



Tailoring the degradation rate of magnesium-lithium alloy with alloying elements of gadolinium and nickel

Mengyao Pang^a, Tao Zhong^b, Siyuan Jin^a, Xiaochun Ma^a, Ruizhi Wu^{a,*}, Legan Hou^{a,*}, Iya I. Tashlykova-Bushkevich^c, Boris Krit^d, Jinghuai Zhang^a

^a Key Laboratory of Superlight Materials & Surface Technology, Ministry of Education, Harbin Engineering University, Harbin 150001, China

^b Department of Science and Technology, Nanning College for Vocational Technology, Nanning 530008, China

^c Physics Department, Belarusian State University of Informatics and Radioelectronics, Minsk 220013, Belarus

^d Moscow Aviation Institute, Russian National Research University, Moscow 121552, Russia

ARTICLE INFO

Keywords:

Mg-Li-Gd-Ni alloy

LPSO

Galvanic coupling corrosion

Degradation rate

ABSTRACT

To explore lightweight degradable materials that are more suitable for fracturing ball, Mg-8Li-4Gd-xNi ($x = 0, 0.5, 1, 1.5$ wt%) alloys for fracturing ball in petroleum extraction were prepared by vacuum induction melting. The features and formation of long-period stacking ordered (LPSO) doped with gadolinium (Gd) and nickel (Ni) were characterized. And the relationship between the degradation rate of alloys and the structure of LPSO in duplex Mg-Li alloys is investigated. The results show that network 24 R LPSO phase and punctate GdNi₃ phase are formed with the addition of Gd and Ni. With the increase of Ni content, the shape of LPSO changes from intermittent network to continuous network and turns into an intermittent network again. The Mg-8Li-4Gd-1.5Ni alloy shows a significant increment in weight loss rate compared with the Mg-8Li-4Gd alloy by 75 times. Atomic force microscope (AFM) results show that the addition of Ni increases the potential difference between the second phase and the β -Li phase from 220 mV to 504 mV. It is difficult for forming LPSO due to higher fault energy when the atomic ratio of Gd to Ni is lower than 4:3, which promotes the LPSO to intermittent network. LPSO and GdNi₃ provide higher potentials as cathodes in corrosion, forming a loose and porous corrosion product layer in the alloy. With the increase of Ni content, micro-galvanic corrosion effect is increased which results in a significantly higher corrosion rate of the alloy.

1. Introduction

With the depletion of fossil energy sources, oil and gas exploration begins to transform into unconventional oil and gas resources that are difficult to extract with complex storage conditions, lower permeability and less economically efficiency [1]. The fracturing ball is a plugging tool for horizontal wells in the segmented fracturing process [2], and plays a critical role in improving the efficiency of oil and gas production [3]. It requires greater pressure for hydraulic fracturing techniques to obtain oil and in the underground environment the temperature is higher [4]. Fracturing balls always serve in the environment of

high-temperature and high-pressure [5], in which it is required that fracturing balls possess both high strength and high corrosion rate simultaneously [6]. It is easier for the lower density fracturing ball to follow the fracking fluid into the ball seat [7]. Fracturing balls need lightweight that can withstand the high pressure, high temperature and have rapid corrosion rate during fracturing process.

Currently, extensive investigations are being conducted on various magnesium alloy fracking ball materials systems, such as magnesium-aluminum (Mg-Al) alloy [8], magnesium-zinc (Mg-Zn) alloy [9] and Mg-rare earth (RE) alloy [10]. However, the prioritization of density requirements for fracturing balls has been relatively low. Doping with

Abbreviations: Mg-Li, magnesium-lithium; Gd, gadolinium; Ni, nickel; AFM, atomic force microscope; Mg-Zn, magnesium-zinc; Mg-Al, magnesium-aluminum; RE, rare earth; Cu, copper; Fe, iron; OM, optical microscope; SEM, scanning electron microscope; EDS, energy dispersive spectrometer; TEM, transmission electron microscope; XRD, X-ray diffraction; XPS, X-ray photoelectron spectroscopy; EIS, electrochemical impedance spectroscopy; SAED, selected area electron diffraction; E_{corr} , corrosion potential; i_{corr} , current density; P_i , degradation rate; $|Z|$, impedance modulus; R_s , solution resistance; CPE, double-layer capacitance; R_{ct} , charge transfer resistance; L, inductance; R_L , inductive resistance; O, oxygen; C, carbon.

* Corresponding authors.

E-mail addresses: rzwu@hrbeu.edu.cn (R. Wu), houlagan@hrbeu.edu.cn (L. Hou).

<https://doi.org/10.1016/j.jalcom.2023.173115>