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Effect of extrusion on corrosion behavior and corrosion mechanism of Mg-Y alloy

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Abstract: The influences of the hot extrusion process on the microstructure, corrosion behavior and corrosion mechanism for Mg-Y magnesium alloy were studied by means of the microstructure observation, weight loss test, electrochemical test and corrosion morphology test. The results showed that with increasing of the extrusion ratio, the shear flow line on the vertical section of the extruded alloy increased, the shear bands parallel lines became more clearly visible, and a large number of fine equiaxed grains distributed in parallel with the flow lines. The open circuit potential had a certain degree of improvement after extrusion, the open circuit potential increased with increment of extrusion ratio, and the corrosion potential of the vertical section was higher than that of the same alloy in the same compression ratio. The shift rate of the corrosion potential relatively became larger with increasing of the extrusion ratio, and the cathode corrosion current corresponding to the branch migration shifted to the positive direction. The high frequency capacitive arc increased with increment of the extrusion ratio, and the radius of capacitive arc of the vertical section was slightly larger than that of the transverse section. The corrosion morphologies of Mg-0.25Y alloy were uniform corrosion, and the corrosion morphologies of Mg-(2.5, 5, 8 and 15) were the pitting corrosion and the small range, deep depth localized corrosion.

Keywords: extrusion; Mg-Y alloy; corrosion behavior; corrosion mechanism; rare earths

Because of the quite special properties of the deformation, magnesium alloy has high specific strength, thermal conductivity, biological adaptability and easy to cycle to adapt to the characteristics of as cars, weapons, aerospace and other industries, which lead to great application prospect[1–3]. However, owing to its low strength, elongation, especially its poor corrosion resistance, the large-scale industrial applications of magnesium alloy was limited. Improvement of the poor performance of magnesium alloy processing, such as extrusion, forging, rolling, etc., has become a research hotspot. The hot extrusion could improve the microstructure and the properties of the alloy, so the hot extrusion is the best way to improve the corrosion performance of magnesium alloy, and the denaturation studies of AZ80, AZ31 Mg Sn alloy AZ91 alloy have been confirmed[4–7]. Extrusion process affects the microstructure state, including grain refinement, the second phase refinement, the organization change, the dislocation and the twin formation, thus has important influence on the corrosion performance of magnesium alloy. The mechanism of how these factors influenced the corrosion resistance and to what extent these factors affected the corrosion resistance of magnesium alloy have not yet been settled.

In this experiment, Mg-(0.25, 2.5, 5, 8 and 15)Y alloys were used as the research objects to carry out the extrusion deformation experiments. The microstructure, corrosion properties were observed and analyzed under the different deformation conditions to study the effects of the deformation conditions on the corrosion performance. The experimental analysis of the plastic deformation on corrosion resistance of Mg-Y alloys was combined to determine the corrosion mechanism of extruded Mg-Y alloys.

1 Experimental

1.1 Materials

According to the phase diagram of Mg-Y alloy, the eutectic reaction occurred at 565 ºC: L→α(Mg)+ γ($Mg_{24}Y_5$). Y element has large solubility limit in magnesium alloys, and the solid solubility at the temperature of 565 ºC was 12.47%. The solid solubility significantly decreased with decreasing of the temperature, which showed the obvious aging strengthening characteristics. However, with increasing of Y content, the ductility of

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Mg-Y alloys showed a high, middle and brittle evolution. Mg-Y alloy would produce brittleness when the content of Y exceeded 8 wt.%[8]. Generally, Y element added in the magnesium had the following functions: improving the high temperature performance, increasing the fluidity, reducing the porosity, improving the thermal cracking and porosity and improving corrosion resistance, etc.. In order to investigate the effect of different contents of Y on the corrosion behavior of Mg-Y alloys, the chemical compositions of Mg-Y alloys are shown in Table 1.

1.2 Method

The diameters of the extruded alloy were 20 and 40 mm respectively, and the specimen sections with the extrusion ratio of 5:1 and 20:1 were symmetrically cut into 4 samples and 1 sample.

