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GALVANIC CORROSION FATIGUE TESTING OF 7075-T6 ALUMINUM BONDED W--ETC(U)
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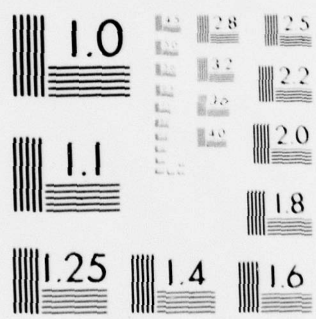

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GALVANIC CORROSION FATIGUE TESTING OF 7075-T6 ALUMINUM BONDED WITH GRAPHITE-EPOXY COMPOSITE

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Fatigue Testing
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Galvanic corrosion effects were determined on 7075-T6 aluminum with attached, adhesively bonded sections of graphite-epoxy composite material. Fatigue tests were conducted on specimens exposed to a sulfur dioxide-salt spray environment in a chamber constructed on a Krouse direct-stress fatigue machine. S-N curves were developed under tension-tension conditions (R = Ø.1) and with unprotected specimens, a 20 percent reduction in fatigue life was attributed to the contacting graphite-epoxy composite material. Protective coatings and nonconductive barriers to break the galvanic

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corrosion circuit were evaluated under the same corrosion fatigue (tension-tension) test conditions. Epoxy primer-polyurethane paint systems, polysulfide sealants and glass cloth barriers were used to measure their effectiveness in galvanic corrosion control. Metallograph and SEM (Scanning Electron Microscope) observations were made of corrosion sites and fatigue surfaces.

INTRODUCTION

Graphite-epoxy composite is a relatively new airframe material with a high-strength-to-weight-ratio and a high modulus that achieves weight reductions of 25 to 50 percent for selected components. Unfortunately, graphite (carbon) is near the low potential (cathodic) end of the galvanized series with an open circuit potential of +170mV while 7075-T6 is at the high potential (anodic) end with a -770mV reading in 3.5% NaCl (reference (a)). With two widely dissimilar conductive materials such as aluminum and graphite in contact in a salt water environment, galvanic corrosion of the aluminum is experienced.

Early research and development efforts on graphite-epoxy composite materials centered on mechanical and structural behavior with only limited efforts directed to corrosion problems and prevention. In reference (b), work on the compatibility of graphite-epoxy composites with metallic materials identified the galvanic corrosion problem. Reference (a) is a significant study conducted at NAVAIRDEVCEN with electrochemical and stress corrosion cracking (SCC) data obtained to define and evaluate the potential galvanic corrosion problem in the naval air-sea environment.

An extension of these efforts has been undertaken by fatigue testing aluminum/graphite-epoxy composite couples in a realistic corrosive environment encountered by Naval aircraft. Galvanic corrosion effects on fatigue life were determined by conducting tension-tension fatigue tests on 7075-T6 aluminum specimens with adhesively bonded graphite-epoxy tabs. A sulfur dioxide-salt spray environment was chosen as the corrosion medium since it is a significant accelerated corrosion test for materials used in Naval aircraft (reference (c)).

PROCEDURE

TEST UNIT

A salt spray chamber was installed on a Krouse direct stress fatigue machine to study graphite-epoxy/metal alloy combinations in a sulfur dioxide-salt spray environment. The fatigue machine, chamber and support equipment are shown in Figure 1.

