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Corrosion fatigue behavior of conversion coated and painted AZ61 magnesium alloy

Md. Shahnewaz Bhuiyan [a], Yoshiharu Mutoh [b,*]

[a] Dept. of Materials Science, Nagaoka University of Technology, Japan
[b] Dept. of Systems Safety, Nagaoka University of Technology, Japan

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ABSTRACT

The present study has been carried out in order to study the fatigue behavior of conversion coated and painted AZ61 magnesium alloy under different corrosive environments: (a) low humidity environment, (b) high humidity environment (80% relative humidity) and (c) 5% NaCl environment. It was found that under low humidity and high humidity environments, the coated and painted specimen showed the same level of fatigue limit, which was almost equal to that of bulk material under low humidity environment. In contrast, under NaCl environment, the coated and painted specimen showed about 11% of reduction in fatigue limit, while that of bulk specimen was about 85% of reduction. Fracture surface observations of the coated and painted specimens under high humidity and NaCl environments showed no existence of environmental attack in the crack nucleation region, where fatigue cracks were nucleated from the surface of coating and painting layer, which then propagated towards the substrate. The absence of environmental attack in the crack nucleation region suggests that the coating and painting layer can perfectly protect the substrate material from the attack of corrosive environments.

1. Introduction

Magnesium and its alloys exhibit an attractive combination of low density and high strength/weight ratio, which makes them ideal candidates for light weight engineering applications. But inadequate corrosion resistance of magnesium alloys has limited their application in practical environment [1–3]. Recent research works [4–6] conducted on magnesium alloys under corrosive environments, especially under high humidity and NaCl environments have revealed: (1) Fatigue limit is significantly reduced under high humidity, whereas it is drastically reduced under NaCl environment. (2) Reduction in fatigue limit under corrosive environment is attributed to the corrosion pit formation and growth to the critical size for fatigue crack nucleation. (3) Corrosion pit formation and growth are attributed to the interactive action of mechanical loading and corrosive environment. Therefore, some effective surface treatment or coating is needed to develop for their practical applications.

A number of surface modification techniques have been proposed for protecting magnesium alloys [7–9], where anodizing is one of the most popular methods [7–11]. However, a generic problem with anodizing is the adverse effect on fatigue properties [12–14]. Khan et al. [13,14] investigated the fatigue behavior of anodized AM60 magnesium alloy under humid environment and reported that while thicker anodized layer was much effective for protecting magnesium substrate from corrosion attack, thicker anodized layer with defects enhanced early nucleation of fatigue crack and then reduced fatigue strength even under low humidity environment. One of another candidates for surface modification will be chemical conversion coating. Compared to anodized coating, conversion coating is more simple in its process and can provide a suitable base for painting. As per the authors' knowledge, no research works have been carried out to understand the effectiveness of conversion coating and painting for improving fatigue strength under corrosive environment. Therefore, it is of significant importance to study the corrosion fatigue characteristics of conversion coated and painted magnesium alloys under corrosive environments.

In the authors' previous paper [6], corrosion fatigue behavior of extruded AZ61 magnesium alloy bulk specimen without coating was investigated under high humidity (80% relative humidity (RH)), sprayed 5 wt.% NaCl and sprayed 5 wt.% $CaCl_2$ environments. From the results, it was found that the fatigue limit was drastically reduced in all three environments. The reduction rate of fatigue limit (defined at 10^7 cycles) under corrosive environment, %RFL, was defined as:

$$\%RFL = \frac{\sigma_{LH} - \sigma_{CE}}{\sigma_{LH}} \times 100 \quad (1)$$

where, σ_{LH} is the fatigue limit under low humidity and σ_{CE} is the fatigue limit under corrosive environments.

The %RFL values for AZ61 under high humidity environment and under sprayed NaCl and $CaCl_2$ environments were 22%, 85% and 77%, respectively. The drastic reduction in fatigue limit under

* Corresponding author. Tel.: +81 258 47 9003.
E-mail address: mutoh@mech.nagaokaut.ac.jp (Y. Mutoh).

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corrosive environments resulted from pit formation and growth to the critical size for fatigue crack nucleation. It was also suggested that the NaCl environment enhanced pit formation and growth more than the $CaCl_2$ environment due to the high Cl^- concentration and low pH value. As mentioned above, detailed investigations on corrosion fatigue of AZ61 were available. The authors have also investigated the effect of conversion coating on corrosion fatigue behavior and found that the conversion coating could improve fatigue limit by about 11% under high humidity environment and 20% under NaCl environment [15]. The reason for this limited improvement of fatigue limit was that the conversion coating layer allowed the corrosive media to reach the substrate magnesium alloy and then to induce general corrosion or corrosion pit. It has been also reported that conversion coating cannot protect magnesium alloys from corrosion in aggressive environment for longer period time exposure without organic top layer (painting layer) [16,17]. Therefore, the preliminary corrosion fatigue tests of the coated and painted specimen have been carried out to confirm the effect of painting and the resultant *S–N* curves have been reported [18], in which significant improvement of corrosion fatigue strength due to painting has been observed. However, detailed morphology of the interface between substrate and coating-painting layer, effect of residual stress and fatigue fracture mechanisms of the coated and painted specimen under low humidity as well as under corrosive environments have not yet been clarified.

