Chapter 19 – HOLISTIC STRUCTURAL INTEGRITY ANALYSIS OF CORROSION IN A DYNAMIC HELICOPTER COMPONENT

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19.1 INTRODUCTION

A dynamic component in the main rotor system of a helicopter has had a recurrent cracking problem, where fracture is occurring at less than 10% of the part's rated 'safe life.' This problem is not unique to the operator for whom this assessment was conducted.

The component in question is made of a high strength aluminum alloy, and it is in contact with a stainless steel retaining ring. During this study, fractured parts were recovered from two different helicopters and were subjected to a detailed fractographic analysis and holistic structural integrity analysis. A synopsis of that effort has been provided here as a case study supporting the power of including corrosion effects in analyses not only for sustainment, but for design as well.

19.2 FRACTURE ANALYSIS

Fracture analysis was conducted using an optical stereoscope and an optical microscope. The fracture face revealed beach marks at lower magnification (Figure 19-1) and striae at higher magnification, which indicated fatigue was the primary crack propagation mechanism.

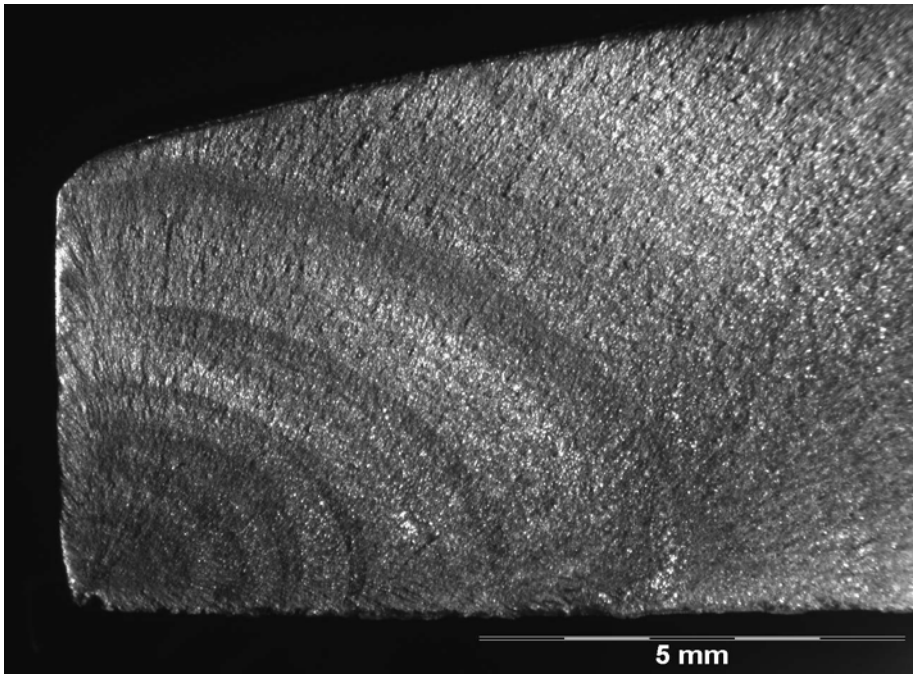

Figure 19-1: Optical Micrograph of Fracture Face Showing Beach Marks.

River marks on the fracture pointed back to a single origin at a corrosion pit (Figure 19-2) that was approximately 175 microns deep and hemispherical in nature. Other surface pitting was evident in areas adjacent to the failure location (Figure 19-3).

