel angular pressing. Compared with the conventional extruded AZ31 alloy, the ECAP processed AZ31 alloy has lower hysteresis strain energy and leads to enhanced fatigue lives. And the dependences of the strain fatigue life on plastic strain amplitude and elastic strain amplitude can be described by the Coffin-Manson and Basquin equations, respectively. The fatigue properties of a AZ31 magnesium alloy was investigated in both thermos mechanically treated extruded and pre-compression conditions. For pre-compression materials, twinning was the dominant deformation mechanism during the tensile loading, and slips were the dominant during the compressive loading, which induced different mean stresses in extruded and pre-compressing materials. Experimental results show that in high strain amplitude, the fatigue lifetime was controlled by plastic strain amplitude which could lead to accumulated cyclic damage. On the other hand, in low strain amplitude, it is invalid for most of dislocation slips are reversal, and the fatigue lifetime was controlled by mean stress.

## 4. Conclusion

(1) The microstructure of the novel magnesium alloy for the sports equipment is refined significantly, and its wear resistance and corrosion resistance are improved as a result of the adding of the alloy elements of Mo and Y and the application of variable-temperature homogenization treatment.
(2) Compared with the AZ31 magnesium alloy, the wear volume of the novel magnesium alloy for the sports equipment is reduced by 59.21% and 67.92% before and after the homogenization treatment respectively, and the positive displacement of the corrosion potential is 84 mV and 95 mV before and after homogenization treatment respectively.
(3) After the same variable-temperature homogenization treatment process, both the novel magnesium alloy and the AZ31 magnesium alloy for the sports equipment are composed of a large amout of α- Mg and a small number of $Mg_{17}Al_{12}$ phase.

### References

Aonuma M., Nakata K., 2012, Dissimilar metal joining of ZK60 magnesium alloy and titanium by friction stir welding [J]. Materials Science and Engineering B, (177): 543-548. doi: 10.1016/j.mseb.2011.12.031.

Belov V.D., Koltygin A.V., Belov N.A., Plisetskaya I.V., 2010, Innovations in cast magnesium alloys, Metallurgist, 17, 2,569-623.

Czerwinski F., 2011, Magnesium alloys corrosion and surface treatments [M]. India: Intech.

Dang C.M., Xie W.D., 2011, Application of aluminum and magnesium alloy materials in automobile industry, Hot Working Technology, 40 (4): 1-4.

He M.F., Liu L., Wu Y.T., Tang Z.X., Hu W.B., 2009, Improvement of the properties of AZ91D magnesium alloy by treatment with a molten AlCl 3 –NaCl salt to form an Mg–Al intermetallic surface layer, Journal of Coatings Technology and Research, 16, 5, 289-312.

Huang Z.H., Qi W. J., Zheng K.H., Zhang X.M., Liu M., Yu Z.M., Xu J., 2013, Microstructures and mechanical properties of Mg–Zn–Zr–Dy wrought magnesium alloys, Bull. Mater. Sci., 23, 5, 125-213.

Liu G.L., 2010, Study on electronic structure and corrosion characteristics of magnesium alloy [J]. Chinese Physics, 59 (4): 2708-2713.

Wang J., 2013, Study on structure and solidification behavior of Mg-Y LPC alloy research [J]. Journal of foundry technology, 34(3): 254-255.