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Environmental effect on the fatigue performance of bare and oxide coated 7075-T6 alloy

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ABSTRACT

Fatigue behaviors of bare and anodic oxide coated 7075-T6 alloy have been investigated in laboratory air and 3.5%NaCl solution environment by using smooth cylindrical specimens. Presence of corrosive attack during fatigue test drastically reduced fatigue performance of the alloy. The deleterious effect was observed to be pronounced at high-cycles fatigue region, where the fatigue strength of the bare specimen was lowered by a factor of 2.9. However, the oxide coated specimens having a thickness of 23 μm showed a modest reduction in fatigue strength. Corrosion fatigue (CF) strength of the bare specimens was predominantly controlled by pitting-induced crack nucleation. Examinations on the surfaces of the corrosion-fatigued and immersed test specimens revealed that cyclic loading stimulated corrosion pit formation during CF tests. Also, corrosion behaviors of both the coated and bare specimen shave been investigated by potentiodynamic test. Despite superior corrosion resistance of coated specimens, fatigue performance was adversely affected under the combined action of corrosion attack and cyclic loading.

1. Introduction

It is well known that corrosion fatigue (CF), which is the result of the combined action of an alternating stress and a corrosive environment, is a common cause of failure in most of the engineering materials [1,2]. Due to the complex mechanical, metallurgical and environmental issues involved in synergistic corrosion-fatigue process, failure stresses and failure times in a corrosive environment are lower than those in a non-corrosive environment. It is known that high-strength precipitation-hardened aluminum alloys such as 7075-T6 are susceptible to pitting corrosion. Corrosion pits are the primary source of fatigue crack nucleation for such kind of aluminum alloys that are commonly used for aircraft structures [3,4]. The fatigue behaviors of aluminum alloys that are susceptible to pitting corrosion has been investigated in a number of studies [5–8]. Particle-induced pitting corrosion was addressed in the literature [9,10] and was presented in a model based on a probability modeling CF behavior of aluminum alloys [11]. A model that uses pit depth and initial crack size to predict fatigue life was proposed by Sankaran et al. [6]. More recently Pao et al. [12] and Genel [8] have shown independently that corrosion pits produced in 7075 alloy by immersion in NaCl solution reduced fatigue life by a factor of 2–3.

Surface treatments are widely used to improve the corrosion resistance of a structure and mechanical components. Anodic oxidation, which is an electrochemical process to form stable oxide films on the surfaces of metals, is widely used to improve corrosion and wear resistance. The oxide film is composed of a compact inner layer and a porous outer layer [13,14]. However, oxide layer easily cracks under cyclic stress due to its brittle character. Recently, that the presence of oxide layer markedly reduces the fatigue strength was shown in a previous study that has been performed on anodic oxide coated 7075-T6 aluminum alloys with and without pre-corrosion [15]. However, as a result of comparing *S–N* curves of the pre-corroded

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bare and coated specimens, it was seen that the coating layer improves the fatigue performance in high-cycles fatigue region. There exists no study that investigates influences of anodic oxide coating on corrosion fatigue performance of 7075-T6 alloy systematically. Hence, the objective of this study is to reveal the CF behavior of 7075-T6 alloy with and without anodic oxide coating in 3.5%NaCl aqueous solution.

2. Experimental studies

2.1. Specimen

Standard commercial 7075-T6 alloy (UNS-A97075) was used in this study (chemical composition (wt.%): 5.5 Zn, 2.6 Mg,1.98 Cu, 0.48 Fe, 0.40 Si, 0.18 Cr, 0.14 Mn, Al balance). The hourglass-shaped, rotating-bending fatigue test specimens with a minimum gauge diameter of 4 mm and a length of 66 mm were machined from bar stock having 12 mm of diameter. Stress concentration factor K_t of the specimen was 1.02 [16]. The surface of reduced section was polished by using SiC paper and alumina slurry. The average surface roughness (Ra) was 0.47 for the bare specimen. 38 specimens were prepared for fatigue testing. Sulfuric acid anodizing process (type II according to MIL-A-8625F) was carried out at a constant current density of 0.02 A/cm^2 in a bath containing 20%H_2SO_4 at 19 ± 1 °C for 35 min. Sealing was done in deionised water at 98 °C for a period of 4 min for each coating thickness in μm. Thickness of the coating layer was 23 μm. The average surface roughness was measured as 1.8 μm for the coated specimens. In order to investigate the initiation and population characteristics of corrosion pits under an optical microscopy, a pre-corrosion test lasting 96 h was performed by immersing the samples (9 mmin diameter and 10 mmin height) in 400 ml of 3.5 wt.% NaCl solution aerated continuously during the test. Potentiodynamic polarization tests were performed at a scan rate of 1 mV s^{-1} by using a potentiostat (Voltalab PGZ 402). Electrochemical software (VoltaMaster 4) was used for data acquisition and analysis. The working electrode was immersed in the test solution for 30 min until steady state open circuit potential (OCP) was obtained. All potentials were referred to the saturated calomel electrode (SCE), while graphite rod was used as counter electrode.

2.2. Fatigue test

All fatigue tests were carried out on a rotating cantilever bending test machine in accordance with ASTM E 468-90 [17] at 1740 rpm (29 Hz) at room temperature. Aqueous solution was prepared from analytical grade reagents and distilled water. The pH of the solutions was set to 6.6 at the onset of each test. Immersion of specimens in test solution was conducted by using a special purpose chamber given schematically in Fig. 1. Five litres of test solution were circulated around the specimens at a flow rate of 0.8 l min^{-1} and aerated continuously by an air pump during the tests. The test solution was fed from the bottom of the chamber in the vertical direction to maintain a good contact of solution with specimens. The leakage of solution from the chamber was prevented by using special O-rings fitted on the shoulders of fatigue specimens. The experiments were continued until the complete fracture of the specimens occurred. A scanning electron microscope (SEM) was utilized, to evaluate crack nucleation and propagation of fracture surfaces.

3. Results and discussion

3.1. Micro-structure and coating

A typical micro-structure of 7075-T6 alloy used in the experiment is seen in Fig. 2. The polished longitudinal section contains a large number of constituent inter-metallic particles lined along the extrusion direction. The SEM micrographs of

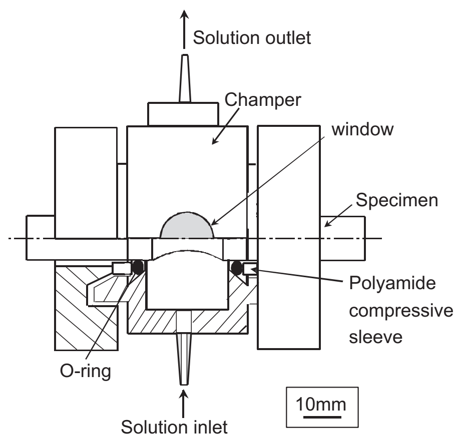

Fig. 1. Corrosion fatigue test chamber.