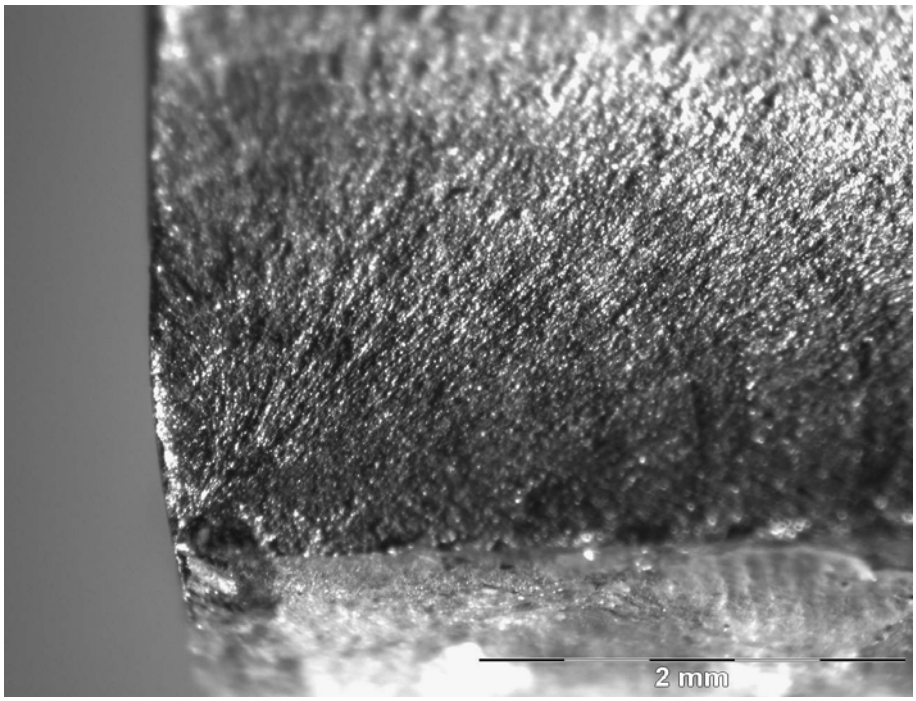

Figure 19-2: Optical Micrograph Showing Pitting at Origin and River Marks Emanating from Region.

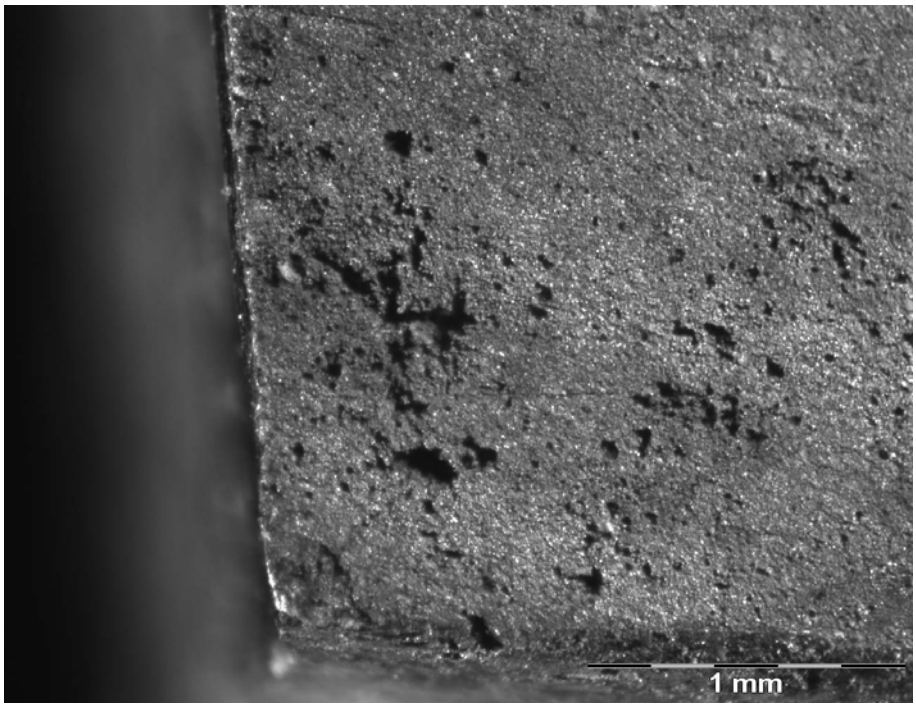

Figure 19-3: Optical Micrograph of Surface Perpendicular to Fracture Plane Showing Clusters of Corrosion Pits.