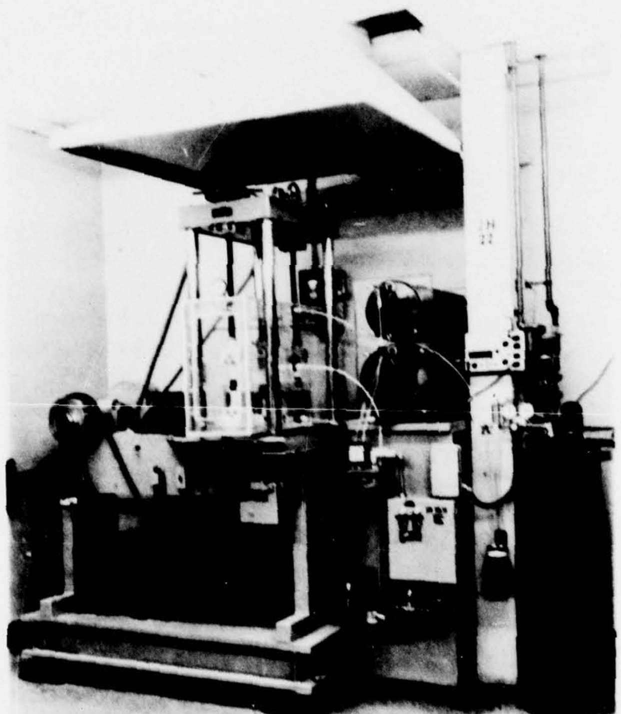


Figure 1 - Galvanic Corrosion-Fatigue Test Unit

The chamber is 2 ft. high by 1 ft. wide by 3 ft. deep and constructed of 0.5 in. thick acrylic plastic. Removable end panels provide access to the two test stations. An atomizing nozzle and tower in the chamber plus the external humidifying tower and solution reservoirs provide the 5 percent salt fog environment. Sulfur dioxide gas injection equipment includes a flowmeter, solenoid valve, timer and compressed gas storage cylinder.

SPECIMENS

Fatigue specimens were made from 0.063 in. thick 7075-T6 unclad aluminum sheet. Specimens were fabricated with the direction of rolling in the longitudinal direction of the panel so failure would occur in the transverse direction. Graphite-epoxy tabs were laid up using six layers of Hercules "Magnamite" 3501/AS1-6 graphite prepreg and "stepped" to minimize stress concentrations at the bond junction to the aluminum specimens. Hysol EA9309 was used to adhesively bond graphite-epoxy tabs to aluminum fatigue specimens as shown in Figure 2. Bonding conditions were 117 kPa (17 psi) in an autoclave at room temperature for 24 hours. A room temperature cure epoxy was used to avoid strength level changes of the aluminum.

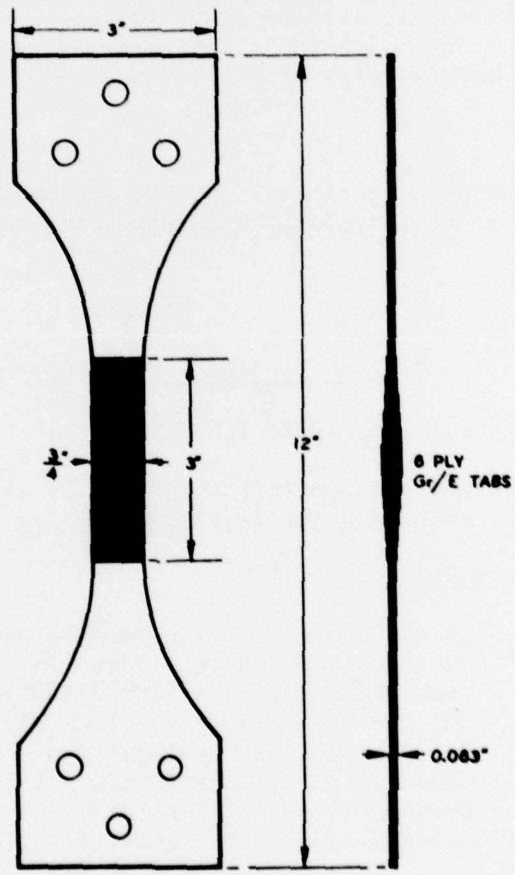


Figure 2 - Galvanic Corrosion Fatigue Specimen Graphite-Epoxy Bonded to Aluminum

TREATMENTS AND COATINGS

Aluminum surfaces were pretreated with the conventional FPL (Forest Products Laboratory) etch prior to adhesive bonding. The FPL treatments were as follows:

Distilled water	68% by weight
Concentrated sulfuric acid	23% by weight
Sodium dichromate	9% by weight

Immersion conditions - 20 minutes at 165-70°C

The bonding process was started within eight hours of the FPL etch treatment to avoid adverse reaction on the aluminum surface.

