APPLICATION OF GEL ELECTRODE TO FATIGUE TESTING OF ALUMINUM COMPONENTS

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INTRODUCTION

The gel electrode [1-4] is a simple probe for detecting and imaging fatigue damage in aluminum alloys, which is substantially more sensitive than conventional techniques. The procedure consists of: 1) precoating the component with a uniform anodized film, 2) fatigue testing for a predetermined number of cycles, 3) contacting the surface with a flexible gel containing potassium iodide and starch, and 4) applying a voltage pulse. If a fatigue crack is present the current flows preferentially to it and an image of the crack is formed in the surface of the gel. The basic principle of the technique was reviewed in same detail at the previous conference in this series [5], with emphasis on selecting the various parameters, such as the pulse duration and the concentration of ingredients, to yield clearly visible and repeatable images.

This paper reviews some of the first applications of the gel electrode to the evaluation of the fatigue performance of prototype aluminum automotive suspension components [6]. This study demonstrated the following advantages of the gel electrode: 1) a component can be probed while remaining mounted in the fatigue test fixture, 2) fatigue sites are detectable very early in a test, 3) designs can be compared on the basis of abbreviated tests, and 4) secondary sites of fatigue are identified.

PROCEDURE

Component Preparation and Fatigue Testing

The suspension components were prototype units forged from 6061-T6 aluminum. Prior to fatigue testing they were cleaned by degreasing with acetone, followed by immersion in chromic acid at 75°C for five minutes. After rinsing with water and alcohol, they were anodized for ten minutes at a potential of +10 V in a 3% solution of tartaric acid, with ammonia added to obtain pH = 5. After anodization, the parts were again rinsed with water and alcohol. This form of anodization produces a uniform surface oxide film 14 nm thick, which is an essential requirement for gel electrode imaging of fatigue.

The components were installed in a test fixture and subjected to cyclic loading simulating overload operation. After a predetermined number of cycles, the fatigue test was stopped and the component was inspected.
Gel Electrode Imaging

In areas where fatigue damage or a fatigue crack developed, the oxide film was ruptured exposing bare aluminum, which in turn was reoxidized by ambient air. However, only a thin (2 nm) oxide reformed. Since it is these regions of thinner oxide that are imaged by the gel electrode (see below), careful handling of the component is very important to avoid false images created by surface abrasion.

The surface of the component was contacted with a flexible gel containing 0.2 M potassium iodide, 0.19 M cornstarch, 0.05 M sodium borate, and an aluminum cathode. The gel was housed in a plastic tube, 3 cm long and 6 mm in diameter, with the cathode sealed into one end. A smooth hemisphere of gel protruding from the open end was held in contact with the component as illustrated in Fig. 1. A -10 V, 50 ms pulse was applied to the cathode forming an image of the crack in the following manner. The negatively charged iodide ions are attracted to the part, and the current flows preferentially by the path of least resistance, i.e., where the oxide is thinner in the fatigue cracks. There the iodide accumulates in the surface of the gel and reacts with the starch to form a black complex. When the gel is removed, this black deposit appears in the surface of the gel as a clearly visible image of the crack. The image was documented by photographing the gel electrode tip with a Polariod camera mounted on a low magnification (14X) optical microscope.

ADVANTAGES

1. In Situ Inspection

An extremely useful advantage of the gel electrode is the ability to probe specific regions of a component without the inconvenience of removing it from the test fixture. This is illustrated by the photograph in Fig. 1 of a prototype steering knuckle being inspected during a so-called J-turn test. The size and configuration of the gel electrode can be varied in accordance with the area to be inspected. In general, small probes of the type shown in Fig. 1 proved to be the most useful because of the constant need to inspect regions of high curvature, i.e., potential stress concentrations.

2. Early Detection

The gel electrode can detect fatigue cracks only ~ 10^{-2} mm long [2,3], whereas conventional crack detection methods cannot in general detect cracks shorter than ~ 2 mm. Consequently, the gel electrode can detect the development of fatigue much earlier in a test. A direct comparison was provided by a series of identical tests on a set of six components in which cracks developed at the same location. These cracks were not observed by conventional techniques such as fluorescent liquid penetrants until after 3 x 10^{5} cycles, or nine hours of testing, whereas a crack was easily identified with the gel electrode after only 5 x 10^{4} cycles, or 1.5 hours of testing.

3. Design Comparison

As a corollary to the above, the fatigue performance of different designs can be evaluated and compared very quickly on the basis of abbreviated tests. A good example was provided by J-turn tests (Fig. 1) of three alternative steering knuckle designs. The normal duration of these tests was 10^{5} cycles. But after only 10^{3} cycles cracks were detected in two designs at the location being probed in Fig. 1. The images of these
cracks are shown in the photographs of gel electrode tips numbers 1 and 2 in Fig. 2. The third design was much better than the first two: after $10^3$ cycles the gel electrode image (#3 in Fig. 2) contains only a few small spots corresponding to very minor fatigue damage. Thus, the relative performance of these three designs could be assessed on the basis of these short tests, representing a 90% reduction in test duration.
Fig. 2. Photographs of gel electrodes showing images of the same area in three alternative steering knuckle designs after overload fatigue testing. Cracks were detected after 1000 fatigue cycles (at the location being inspected in Fig. 1) in the first two designs while the third exhibited very minor localized damage.

4. Detection of Secondary Sites of Fatigue

Conventional techniques can identify the more substantial cracks which develop at the primary sites of fatigue, but the minor damage that can develop concurrently at secondary sites is usually undetectable. This can become an expensive problem because a design change to strengthen the primary site can accentuate the stresses at an unknown secondary site, converting it into a new primary site. This problem in the design iteration process can be substantially alleviated with the gel electrode because it has sufficient sensitivity to detect the secondary sites in the original design.

An example of this benefit was encountered during the so-called high speed durability tests illustrated in Fig. 3. In earlier tests of design #1, the cyclic loading of the steering arm created cracks on the web (Fig. 3). These were detected by conventional techniques and the web was strengthened in design #2. Later, design #1 was inspected with the gel electrode and, in addition to the fatigue cracks in the web, a small crack ~1.6 mm long (Fig. 4) was found on the shoulder of the steering arm (Fig. 3). The strengthening of the web transferred the stress to this shoulder, resulting in the formation of substantial fatigue cracks in this area in design #2. Thus, a third design was required. If the first design had been evaluated originally with the gel electrode, both the web and the shoulder would have been redesigned simultaneously, eliminating the need for design #2.

SUMMARY

The gel electrode has a unique combination of simplicity and high sensitivity for the detection of fatigue cracks in aluminum alloys. The application of the technique to assessing the fatigue performance of prototype automotive components has demonstrated the following advantages.

1. A component can be inspected without removal from the test fixture.
2. Fatigue cracks are detected much sooner in a test than by conventional methods.
Fig. 3. Photographs of a prototype steering knuckle undergoing a high speed durability test.

Fig. 4. Gel electrode image of a small fatigue crack produced on the shoulder (see Fig. 3) of a steering knuckle after 3 x 10^6 cycles.
3. Different designs can be compared on the basis of tests abbreviated by as much as 90%.

4. Sites of hitherto undetectable secondary fatigue damage are identified. This capability is expected to reduce the number of design iterations required to achieve acceptable fatigue performance.

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REFERENCES