Study on Properties of New Mg-Y-Nd-(La+Ce)-Zr Degradable Magnesium Alloy

Jiang Zhang and Yuelai Dai*
Ningbo Sub-academy of the National Weapons Science Research Academy, Ningbo, Zhejiang, 315103, China
*Corresponding author’s e-mail: daiyuelai_1988@126.com

Abstract. The new Mg-Y-Nd-(La+Ce)-Zr magnesium alloy was taken as the research object to study the types and contents of rare earth alloys. The corrosion properties were studied by scanning electron microscope and electrochemical experiments. The results showed that the new Mg-Y-Nd-(La+Ce)-Zr magnesium alloy had no toxicity to human cells and had ideal corrosion resistance. The mean corrosion rate at 96 h was <0.3mg/(cm²h). The mechanical properties test showed that the new magnesium alloys had good mechanical properties, its tensile strength >220Mpa, elongation >20%.

1. Introduction

The biological materials implanted in human body should be non-toxic and have no adverse reactions, have good compatibility with human tissues, be able to degrade themselves, and meet certain mechanical properties [1]. Currently, among the totally degraded scaffolds, the mechanical properties of polymer scaffolds are not good enough to support blood vessels, while the degradation rate of pure iron scaffolds is too slow. Using magnesium alloy as medical degradable biomaterials has a good basis for medical safety [2]. Conventional magnesium alloy degrade too fast, which limits their clinical application in medicine. Research on biodegradable magnesium alloys mainly focuses on AZ31 [3], AZ91[4], Mg-Zn [5], Mg-Ca [6], Mg-RE [7] and other series. Compared with the traditional scaffold materials, the new Mg-Y-Nd-(La+Ce)-Zr biodegradable magnesium alloy materials have obvious advantages, which has strong compatibility with human tissue, and extremely low incidence of thromboembolism. It also shows good mechanical properties. After a period of vascular support, the new magnesium alloy can degrade slowly, and the magnesium ion concentration released in the process of degradation is much lower than the blood concentration (0.70-1.05mmol/L), with few side effects. The trace rare earth elements in the new Mg-Y-Nd-(La+Ce)-Zr magnesium alloy have anti-tumor, anti-mutation and anti-inflammation effects. The new Mg-Y-Nd-(La+Ce)-Zr magnesium alloy was taken as the research object to design and optimize its composition, studying its corrosion properties and testing its mechanical properties.

2. Composition design of Mg-Y-Nd-(La+Ce)-Zr magnesium alloy

The addition of some rare earth elements in the melting of magnesium alloy can not only play an auxiliary role, but also improve some properties of magnesium alloy. The addition of rare earth element decoration (Ce) can make magnesium alloys produce more continuous beta phase and inhibit the further development of corrosion. The addition of Y and Nd has a great impact on the microstructure of magnesium alloys. Firstly, the two alloy elements can combine with magnesium to...
form binary phase and become the core of heterogeneous nucleation of magnesium matrix. In the solidification process, Y and Nd gather at the front edge of the alloy to form components of supercooling, hinder the growth of magnesium matrix, refine the as-cast microstructure of magnesium alloy, and greatly improve the comprehensive mechanical properties of the alloy. Studies have shown that the addition of Nd can improve the corrosion resistance of magnesium alloy [8], and Nd element has no cytotoxicity [7]. The design composition of rare earth Y is (3.0-4.5) wt%, and the design composition of rare earth Nd is (2.2-3.0) wt%. In the solidify process, Nd will be precipitated in the first place. At the same time, Y also starts to precipitate from the solid solution, forming different binary phase (Mg24Y5, Mg12Nd) and ternary phase Mg-Y-Nd. It has good mechanical properties and corrosion resistance. With the addition of rare earth lanthanum (La), the dispersed binary phase can be formed with magnesium, and the content of corrosion resistance binary phase is significantly increased. The addition of Zr can obviously refine the grain of magnesium alloys, strengthen the material and improve the corrosion resistance, and the biocompatibility of trace Zr in magnesium alloys has been confirmed. Magnesium alloy materials are smelted by flux-coating method. In the melting process of rare earth magnesium alloys, the addition of rare earth elements is mainly in the form of magnesium-rare earth intermediate alloy. Magnesium intermediate alloys are mainly Mg-20% Y, Mg-20% Nd and Mg-12% La-8% Ce. Zirconium with grain refinement is added in the form of mg-30% Zr. The material composition is shown in table 1 below.