Protective coatings applied to prevent corrosion included: MIL-S-8802 D(2), Class A-2 polysulfide sealant, MIL-P-23377 epoxy primer and MIL-C-81773 aliphatic polyurethane paint topcoat. A barrier coating to separate (electrically uncouple) the graphite-epoxy tabs from the aluminum was fabricated from two plys of 3M Scotchply 1003 made with "K" filament.

TEST METHOD

Specimens were statically loaded, presoaked (exposed to the corrosion environment without cycling) and then fatigued under test parameters given in Table 1.

TABLE I

Tension-Tension Fatigue Corrosion Test

Presoak - 16 hours in SO_2-salt spray fog

Fatigue - Tension-tension fatigue (R = 0.1) at 1200 cpm maintaining SO_2-salt spray fog

SO_2-Salt Spray Conditions

Spray Solution - 5% by weight NaCl, pH 6.5-7.2
Cabinet temperature - 35°C (95°F)
Tower temperature - 46°C (114°F)
SO_2 gas injection - continuously 1 hr/6 hr cycle
SO_2 gas flow during injection - 6 to 8 cc/min
Condensate collection rate - 1 to 2 mls/hr
Condensate pH - 2.5 to 3.2
Condensate specific gravity - 1.025 to 1.040

R E S U L T S A N D D I S C U S S I O N

TENSION-TENSION FATIGUE

Fatigue life of bare 7075-T6 was reduced from 150,000 cycles at the 40 ksi stress under ambient conditions to 8,400 cycles (FPL etched) under the same stress when exposed to sulfur dioxide-salt spray as given in Table I. A further reduction to 6,400 cycles was experienced with bonded graphite-epoxy tabs due to the galvanic coupling effect. This is shown in Figure 3.

