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Effect of Microstructure and Texture on Corrosion Resistance of Magnesium Alloy

Renlong XIN[a], Maoyin WANG[b], Jiacheng GAO[c], Pei LIU[d], Qing LIU[e]

College of Materials Science and Engineering, Chongqing University,
Chongqing, 400044, China

[a]rlxin@cqu.edu.cn, [b]wang527146@163.com, [c]gaojch@cqu.edu.cn,
[d]hopeliupei.1986@163.com, [e]qingliu@cqu.edu.cn

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Abstract. Magnesium alloys are considered as candidate materials for biodegradable implants. However, the key issue is that they corrode too fast in physiological environment. The aim of this study is to investigate the effect of microstructure and texture of magnesium alloys on their corrosion resistance. Magnesium alloy AZ31 extruded rod, hot rolled sheet and extruded sheet with different initial microstructure and texture were prepared. Then they were immersed in conventional simulated body fluid (SBF) for several days for corrosion evaluation. The corrosion products and precipitates on their surfaces were examined by scanning electron microscopy (SEM). The preliminary results showed that the initial microstructure and texture of AZ31 alloys has considerable effect on the weight loss rate of the alloys, suggesting that it is possible to enhance the corrosion resistance of AZ31 alloys through tailoring the microstructure and texture of the alloys.

Introduction

Biodegradable implant materials offer a temporary support during tissue recovery and can be gradually dissolved, absorbed, consumed or excreted, so there is no need for the secondary surgery to remove implants. Magnesium alloys are considered as candidate materials for biodegradable implants because of their excellent biocompatibility and mechanical properties [1, 3]. Zreiqat et al. reported that the presence of Mg^{2+} in the body system is beneficial to bone strength and growth [4]. Moreover, negative effects of stress-shielding are expected to be avoided as the elastic modulus and compressive yield strength are comparable to the cortical bone substance.

The problem for magnesium alloys is that their corrosion rate is too high. Therefore, improving the corrosion resistance of biodegradable magnesium alloys is the main focus of considerable research. Conventionally the biodegradation rate of Mg alloys can be adjusted in various ways, particularly by alloying and surface treatments [1, 5]. However, there remains a concern regarding the potential toxicity caused by the alloying elements of zirconium, neodymium, cadmium and other rare earths.

Most of the previous studies on magnesium alloy biomaterials focused on the Mg-Al and Mg-RE alloy systems. In this study, the corrosion property of three types of AZ31 alloys specimens with different grain size and texture was investigated. The aim of this study is to explore the possibility of enhancing the corrosion resistance of biomaterial AZ31 alloys through tailoring the microstructure and texture of the alloys.

Experimental

Three types of magnesium alloy AZ31 including extruded rod, hot rolled sheet and extruded sheet with different initial grain size and texture were used as starting materials. Thin plate specimens with the dimension of 10 mm × 10 mm × 10 mm were cut from the magnesium alloys. The large surfaces of the specimens were wet ground, polished and ultrasonically cleaned following a routine way, and then their microstructure and texture were examined using a FEI Nova 400 FEG scanning electron microscope (SEM) equipped with an electron backscatter detector (EBSD).

Four small lateral surfaces of each specimen were coated by a thin olefin layer, whereas two large surfaces were exposed for corrosion evaluation. Then the specimens were immersed in conventional simulated body fluid (SBF) at 37.5 °C for several days. After 1, 3, 5 and 7 days' immersion, the specimens were collected, dried and weighed, and the pH of SBF solution was measured by a pH meter. The morphology and elements of the corrosion products and precipitates were investigated by SEM equipped with an energy dispersive detector (EDS) after 3 days' immersion in SBF.

Results and discussion

Fig. 1 show EBSD maps of the AZ31 specimens. It can be seen that the extruded rod specimen exhibited an initial fiber texture, whereas a strong basal texture was observed in both the hot rolled sheet and extruded sheet specimens. The grain size of the extruded rod, hot rolled sheet and extruded sheet specimens is ~ 8.8 μm, 7.0 μm and 20.4 μm, respectively.