Table 1. Composition design of new Mg-Y-Nd-(La+Ce)-Zr magnesium alloy

| Alloy composition (wt%) | Y  | Nd | La+Ce | Zr | Mg |
|------------------------|----|----|-------|----|----|
|                        | 4.2| 2.7| 0.6   | 0.5| Balance |

3. Corrosion properties of new Mg-Y-Nd-(La+Ce)-Zr magnesium alloy

In order to simulate the corrosion test in human vascular environment, the simulated corrosion solution was Hank solution, and the solution temperature was kept at 37±0.5°C in the constant temperature water tank. Hydrochloric acid and NaOH were used to adjust the initial pH value of solution to 7.5. The sample size of biological environment immersion experiment was d22mm X 3mm, and the immersion experiment period was 10 days. The corrosion degradation of magnesium alloys was studied by means of average corrosion rate and pH change of immersion solution. The corroded sample was first rinsed with distilled water and then washed in chromic acid solution at 100°C for 8 minutes to remove corrosion products from the surface of the samples. Figure 1 showed SEM images of corrosion areas after the sample was soaked in Hank solution for 240 h and the corrosion products were washed away. There was no deep pitting on the surface of the sample. Figure 2 showed the optical micrographs of corrosion profiles of the sample soaked in Hank solution at 37°C for 240 h. The corrosion boundary of the sample was relatively flat, and the corrosion was mainly concentrated on the surface, and the corrosion extended in all directions rather than in depth. The average corrosion velocity v is calculated by the following formula:

\[ v = \frac{87.6 \cdot m}{P \cdot A \cdot T} \]  

(1)

Where: m is mass loss, mg; P is the density of metal g/cm3; A is the area of sample exposed to solution, cm2; T is the soaking time, h.

The corrosion rate of Mg-Y-Nd-(La+Ce)-Zr magnesium alloy is about 0.25mm/a, average corrosion rate of 96h <0.3mg/(cm2h).
Figure 1. SEM images of corrosion areas after the sample soaked in Hank solution at 37°C for 240 h

Figure 2. The optical micrographs of corrosion profiles of the sample soaked in Hank solution at 37°C for 240 h

4. Mechanical properties of Mg-Y-Nd-(La+Ce)-Zr magnesium alloy
The size of new Mg-Y-Nd-(La+Ce)-Zr magnesium tensile specimens is shown in figure 3. Tensile properties were tested on Gleeble3500 at a tensile speed of 1 mm/min. As shown in figure 4, the yield strength and elongation of Mg-Y-Nd-(La+Ce)-Zr can reach 220MPa and 20% respectively. As the temperature increases, the service strength decreases while the elongation increases.

Figure 3. The size of new Mg-Y-Nd-(La+Ce)-Zr magnesium tensile specimens
Figure 4. Tensile curves of new Mg-Y-Nd-(La+Ce)-Zr magnesium alloys at room temperature

5. Conclusion
The corrosion rate of Mg-Y-Nd-(La+Ce)-Zr magnesium alloy can reach 0.25mm/a, indicating that the corrosion resistance of Mg-Y-Nd-(La+Ce)-Zr magnesium alloy in solid solution state has reached a relatively high standard. The corrosion mode of magnesium alloys with high purity and Mg-Y-Nd-(La+Ce)-Zr is uniform corrosion. The new magnesium alloy Mg-Y-Nd-(La+Ce)-Zr has good mechanical properties, with tensile strength >220Mpa and elongation >20%.

Acknowledgments
This study was supported by the public welfare project of Zhejiang, China, Nos. LGF18E010001, LGF19E010001.

References
[1] Pei G X. (2006) Opportunities and challenges in tissue engineering in the 21st century. International journal of bone science, 27:2-4.
[2] Saris N, Mervaala E, Karppanen H, et al. (2000) Magnesium: An update on physiological, clinical and analytical aspects. Clin Chim Acta, 294:1-26.
[3] Alvarez-Lopez M, Pereda M, VaJle J, et al. (2010) Corrosion behavior of AZ31 magnesium alloy with different grain sizes in simulated biological fluids. Acta Biomaterialia, 6: 1763-1771.
[4] Liu C, Xin Y, Tian X, et al. (2007) Corrosion behavior of AZ91 magnesium alloy treated by plasma immersion ion implantation and deposition in artificial physiological fluids. Thin Solid Films, 516: 422-427.
[5] Zhang S, Zhang X, Zhao C, et al. (2010) Research on an Mg-Zn alloy as a degradable biomaterial, Acta Biomaterialia, 6: 626-640.
[6] Kannan M, Raman R. (2008) In Vitro degradation and mechanical integrity of calcium-containing magnesium alloy in modified-simulated body fluid. Biomaterials, 29: 2306-2314.
[7] Feyerabend F, Fischer J, Holtz J, et al. (2010) Evaluation of short-term effects of earth and other elements used in magnesium alloys on primary cells and cell lines. Acta Biomaterialia, 6: 1834-1842.
[8] Li C, Li M Z, Wang Y Q, et al. (2011) Rare Metal Materials and Engineering, 40: 156-161.