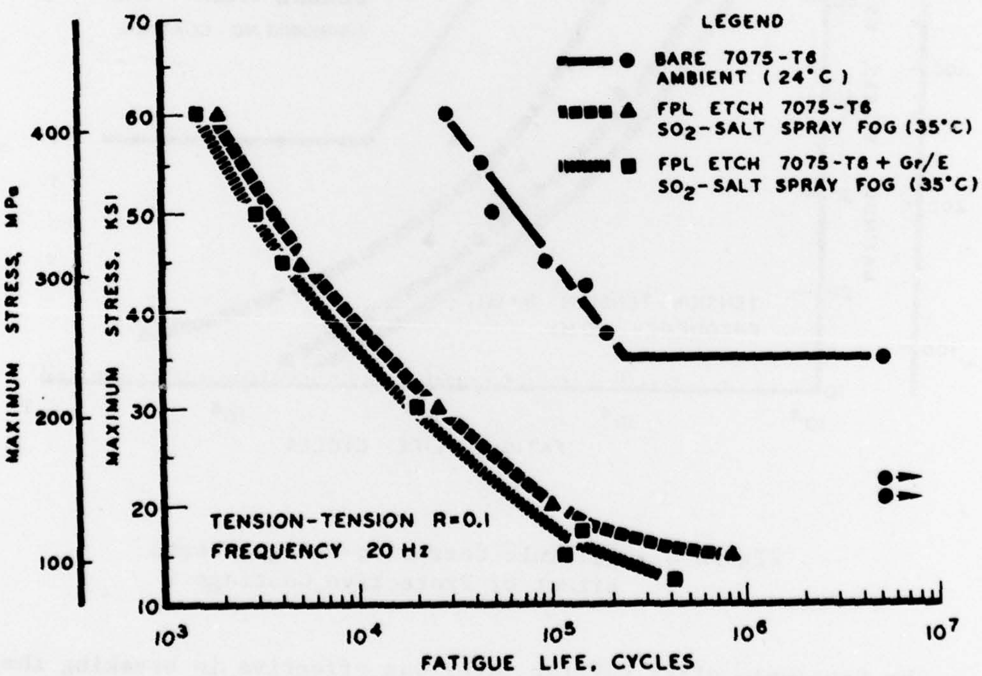


Figure 3 - Galvanic Corrosion Fatigue Tests Without Protective Coatings

A degree of baseline fatigue life (bare 7075-T6 at ambient conditions) was recovered by applying protective coatings of polysulfide sealant to the coupled edges and overcoating with inhibited epoxy primer-polyurethane topcoat. This protective scheme provided an additional 20,000 cycles of fatigue life at 40 ksi over the uncoated condition as shown by the "sealant and paint" curve in Figure 4.

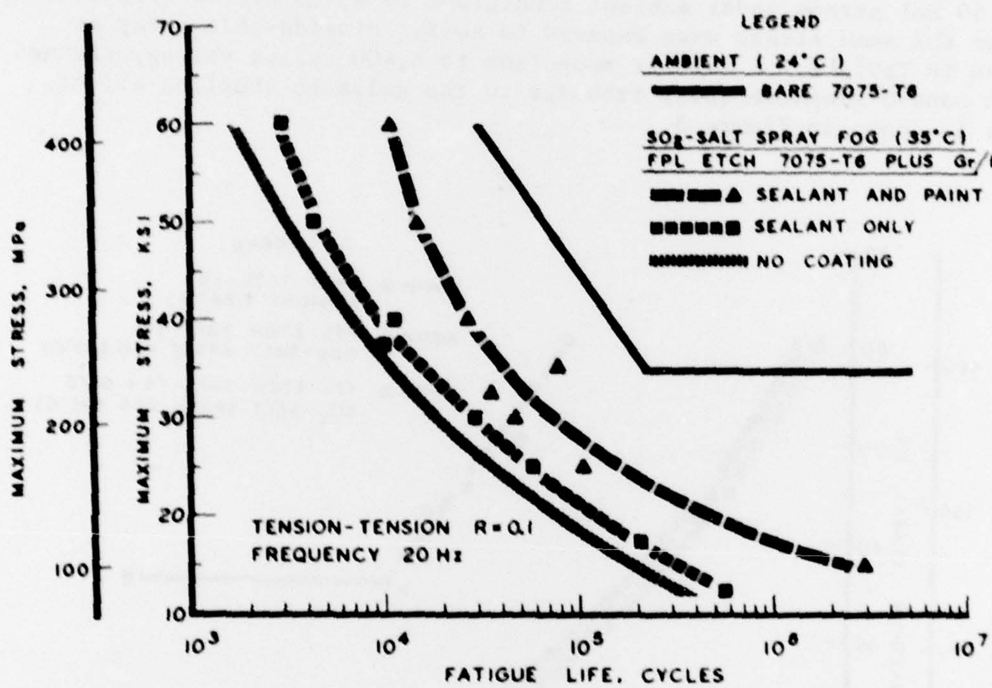


Figure 4 - Galvanic Corrosion-Fatigue Tests
Effect of Protective Coatings

The Scotchply glass barrier layer was effective in breaking the galvanic couple between the graphite-epoxy tabs and aluminum fatigue specimens. Resistance across regular adhesively bonded graphite-epoxy to aluminum was measured as 60-100 ohms. With the glass barrier cloth acting as an insulator, resistance was 100 megaohms, a 10^6 - fold increase. The S-N curve for specimens with the glass cloth, barrier bonded between the graphite-epoxy and aluminum, exposed to the corrosive environment, is shown in Figure 5.