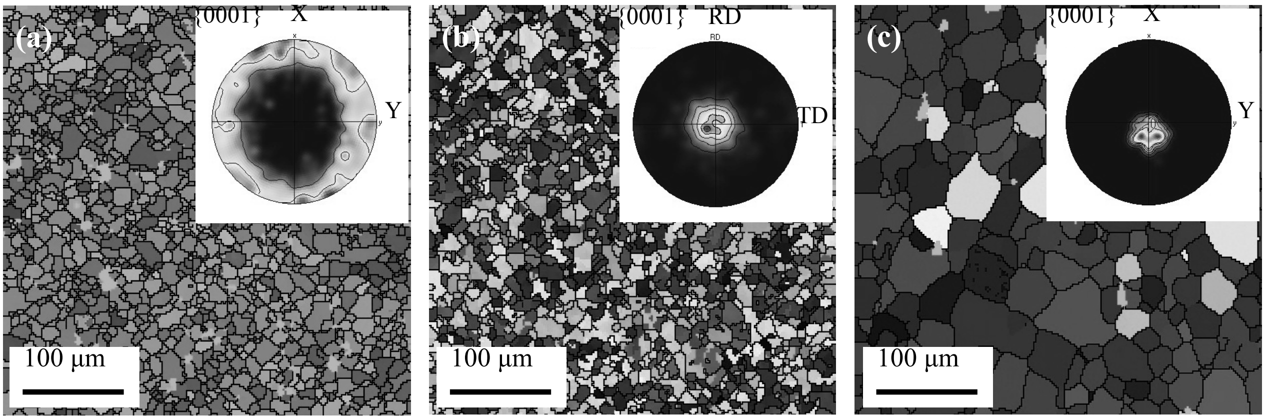

Fig. 1 EBSD maps of the as-prepared AZ31 specimens before immersion in SBF.
(a) extruded rod; (b) hot rolled sheet; (c) extruded sheet.

Fig. 2 show SEM images of AZ31 specimens after immersion in SBF for three days. The surface of the AZ31 alloy specimens exhibited two types of regions with different features as shown in Fig. 2a ~ 2c and Fig. 2d ~ 2f, respectively (hereinafter referred to as Region 1 and Region 2, respectively).

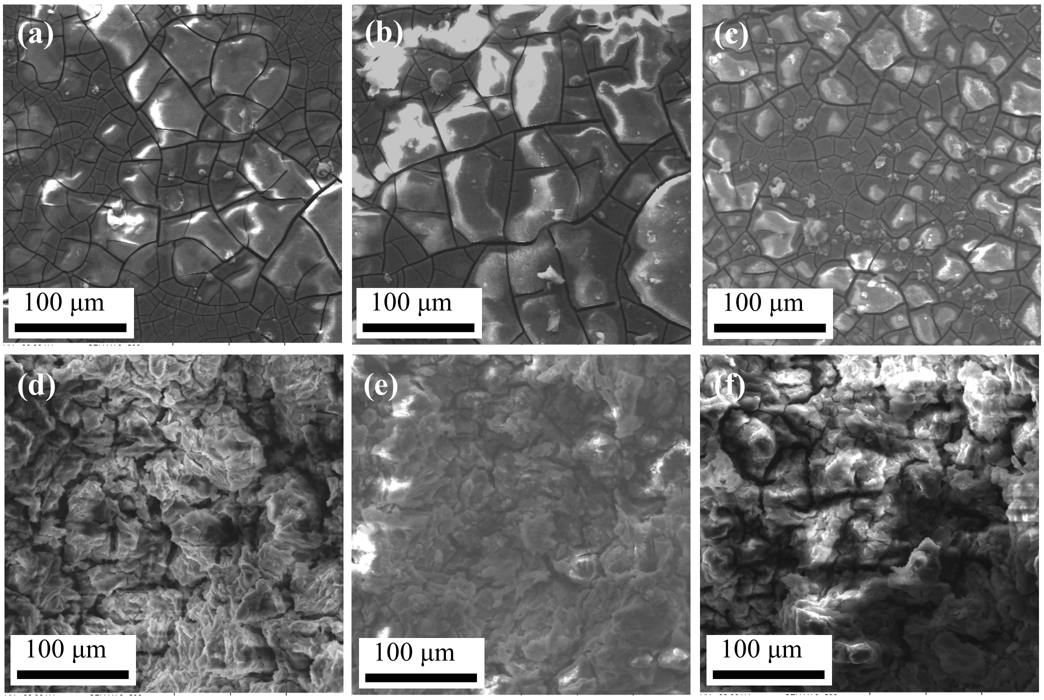

Fig. 2 SEM images of the AZ31 alloys after three days' immersion in SBF.
(a) and (d) extruded rod; (b) and (e) hot rolled sheet; (c) and (f) extruded sheet.

Region 1 that occupied most of the surface was covered by a thick and cracked corrosion film (Fig. 2a ~ 2c). The main corrosion products were probably brucite ($Mg(OH)_2$) according to previous studies [2]. It seems that corrosion was mainly occurred from Region 2 which was not protected by a film (Fig. 2d ~ 2f, and Fig. 3a).

Fig. 3a show SEM image of the interface of Region 1 and 2. The EDS spectrum (Fig. 3a) revealed that Region 1 was enriched with calcium and phosphorous in comparison with Region 2. The white precipitates on Region 1 (Fig. 3b) was confirmed to be a calcium phosphate salt with Ca/P ratio in the range of 1.5 ~ 2.

