G Model
CS-6379; No. of Pages 6
ARTICLE IN PRESS
Corrosion Science xxx (2015) xxx–xxx
Contents lists available at ScienceDirect
Corrosion Science
journal homepage: www.elsevier.com/locate/corsci

Galvanic corrosion behaviour of carbon fibre reinforced polymer/magnesium alloys coupling

Yingcai Pan[a], Guoqing Wu[a,*], Xu Cheng[a], Zongke Zhang[a], Maoyuan Li[b], Sudong Ji[b], Zheng Huang[a]

[a] School of Materials Science and Engineering, Beihang University, Beijing 100191, China
[b] The System Design Institute of Mechanical-Electrical Engineering Beijing, Beijing 100048, China

ARTICLE INFO

Article history:
Received 8 June 2015
Received in revised form 12 June 2015
Accepted 14 June 2015
Available online xxx

Keywords:
A. Magnesium
A. Polymer
B. SEM
C. Kinetic parameters
C. Oxide coatings

ABSTRACT

The galvanic corrosion behaviour of carbon fibre reinforced polymer (CFRP, T300/648) in contact with different magnesium alloys (AZ31, LZ91 and LZ141) in a sodium chloride solution and the influence of micro-arc oxidation (MAO) film on the corrosion behaviour of CFRP/magnesium alloys coupling were investigated using the electrochemical method. The results showed that the galvanic activity of CFRP/magnesium alloys coupling increased with the increase of lithium concentrations. The duration of the inhibitory effect of MAO film on the corrosion of CFRP/Mg–Li coupling is longer than that of CFRP/Mg–Al coupling due to its double-layer structure.

1. Introduction

Fibre metal laminates (FMLs), consisting of alternative layers of thin metal sheets and composite layers, have great potential to use in aerospace applications due to their exceptionally light weight, superior fatigue behaviour and high impact resistance [1]. Normally, the densities of FMLs based on aluminium and titanium alloys sheets are about 2.29–3.66 g/cm^3 [2,3]. In order to further reduce the FMLs materials weight, many investigations were carried out by replacing the aluminium alloys with Mg–Al alloys (AZ31) [4,5], saving of around 24% materials weight. It is well-known that Mg–Li alloys are one of the lightest magnesium alloys with density of around 1.30–1.60 g/cm^3. Hence, it is highly expected that the application of Mg–Li alloys sheets in the FMLs can further reduce the material density to around 1.50 g/cm^3 and also improve the electromagnetic shielding capability as well as damping performance of the FMLs.

Nevertheless, the use of metal sheet and carbon fibre in FMLs may cause the galvanic corrosion which degrades the overall performance of FMLs materials [6]. In order to improve the galvanic corrosion resistance of carbon fibre in contact with metals, some pre-treatment techniques, such as anodizing and epoxy coating, were used to modify the metal surface [6,7]. There are an extensive amount of analytical work reported in literature to investigate the galvanic corrosion behaviour of CFRP coupled with aluminium alloys, titanium alloys and carbon steels [8–11]. However, the galvanic corrosion behaviour of CFRP/Mg–Li coupling and the influence of the MAO film on the corrosion properties of CFRP/magnesium alloys coupling have been overlooked.

In this paper, the open circuit potentials (OCP) of three magnesium alloys (AZ31, LZ91 and LZ141) and CFRP (T300/648) in a 3.5 wt.% sodium chloride solution were analyzed using the open circuit technique in the electrochemical station. Besides, the galvanic corrosion current densities of galvanic couplings of CFRP/magnesium alloys with and without MAO coatings were also analyzed using the galvanic corrosion technique in the electrochemical station. The aims of this work are to evaluate the galvanic activity of CFRP in contact with different magnesium alloys, and also to study the influence of MAO film on the galvanic corrosion of CFRP/magnesium alloys coupling.

2. Material and methods

2.1. Materials

The magnesium alloys (AZ31) sheets with 2 mm thickness are used in this study (produced by Luoyang Shengte Corp. Henan, China). The magnesium lithium alloys (LZ91 and LZ141) sheets

* Corresponding author. Fax: +8610 82313240.
E-mail address: guoqingwu@buaa.edu.cn (G. Wu).

http://dx.doi.org/10.1016/j.corsci.2015.06.024
0010-938X/© 2015 Published by Elsevier Ltd.

Table 1
Chemical compositions (in wt.%) of three magnesium alloys investigated in this study.

	Li	Al	Zn	Mg
AZ31	–	2.7	1.1	Bal.
LZ91	9.2	–	1.2	Bal.
LZ141	13.8	–	1.1	Bal.

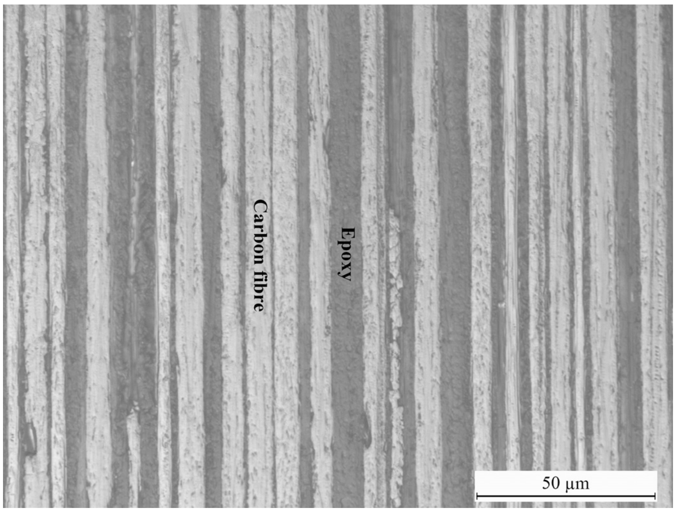

Fig. 1. Optical micrographs of the CFRP (T300/648) surface after grind, carbon fibre (white area) and epoxy (dark area).