Although the components contained a corrosion protection coating in service, the contact of a stainless steel retaining ring against the aluminum, in combination with the dynamic operating environment, is believed to have damaged the coating. Unrelated maintenance activities on these components may also have adversely affected coating integrity. Once the coating was compromised, the presence of a crevice and galvanic couple (between the retaining ring and the component) and a harsh operating environment made the component very susceptible to pitting. The violation of surface integrity caused by the pitting then made the part susceptible to corrosion fatigue.

19.3 HOLISTIC LIFE ASSESSMENT

The fractographic study confirmed the failure mode to be corrosion-pitting fatigue. The next step was to conduct holistic life assessments to understand the nature of failure progression and to establish a recommended course of action for the operator.

Fortunately, the design load spectrum for the component was available for use in the analysis. This information was used in combination with a Finite Element Analysis (FEA) of the component to understand the nature of the crack driving force. The FEA accurately modeled the location of the fracture plane and also computed the nature of the stress distribution in the component, which was a combination of tension and bending.

An AFGROW (a publicly-available crack growth code) model of the component in the fracture plane was designed that accounted for the applied tension and resultant bending. The automation capability of AFGROW was used to model load shedding as the crack propagated.

From that point, several crack growth scenarios were executed assuming no corrosion. Initial crack sizes associated with the Initial Discontinuity State (IDS) for the material [1],[2] accurately reproduced a total component life that reflected the certified safe life of the component. Other larger crack sizes were also modeled to develop residual life curves (i.e., remaining life from various crack sizes).

This exercise was repeated assuming the presence of a 175-micron deep, hemispherical corrosion pit at the critical location on the component. In the models used, the presence of the pit amplifies the beta solution associated with the crack, which causes a shift in stress intensity, an increase in crack growth rate, and a decrease in fatigue life [3]. The results shown in Figure 19-4 illustrate the very severe influences of a corrosion pit in this scenario. If the pit had existed from time zero, the analysis shows that the part would only have about 1.5% of its original rated life capability. In reality, the components are failing at closer to 10% rated capability, but this is simply an indicator that the pits are not in the components at manufacture; rather, they form during operational usage. However, it is safe to say that once the coating is compromised, pitting is likely to follow, and once the pits form, failure of the component will follow shortly thereafter.