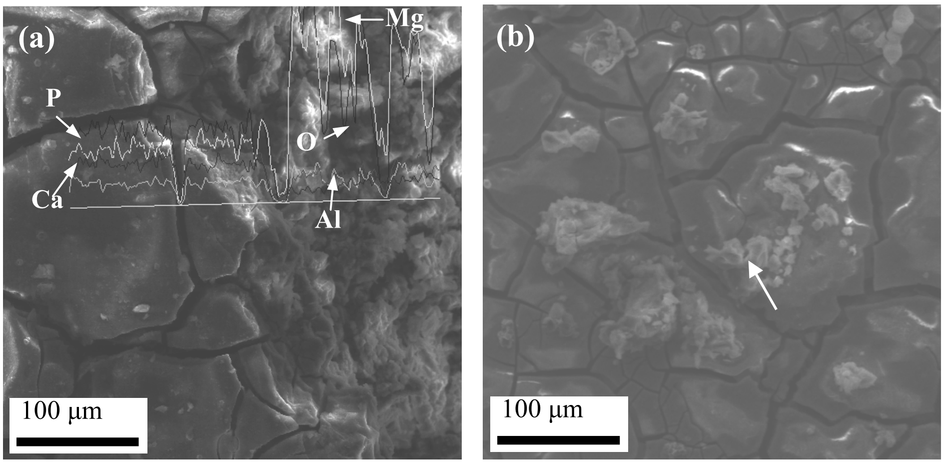

Fig. 3 SEM images of the AZ31 samples after three days' immersion.
(a) Extruded sheet, and (b) extruded rod. The inset in (a) is an EDS spectrum of that area.
The white precipitates indicated by arrows in (b) were confirmed as calcium phosphates.

Fig. 4a illustrates weight loss rate of the AZ31 specimens with immersion in SBF extended to 7 days. We can see that during the first day of immersion in SBF, the extruded rod and sheet specimens, both with a basal texture, exhibited a much slower weight loss rate than the hot rolled sheet specimen with a fiber texture. The extruded sheet specimens with a basal texture and comparative large grain size exhibited the slowest weigh loss rate during almost all the days of immersion. After three days' immersion in SBF, the weight loss rate of the extruded rod and hot rolled sheet, which have comparable initial grain sizes, was close.

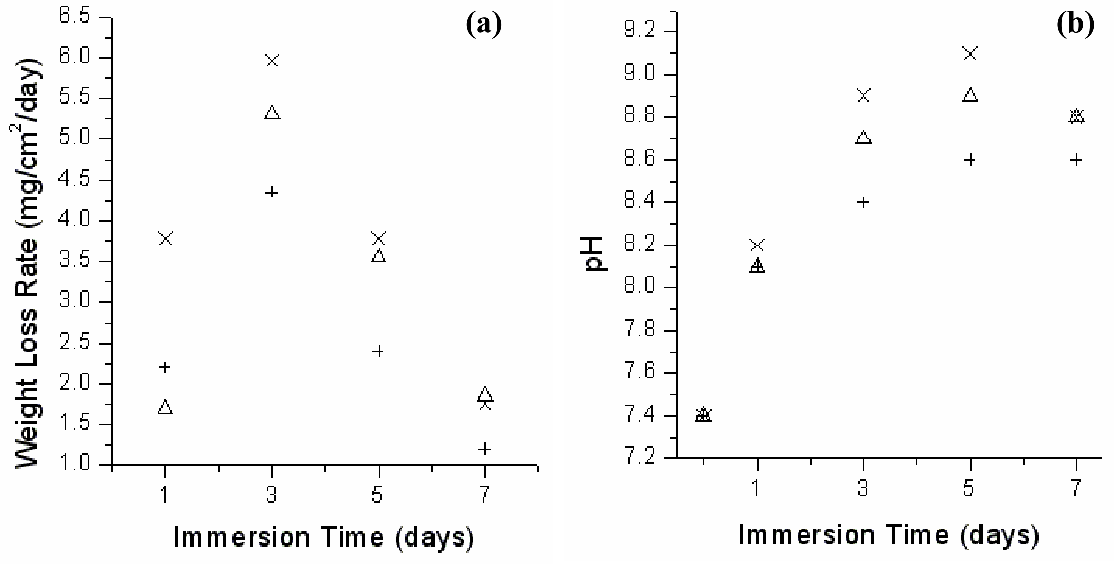

Fig. 4 Weight loss rate of (a), and pH of SBF solution for the AZ31 extruded rod (△), hot rolled sheet (×) and extruded sheet (+).

Fig. 4b illustrates pH variation of the AZ31 specimens with immersion in SBF extended to 7 days. For all the cases, the pH of SBF solution raised continually up to 8.5 ~ 9 after the AZ31 specimens were immersed in the solution. Fig. 4a and 4b indicated that the result of pH variation of SBF solution was consistent with that of weight loss rate of the specimens. Therefore, the weight loss rate can somehow indicate the corrosion of the AZ31 specimens in this study, as the pH raise was attributed to the formation of OH^- in SBF solution that was in proportion with the amount of corrosion [2]. Certainly, the corrosion of magnesium alloy is normally better evaluated through H_2 evolution in SBF that might be used in the further experiments [1].

Summary

In summary, the comparative studies on three types of magnesium alloy AZ31 showed that the extruded sheet specimen exhibited the best corrosion resistance in conventional SBF solution, which was probably due to its initial basal texture and uniform large grain size. It might suggest that control of microstructure and texture is a possible way to enhance the corrosion resistance of magnesium alloys.

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