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Effect of anodized layer thickness on fatigue behavior of magnesium alloy

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Abstract

The process of anodizing has been adopted as an effective way to protect underlying material from corrosive environments. In the present study, since the corrosion protection ability would depend on thickness and quality of the anodized layer, effect of anodized layer thickness on fatigue behavior of AM60 magnesium alloy was investigated using three different anodized layer thicknesses of 15, 5 and 1 μm. The specimen with 15 μm thick anodized layer showed rough and irregular interface between substrate and anodized layer. Many defects were also observed in the anodized layer. But as the thickness of anodized layer was reduced from 15 to 5 to 1 μm, interface roughness was tended to be diminished. The role of interface roughness was reflected in the fatigue strength of three groups of specimens, where the specimen with the smoothest interface, 1 μm thick anodized specimen, showed the highest fatigue strength among the three groups. For the specimen with 15 μm thick anodized layer, the estimated value of ΔK at fatigue limit was almost equal to ΔK_{th} ($\approx$0.86 MPa$\sqrt{m}$) while for the specimens with 5 and 1 μm thick anodized layers the estimated ΔK values were well below the ΔK_{th}, where the initial crack should be considered as small crack. Well-known Kitagawa–Takahashi diagram for the present three kinds of anodizing layer thickness suggested that the anodizing layer thickness would be preferred less than 5 μm.

Keywords: Magnesium alloy; Anodizing thickness; Fatigue behavior; Interface roughness; Stress intensity range; Small crack behavior

1. Introduction

Due to global environment and saving energy, trend for reducing weight of machine components, especially in automotive and aerospace industries, leads to the emergence of magnesium (Mg) alloy from the development stage to the application stage [1]. But the poor corrosion resistance of Mg alloys should have to be taken into consideration and hence a protective surface treatment becomes an essential part of the manufacturing process for Mg components that are to be used in humid or corrosive environments. It is well established that anodic oxidation or anodizing is reliable enough to protect the underlying material from corrosion, which is especially popular in aluminium industry. This process has also applied to Mg alloy.

Although progressive research works on fatigue of magnesium alloy have been carried out, the effect of anodizing layer on fatigue performance has not yet been well understood: in many cases the fatigue strength was significantly degraded [1], while was not in some cases [2]. Therefore, thorough and detailed investigations are still required. Especially investigation on the effect of anodizing thickness on fatigue behavior is indispensable since under high humid or corrosive environments the thicker coating material could play an important role.

Of the two stages of fatigue, namely crack nucleation and crack propagation, most attention has been concentrated on the former one. Research works on Al alloys showed that anodized films would be readily cracked when deformed [2]. Since oxide layer has grown out from the substrate and adheres extremely well to it, any cracks that develop in the layer act as stress raisers and can thus contribute as starters for fatigue crack propagation [3]. What has received less attention is the detailed morphology of the interface between substrate and coating layer and its relationship with the thickness of coating layer. Very few research works have been carried out to investigate the effect of interface between substrate/coating layer on degradation of fatigue performance, though many researchers have reported the nucle-

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ation of fatigue cracks from the interface between coating and substrate [4].

In the present study, specimens with different thickness of anodizing layer on the specimen surface were prepared. Fatigue tests of these specimens were carried out. Effect of anodized layer thickness on fatigue strength and effect of interface morphology between anodized layer and substrate were investigated based on the detailed fracture process observations and the fracture mechanics approach.

2. Experimental procedures

2.1. Materials

In the present work, the materials used were anodized and painted AM60 alloy plates with three kinds of anodizing layer thickness: 15, 5 and 1 μm. Prior to anodizing, the specimen surfaces were mechanically polished with SiC emery papers to minimize the surface roughness and to achieve mirror-like surfaces. The chemical composition and mechanical properties of the substrate AM60 alloy is presented in Tables 1 and 2, respectively. In order to observe the microstructures of the anodized specimens, the cross-sections of the specimens were mechanically polished with successively finer SiC emery papers up to grit number of 3000. Etching of the polished surface was carried out with a solution of picric acid (ASTM E-125). Fig. 1 shows the microstructure of an anodized material. It was not possible to detect any observable microstructural difference in the substrate material among the three groups of specimens due to anodization. Fig. 2 shows typical EDS analysis conducted on the anodized material which allowed the determination of the approximate local chemical composition. From the figure, the anodized layer could be clearly identified.