In the present study, as a part of a series of research works on corrosion fatigue behavior of extruded AZ61 magnesium alloy, corrosion fatigue tests of conversion coated and painted specimens were carried out under two different corrosive environments: (a) high humidity (80% RH) and (b) sprayed 5 wt.% NaCl solution environment. Effect of painting layer on fatigue strength and effect of interface morphology between the coating-painting layer and the substrate were discussed based on the detailed fracture surface observations and the fracture mechanics approach.

2. Experimental procedure

2.1. Material and specimen

The material used in the present study was an extruded AZ61 magnesium alloy. Chemical composition and mechanical properties of the alloy is listed in Tables 1 and 2, respectively. For metallographic examination, freshly polished specimen was etched in an acetic-picral solution and observed under an optical microscope. An example of the microstructure is shown in Fig. 1. As seen from the figure, the grains were equiaxed and no deformation twins were observed.

Fig. 2 shows shape and dimensions of the specimen used for the fatigue test, where the gauge diameter and length are 3 mm and 6 mm, respectively. After machining, the gauge part of specimen was polished in the loading direction with 280 to 800 grit emery papers in laboratory air and with 1000 to 1500 grit emery papers under kerosene oil to prevent corrosion of the specimen surface during polishing process. After all polishing processes were completed, the specimens were cleaned by ethanol in an ultrasonic cleaner. The specimens were then divided into two groups: one group was as-polished and the other group was offered to further process for conversion coating and painting. The conversion coating and painting process applied in the present study is outlined in Fig. 3. The composition of conversion coating layer was analyzed by using an energy dispersive spectroscopy (EDS). Fig. 4 shows the results of EDS mapping analysis. As can be seen from the figure, the coating layer mainly consists of phosphorus. Hereafter, the as-polished surface specimens and the conversion coated and painted specimens are noted as the bulk specimen and the coated and painted specimen, respectively.

Table 1
Chemical composition of the AZ61 magnesium alloy used (mass%).

Al	Zn	Mn	Fe	Si	Cu	Ni	Mg
5.95	0.64	0.26	0.005	0.009	0.0008	0.0007	Bal.

Table 2
Mechanical properties of the AZ61 magnesium alloy used.

	Yield stress, $\sigma_{0.2}$ (MPa)	Tensile strength, σ_B (MPa)	Elongation (%)	Young's modulus, *E* (GPa)
AZ61	185	318	18	43

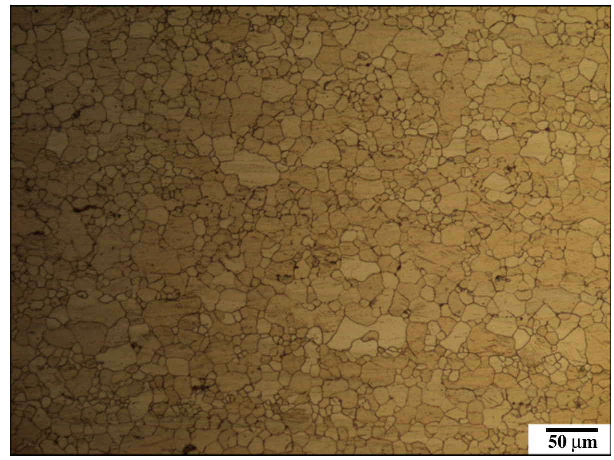

Fig. 1. Microstructure of the AZ61 magnesium alloy used.

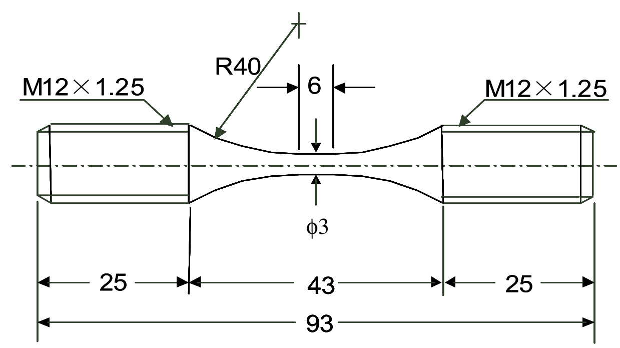

Fig. 2. Shape and dimensions of the fatigue test specimen.

2.2. Fatigue test

The fatigue tests under low humidity and corrosive environments were carried out on a servo-hydraulic fatigue testing machine using a sinusoidal wave form with a stress ratio of −1 and a frequency of 20 Hz. Three different testing environments were used to clarify the role of conversion coating and painting: (a) low humidity (16–20°C, 36–40% RH), (b) high humidity (55°C, 80% RH) and (c) sprayed 5 wt.% NaCl solution environment with a pH value of 6.59 (noted as NaCl environment). Fatigue tests under high humidity environment were conducted in a specially designed chamber, which can control the relative humidity level ranging from 30% to 80% RH. The sprayed 5 wt.% NaCl tests were