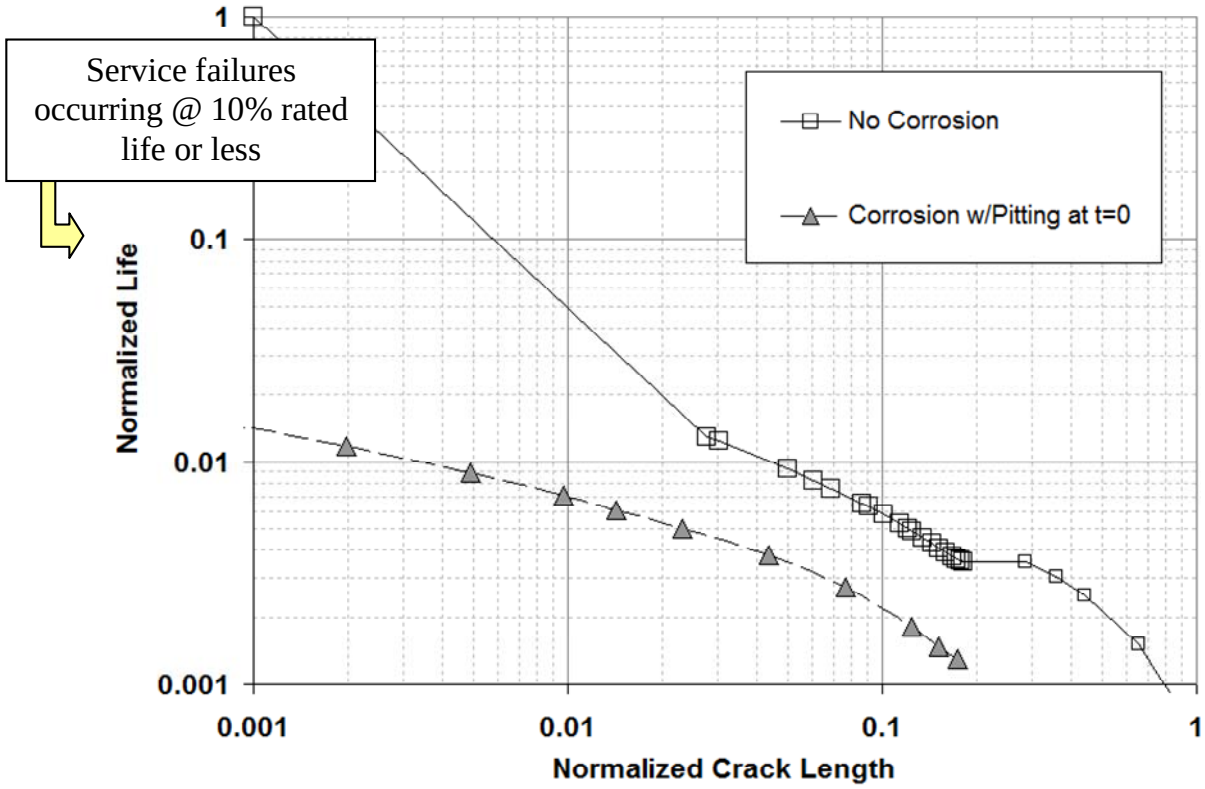

Figure 19-4: Plot of Normalized Life versus Normalized Crack Length for a Helicopter Main Rotor Component With and Without Corrosion Pitting.

Note that Figure 19-4 has been normalized where a life of "1" equals the rated safe life of the component. A crack size of "1" is equal to the critical crack size of the component.

19.3.1 Disposition

The results of these analyses, in conjunction with field experience, lead us to categorize the subject of this study as 'corrosion-intolerant structure.' Non-Destructive Testing (NDT) solutions were investigated, but the conclusion was that the component is so sensitive to corrosion that safety-by-inspection would simply result in a burdensome inspection frequency. While inspection is a plausible short-term solution for this type of component and situation, it is not feasible, both in terms of dollars and in terms of operational requirements, for long-term sustainment activities. Thus, more permanent and effective long-term solutions are required, such as a material substitution that exhibits greater fatigue resistance and greatly reduced susceptibility to pitting. Another promising alternative includes conducting a residual stress treatment, such as laser peening, to critical areas of the component, which when properly executed could make treated areas insensitive to violations of surface integrity caused by pitting and greatly enhance the life capability.

19.4 SUMMARY

This case study presented a holistic structural integrity analysis of a dynamically loaded helicopter component that failed due to corrosion-pitting fatigue. Fatigue analysis, including the effects of pits, suggested that in a worst case, life capability would be only 1.5% of the original certified 'safe life' if the pits were assumed to be present from time of manufacture. Failures in service were occurring at closer to

10% of the original certified life, which reflects the fact that the pitting occurred later during service and not at 'time zero'.

This component is best described as 'corrosion-intolerant-structure.' Furthermore, the frequency of maintenance and inspection required to keep the component safe would not only be burdensome but could also contribute to the problem through accidental breach of the coating system.

The recommended solutions to this problem include material substitution (to a material that is more fatigue and corrosion resistant) and/or treating the parts with engineered residual stresses, such as those possible through laser peening. As stated above, frequent inspection is not believed to be a supportable option, and simply replacing the components with new, original-specification parts only resets the clock. It does not eliminate the problem.

19.5 REFERENCES

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[2] Mills, T.B., Honeycutt, K.T., Brooks, C.L., Sharp, P.K., Loader, C. and Crawford, B., "Development and Demonstration of an Holistic Structural Integrity Process using the Initial Discontinuity State Concept for 7050-T7451 Aluminum", USAF ASIP Conference, Memphis, TN, USA, November 2004.

[3] Mills, T.B., Honeycutt, K.T. and Brooks, C.L., "Demonstration of an Holistic Structural Integrity Process Using Corrosion/Fatigue Interactions from Laboratory Experiments and Field Experience", Proceedings, 6th International Aircraft Corrosion Workshop, Solomons, MD, USA, August 2004.