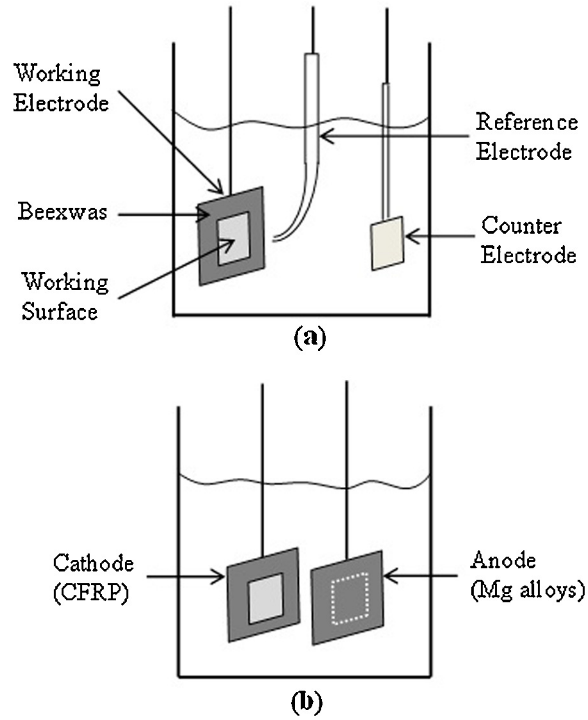

Fig. 2. The schematic illustration of the experimental setup: (a) open circuit potentials test and (b) galvanic corrosion current density test.

were prepared by firstly stir-casting in a resistance furnace under argon atmosphere, then forged and rolled to make the slab. The chemical compositions of these three alloys are shown in Table 1. The 2 mm carbon fibre reinforced polymer (CFRP) composites sheets, consisting of unidirectional carbon fibre (55 Vol.%, type T300) and epoxy (type 648), are produced by the System Design Institute of Mechanical-Electrical Engineering in Beijing, China. The magnesium alloys and CFRP specimens were cut into pieces (20 mm × 20 mm × 2 mm). Before the test, the surfaces of the magnesium alloys were ground using 1200 mesh papers and the CFRP surface were also sufficiently ground to expose the carbon fibre (around 55% surface area, see Fig. 1). At last, all the samples were ultrasonically cleaned.

2.2. Micro-arc oxidation process

Micro-arc oxidation (MAO) process was carried out by using an inverter pulsed power supply (Type GGMF25/600-A). The magnesium alloy specimens were used as anode, and two AISI 316 L panels cathodes (50 mm × 20 mm × 3 mm) were positioned on both sides to ensure a homogeneous coating over the entire surface. The distance between both electrodes amounts to 4 cm. During treatment, the voltage used is 120 V, and the coating time is 25 min with a fixed frequency of 500 Hz and duty ratio of 45%. The electrolyte contains 50 g/L sodium hydroxide (NaOH) + 40 g/L sodium metasilicate nonahydrate (Na_2SiO_3 $9H_2O$) + 20 g/L sodium borate dehydrate ($Na_2B_4O_7$ $10H_2O$) + 40 g/L citric acid trisodium salt dehydrate ($C_6H_5Na_3O_7$ $2H_2O$) [12]. After MAO treatment, the coated samples were rinsed with distilled water and dried in air.

2.3. Electrochemical measurements

The electrochemical measurements of open circuit potential and galvanic current were conducted separately on a Versa STAT MC-4 electrochemical station. Beeswax was used to mask the surfaces of the alloy and the composites, leaving an exposed area of around 1 cm^2. The open circuit potential measurements were carried out in a conventional three-electrode cell for 2 h with the data acquisition rate of one point per one-second. The magnesium alloys and CFRP specimens were used as a working electrode, platinum plate as a counter electrode and a saturated calomel electrode (SCE) (Hg/Hg_2Cl_2 in saturated KCl) as a reference electrode (Fig. 2a). The galvanic current densities of bare and coated alloys coupled with CFRP were measured using the galvanic corrosion technique in the electrochemical station, and their current densities were recorded for 8 h with the data acquisition rate of one point per 15 s. The distance between both electrodes is around 3 cm (Fig. 2b). All measurements were carried out in a 3.5 wt.% sodium chloride solution (pH 6.5, 25 ± 2 °C) open to air and not to be stirred.

2.4. Microstructure characterization

The surface morphology, cross-section microstructure and chemical composition of the coatings were examined using the scanning electron microscopy (SEM, Phenom^{TM} Pro) with energy dispersive analysis of X-rays (EDX). Phase composition in coatings was analysed using the X-ray diffraction (XRD, D/MAX-2000) with a Cu K_{a1} source.

3. Results

3.1. Open circuit potential measurements

Fig. 3 shows the open circuit potentials (OCP) of the CFRP and three magnesium alloys at different testing times. As can be seen, the OCP of CFRP composite (T300/648) is around +0.28 V_{SCE} with small dispersion, and for the AZ31 alloy is about −1.575 V_{SCE}. The LZ91 and LZ141 alloys are around −1.645 V_{SCE} and −1.648 V_{SCE}, respectively, which are more negative than the potential of AZ31 alloy. M. Schneider reported that [13], when the potential difference between two materials is less than 0.05 V, the galvanic

Please cite this article in press as: Y. Pan, et al., Galvanic corrosion behaviour of carbon fibre reinforced polymer/magnesium alloys coupling, *Corros. Sci.* (2015), http://dx.doi.org/10.1016/j.corsci.2015.06.024