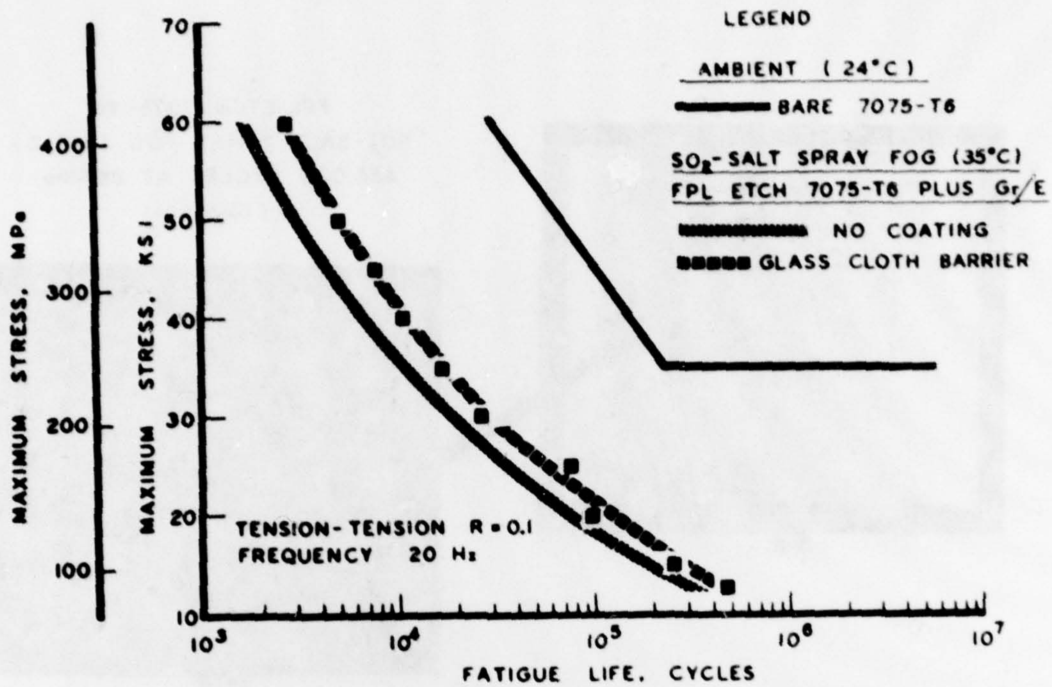


Figure 5 - Galvanic Corrosion Fatigue Tests
with Glass Cloth Barrier

It should be noted that the glass cloth restored fatigue life to the aluminum to the same extent as the use of sealants. In both cases, the galvanic circuit between the aluminum and the composite is eliminated.

CORROSION OBSERVATIONS

Corrosion of the 7075-T6 aluminum in the proximity of the graphite-epoxy composite is shown in the Figure 6 macrophotographs. Pitting is most severe on the panel edge and at the aluminum/graphite-epoxy tab boundary. The basket weave pattern in the retained adhesive layer is simply an impression of the peel-ply from the graphite prepeg after removal of the graphite-epoxy tab.