The painting material was of Acylic melamine resin system which was deposited using electrostatic painting process. The main purpose of painting is for preventing environmental attack and for fine sight. Mechanical and fatigue properties of painting layer are not available. However, the average nano-hardness value of the painted layer was 588 MPa, which was lower than that of the substrate (688 MPa). Therefore, effect of painting layer on fatigue strength would be limited.

Table 1
Chemical composition of AM60 (wt%)

Al	5.5–6.5
Mn	0.13
Si	0.5
Cu	0.35
Zn	0.22
Ni	0.03
Mg	Bulk

Table 2
Mechanical properties for the base metal (AM60)

Tensile strength (MPa)	224
0.2% proof stress (MPa)	103
Elongation (%)	9.0
Young's modulus (GPa)	43

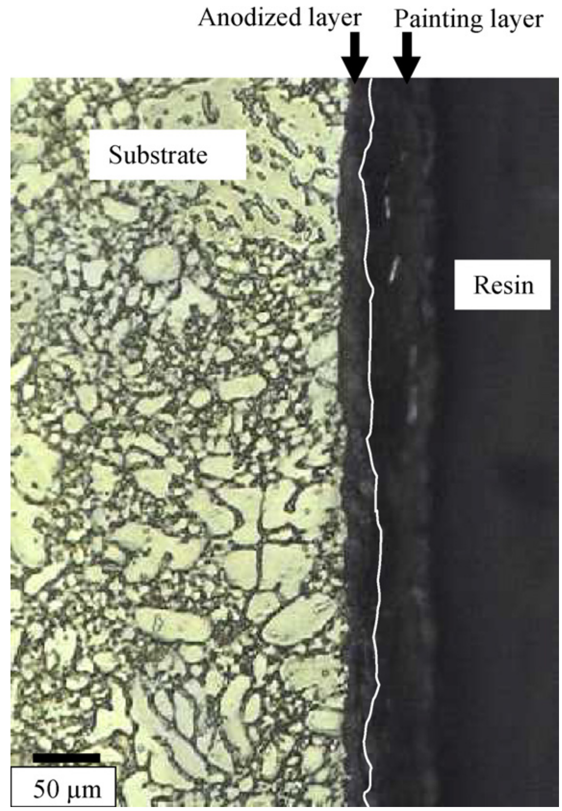

Fig. 1. Microstructure of an anodized specimen having an anodized layer of 15 μm.

2.2. Fatigue strength test

Fatigue strength tests were carried out with the anodized and unanodized specimens under a controlled temperature of 20 °C and a relative humidity of 55% RH. A main material defect in die-casting alloy is porosity that is caused by microshrinkage and by dissolved gases leading to voids. These defects were observed mainly in the middle part of the specimen. For this reason, four-point-bend loading with outer and inner span lengths of 30 and 10 mm was selected to avoid or minimize the effect of casting defects on fatigue strength. All the fatigue tests were carried out at a stress ratio of 0.1 and a frequency of 20 Hz using a servo hydraulic fatigue machine. Rectangular plate specimens, dimensions of which are shown in Fig. 3, were prepared from the as-received die cast plate with thickness of 3 mm. After fatigue testing, the fracture surfaces were observed under a scanning electron microscope (SEM).

2.3. Interrupted fatigue test

Interrupted fatigue tests were carried out with three groups of anodized specimens under three-point bending mode with a span length of 30 mm at a stress amplitude of 70 MPa. Cyclic loading was applied up to 30, 40, 50 and 60% of the fatigue life and then interrupted. Other test conditions were the same as the