The hot extrusion processing of Mg-(0.25, 2.5, 5, 8 and 15)Y alloys were as follows: the alloys ingot were heated to 260 ºC in the preheated furnace for 2 h; the preheated ingots were squeezed into the round bars with the diameters of 40 and 20 mm (corresponding to the extrusion ratios of 5 and 20) in a YH61-500G type horizontal extruder. The extruded round bars would be forced to cool with water at the outlet of the extruder.

Extrusion ratio: The area ratio of the section area before and after extrusion was used as a parameter of the degree of deformation, that is:

$$\lambda=A_0/A_1=(d_0/d_1)^2 \quad (1)$$

where, λ is the extrusion ratio, A_0 section area before extrusion, A_1 section area after extrusion, d_0 and d_1 are the diameters before and after extrusion.

The immersion tests were conducted in the 3.5 wt.% NaCl solution, which was prepared with AR grade NaCl and distilled water at room temperature. For metallographic characterization, the samples were prepared by ingot casting process. The specimens were encapsulated by epoxy resin with a surface of 10 mm×10 mm exposed to the solution. The specimens were wet ground through successive grades of silicon carbide abrasive papers from P120 to P1500 followed by diamond finishing to 2.5 μm in water, degreased with acetone, washed with deionized water, rinsed with the opropyl alcohol in an ultrasonic bath and dried in cool flowing air before tests. All tests were performed in duplicate to guarantee the reliability of the results. The etching reagent of 5 mL HNO_3+95 mL ethanol was used to reveal the constituents and general microstructure of Mg-Y alloys. The formula of the average corrosion rate v(mg/(cm^2·h)) was as follows[9]:

$$\bar{v} = \frac{\omega_0 - \omega_1 + \omega_2}{At} \quad (2)$$

Where, A is the sample area (cm^2); t the experimental time (h); ω_0 the original sample mass (mg); ω_1 the sample mass after removal of the corrosion products; ω_2 the corrosion mass loss of the same size sample after removal of the corrosion products (mg).

The test electrochemical measurement system was composed of PGSTAT 30 Potentiostat/Galvanostat model Y273A, HF frequency response analyzer SI1255 and corresponding analysis software. The polarization measurements and the open circuit potentials were carried out at a scan rate of 0.5 mV/s, from −100 to +400 mV with respect to the corrosion potential (E_{corr}). EIS measurements were conducted using potentiostat/Galvanostat Model 273A coupled with HF Frequency Response Analyzer SI1255 with a perturbing signal of AC amplitude of 5 mV and a frequency ranging from l00 Hz to 5 mHz.

After mechanical polishing, the sample was corroded by 4% nitrate alcohol corrosion liquid. The microstructure observation was observed by a Zeiss Axiocert 2000MAT Carl microscope. The microstructure and corrosion morphologies were observed by a JSM-6510A scanning electron microscope.

Table 1 Chemical composition of Mg-Y alloy

Alloy	Nominal chemical composition/wt.%		Actual chemical composition/wt.%	
	Y	Mg	Y	Mg
Mg-0.25Y	0.25	Bal.	0.24	Bal.
Mg-2.5Y	2.50	Bal.	2.08	Bal.
Mg-5Y	5.00	Bal.	5.23	Bal.
Mg-8Y	8.00	Bal.	7.46	Bal.
Mg-15Y	15	Bal.	13.78	Bal.

2 Results and analysis

2.1 Microstructure of extruded alloy

The horizontal and longitudinal microstructures of Mg-(0.25, 2.5, 5, 8 and 15)Y alloys with the extrusion ratio of 5:1 and 20:1 are shown in Figs. 1 and 2. The coarse $Mg_{24}Y_5$ phases in perpendicular to the stress direction were crushed, and broken down into tiny particles, which discretely distributed within the α-Mg matrix. The relative rotation occurred during the grains, which drove the slip and deformation of the broken intermetallic compounds. A large number of small, dense intermetallic compound particles dispersed in the transverse section.

The cast microstructure of the five kinds of alloys after extrusion completely disappeared, the grain size of the alloy was obviously refined, the grain boundaries became uniform and fine, and the microstructure in the interior of the alloys had no cracks and pores. As the extrusion ratio increased, the deformed degree increased, the microstructure was further refined, the extrusion streamline became more apparent, the grains became finer. As for the two extrusion ratios, the extrusion shearing fringe parallel lines distributed along the extrusion direction in the longitudinal section, the extrusion shearing fringe