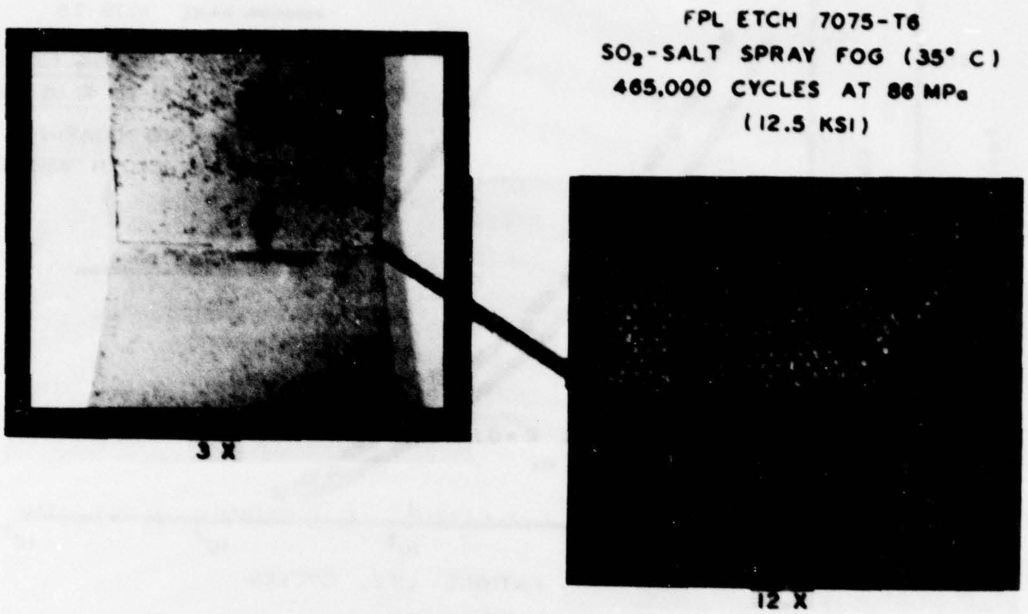


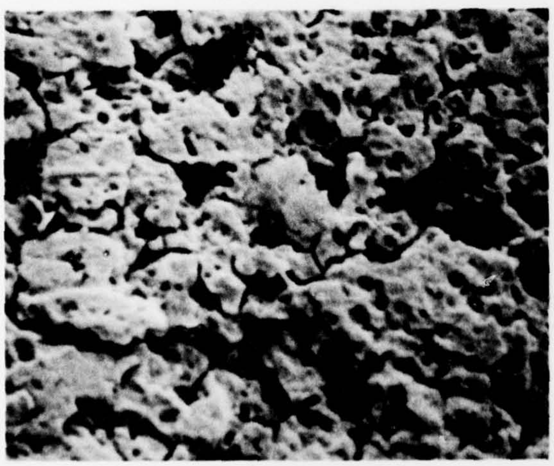
Figure 6 - Corrosion of 7075-T6 Fatigue Specimens
Evident After Removal of Graphite-Epoxy Composite Tab

Figure 7 is a SEM study of a corroded aluminum surface area from Figure 6. Intergranular corrosion is quite evident in the magnified views and was accelerated by the proximity of the graphite-epoxy to the aluminum.

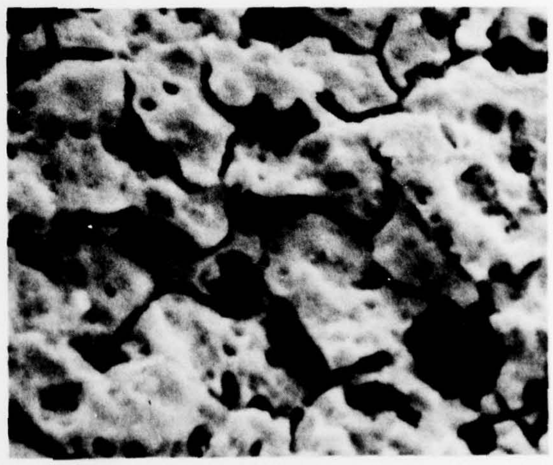
The photomicrographs of Figure 8 are of the same specimens as shown in Figures 6 and 7, but were taken at the opposite end of the graphite-epoxy tab where the fatigue failure occurred. The cross-section was made across a deep pit that developed in the aluminum at the end of the graphite-epoxy tab. This pit, or a similar pit, served to initiate fatigue failure of their specimen. Mount supports shown in the upper portions of the Figure 8 (a) and (b) are not part of the specimen.

