CONTINUAL CORROSION-FATIGUE CRACK GROWTH IN AL-ALLOYS SUBJECT TO CYCLIC COMPRESSION

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We experimentally investigated the effect of environments on the behavior of cracks in circumferentially notched cylindrical specimens made of 7075 Al-alloy under compressive cyclic loads. In air, fatigue damage was not catastrophic and the saturation depth of a compression fatigue crack was independent of the loading frequency. In artificial seawater, we observed the continuous growth of compression fatigue cracks. The role of the processes of hydrogen embrittlement and anodic dissolution in promoting fatigue damage under compressive cyclic loading is analyzed and a mechanism which rationalizes the experimentally revealed behavior is proposed. The mechanism explains the detrimental influence of corrosive environments by the crack tip blunting caused by the anodic dissolution of the material and accompanied by the formation of residual tensile stress ahead of the crack propagating under compressive cyclic loading. Some practically important aspects of the new description of the phenomenon of corrosion fatigue under compressive loads are discussed.

In the late 60s, it was recognized that fully compressive cyclic loads may provoke fatigue damage of metals and alloys in regions of local stress concentration [1-3]. In [4-7], this phenomenon (usually referred to as compression fatigue) was explained by the dislocation plasticity which leads to the formation of residual tensile stresses associated with local stress raisers. This “notch-dependent” compression fatigue crack usually grows with progressively decreasing rate until its complete arrest observed as soon as the crack reaches a certain (saturation under given conditions) size. Therefore, from the engineering standpoint, this phenomenon is believed to be noncatastrophic.

The major part of the “active life” of compression fatigue cracks is spent at low propagation rates corresponding to the so-called near-threshold mode in which the process of propagation of fatigue cracks under tensile cyclic loading is known to be very sensitive to environmental effects. Anyhow, no experimental research into the environmentally assisted compression fatigue of metallic materials has been undertaken yet.

The present work is devoted to the detailed investigation of the phenomenon of compression fatigue and, specifically, to the experimental verification of its noncatastrophic character while approaching the real service conditions by analyzing the effect of a corrosive environment on the fatigue crack growth behavior of Al-alloys under fully compressive cyclic loading.

1. Material, Specimens, and Testing Technique

Tested materials were supplied as rolled plates. All specimens used in the present study were subjected to stress relief after machining for 2 h at 190°C. The corresponding microstructure consisted of elongated grains with average sizes of 200 μm by 50 μm. The parameters of tensile strength were obtained in the course of conventional testing of cylindrical specimens 6 mm in diameter. Circumferentially notched cylindrical specimens (Fig. 1) were used in testing for compression fatigue crack growth. This shape was regarded as preferable due to the relative simplicity of preparation and testing of specimens. As an additional advantage of this geometry, we can mention the fact that the crack front is not bordered by the free surface of the specimen and, hence, the uniform stress-strain situation exists at the tip of a crack throughout its front. The specimens were machined to attain the following values of the parameters: a notch angle of 60°, the radius of the notch tip of 0.1 ± 0.02 mm, and the diameter of the notched section \( d = 5 \pm 0.05 \) mm. To guarantee good alignment relative to the loading axis, cyclic loads were transmitted to the specimen through quenched steel spheres placed in conic indentations coaxially machined in the specimens and loading rods (see Fig. 1).
A resonance fatigue testing machine with a capacity of 20 kN and a computer-controlled servohydraulic "Schenck" system with a capacity of 10 kN were used for high-frequency and low-frequency compression fatigue crack growth tests, respectively. The stress ratio $R = 0.2$ and the minimum value of the nominal stress $\sigma_{\text{min}} = -0.75\sigma_y$ remained constant for each specimen. We used a cyclic (sine wave) load frequency of 2 Hz or 110 Hz. Fatigue tests were carried out in air under the following ambient conditions: $22 \pm 1^\circ\text{C}$ and a relative humidity of 40–60% and in artificial seawater (3.5% aqueous solution of sodium chloride satisfying the ASTM requirements) under the free corrosion potential. The second environment was supplied to the notched section of tested specimens by the drop method. All parameters were kept constant in the course of testing of a single specimen but the number of compressive loading cycles was systematically varied from one specimen to another.

Each test was concluded by applying a monotonically increasing tensile load until the final rupture of a specimen (under ambient conditions). After this, the specimens were subjected to fractographic analysis by using optical and scanning electron microscopy. The first one was used to measure the depth of fatigue cracks and a minimum of 12 measurements at a 500-times magnification were conducted for each specimen. The morphology of fatigued areas was observed at higher magnifications by using a Philips SEM 505 operating at a beam voltage of 30 kV.