(a) Magnification X50

(b) Magnification X100



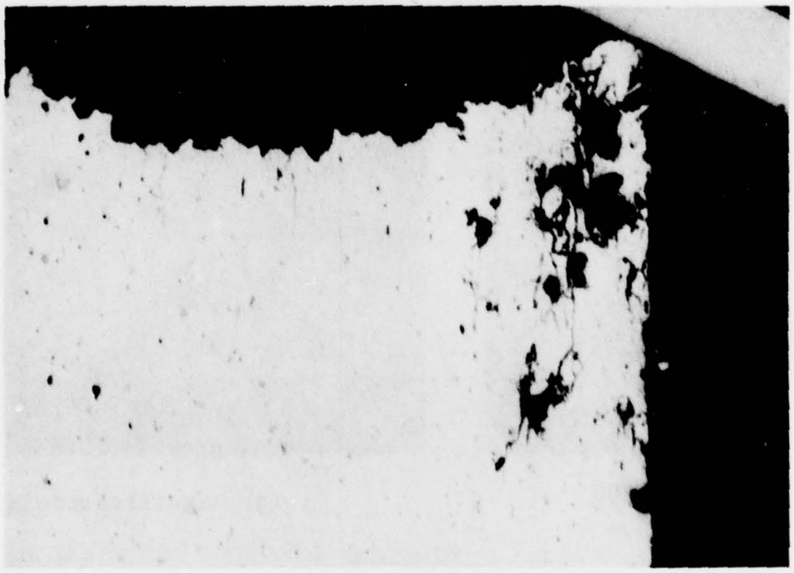
(c) Magnification X200



(d) Magnification X500

Figure 7 - Scanning Electron Micrographs of FPL Etched 7075-T6 Surface Near Graphite-Epoxy Composite, Specimen Exposed to SO_2 - Salt Spray and Fatigued at 86MPa for 465,000 Cycles

(a) Magnification X50



(b) Magnification X100

Figure 8 - Cross Section of 7075-T6 Fatigue Failure After Tension-Tension Fatigue Corrosion Test. Fatigued at 86 MPa for 465,000 Cycles.

Fatigue failures originated from pitting sites at graphite-epoxy and aluminum intersections. Figure 9 shows an isometric view of an aluminum specimen in the vicinity where the graphite-epoxy tab was attached. Note the severe pitting of the aluminum. These pits act to concentrate stress and initiate fatigue cracking.

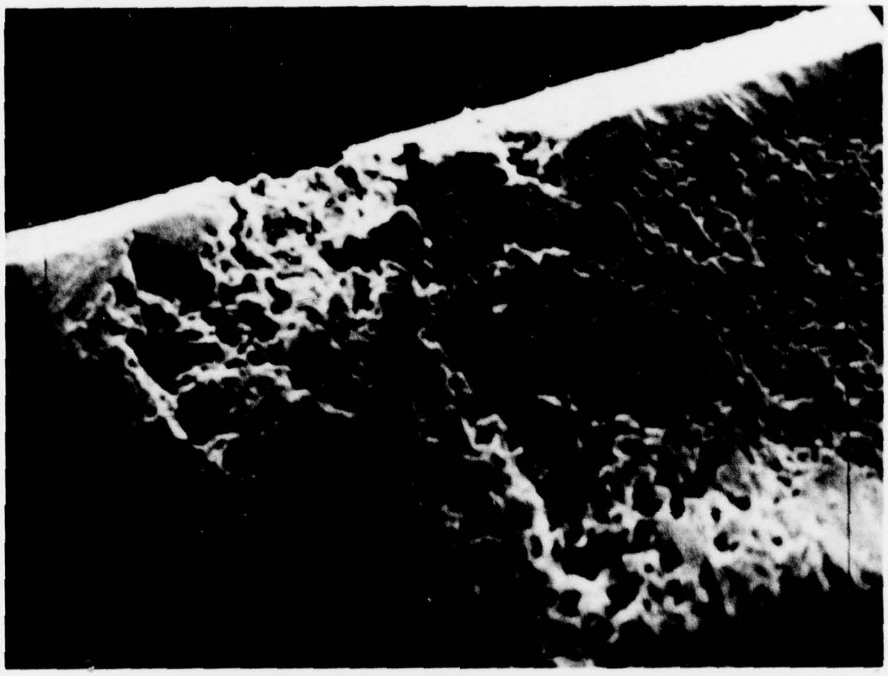


Figure 9 - Scanning Electron Micrograph of Pitting Corrosion in 7075-T6 Aluminum at Graphite-Epoxy/Aluminum Interface (Original Magnification - 100X)

An examination of a fracture surface (Figure 10) reveals fatigue striations as well as pits (circular dark areas) after failure in the sulfur dioxide-salt spray test environment.

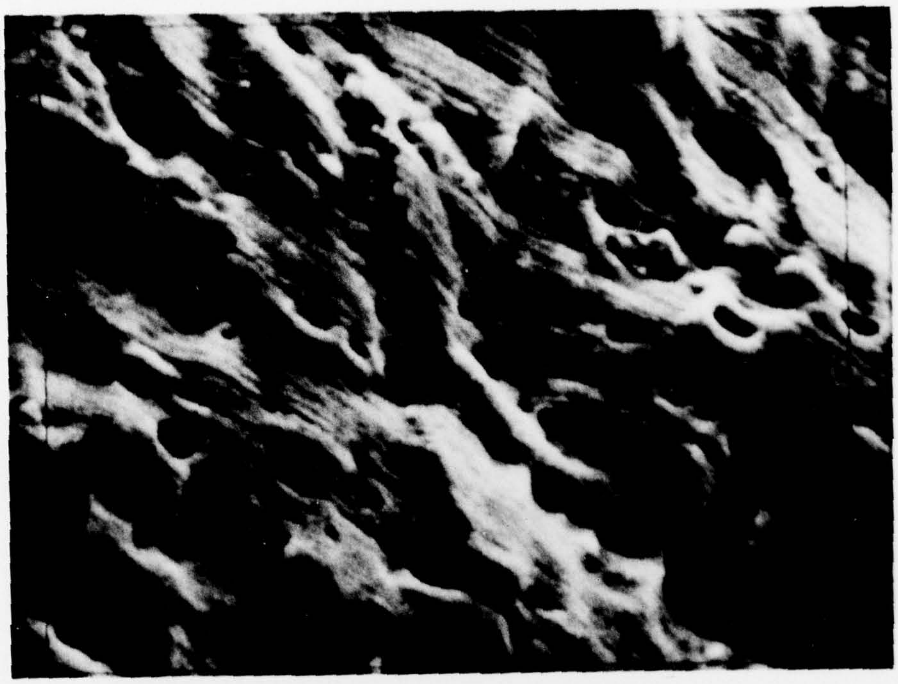


Figure 10 - Scanning Electron Micrograph of Galvanic Corrosion Fatigue Fracture Surface (Original Magnification 500X)

Figures 9 and 10 were photographically enlarged about 25 percent over original magnification.

CONCLUSIONS

1. The sulfur dioxide-salt spray environment significantly reduces S-N curve fatigue life of 7075-T6 aluminum. Additional fatigue life loss is experienced with graphite-epoxy composite bonded to bare aluminun because of the galvanic corrosion effect. Accelerated pitting caused by the galvanic effect acts to provide stress concentrations that nucleate fatigue cracks.

2. Application of protective coating systems vastly improves fatigue life of the 7075-T6 aluminum with adhesively bonded graphite-epoxy composite exposed to the sulfur dioxide-salt spray test environment. The system used was MIL-S-8802 polysulfide sealant applied to composite/aluminum junctions and coating exposed surfaces with MIL-P-23377 inhibited epoxy primer and MIL-C-81773 polyurethane paint topcoat.

3. A glass cloth barrier bonded between the graphite-epoxy composite and 7075-T6 aluminum effectively prevented accelerated pitting due to galvanic corrosion.

RECOMMENDATIONS

The combination of a nonconductive barrier to break the internal galvanic corrosion circuit plus sealant and paint coatings to exclude external corrosion is recommended to control corrosion at junctions of graphite-epoxy composite and aircraft alloys.

FUTURE PLANS

FM 300, an adhesive being used to bond graphite-epoxy layers to aluminum honeycomb in the F-18, will be evaluated as a barrier coating since it has a tight waave scrim cloth. The FM300 will be compared to 3M Scotchply 1003 glass cloth with and without protective overcoat systems.

ACNOWLEDGEMENT

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