Environment Spectra and CPC Effects on Corrosion/Fatigue

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Fatigue crack propagation (FCP) can be affected by environment in a variety of ways, each of which may compromise the aircraft's structural integrity.[1] Corrosion occurring during ground basing can alter the initial discontinuity state (IDS) and create a modified damage state (MDS), which may promote fatigue crack formation and growth during flight. This corrosion may also cause stress enhancement due to material thinning, or even retardation of fatigue crack growth if sufficiently rigid corrosion product forms in a crack. Also, atomic hydrogen produced on the alloy surface during localized corrosion may enter the metal and contribute to damage on subsequent mechanical loading. This corrosion fatigue (or environmental fatigue) problem has been the objective of considerable scientific study over the past 30 years, but important uncertainties hinder accurate rate and life prediction of operating airframe components.

These uncertainties are the motivators behind this project whose goals are to improve the laboratory characterization, mitigation methods, basic understanding, and modeling of FCP laws necessary to manage fatigue in aerospace aluminum alloy structures. The work focuses on environment-fatigue interactions and deals with major issues associated with the effect of unique environments and corrosion prevention compounds (CPCs) on FCP rates in aluminum alloys. Figure 1 shows the effect of water vapor pressure and frequency on FCP. Figure 2 shows the inhibition of FCP by chromate, especially at low frequencies. Even in these model systems, the effects of environment composition (including inhibitors) are clear. Such unique environments include occluded regions in fuselage and lower wing joints. Emphasis will be placed on tension-tension fatigue, as this is typical of fuselage and lower wing loading. The ultimate goal of this research is to incorporate the environmental sensitivity of da/dN into programs to manage the damage tolerance and structural integrity of aging aircraft components.

Environmental effects on fatigue under spectrum loading are particularly poorly understood. Current Aircraft Structural Integrity Program (ASIP) methods employ a da/dN curve that is modified for "standard environmental effects" associated with, for example, variable amplitude load cycling in water vapor saturated air at 25°C. It is not clear whether this method is excessively conservative, sufficiently accurate, or speculative. Excessive caution may be caused by the model not accounting for rapid freezing of the occluded solution, which would lead to large closure effects. Work by Ferrer and Kelly has simulated the chemistry of this occluded solution (the Lap Joint Simulant Solution (LJSS)), however further research must be conducted to prove the validity of the LJSS.[2] Insufficient caution may be caused by the presence of an unexpected uniquely aggressive and concentrated occluded solution during ascent and descent, leading to accelerated FCP during those stages. Hence, knowledge of the chemistry of the occluded solution needs to be used in conjunction with spectrum loading to design more accurate corrosion/fatigue experiments (Figure 3).

The use of CPCs as a corrosion mitigation method is cost effective. Limited data also suggest that CPCs are successful in reducing stress corrosion cracking (SCC) and environmentally assisted FCP (EFCP). Although their effects are temporary, the reductions can be regained upon reapplication.[3] Current research being conducted at the University of Virginia is aimed at developing a test protocol for delineation of CPC protection ability on boldly exposed and occluded regions for 2XXX and 7XXX aluminum alloys. As new inhibitors have not been tested with regards to EFCP, this project will act as an extension of the current CPC work in determining their effects on EFCP.

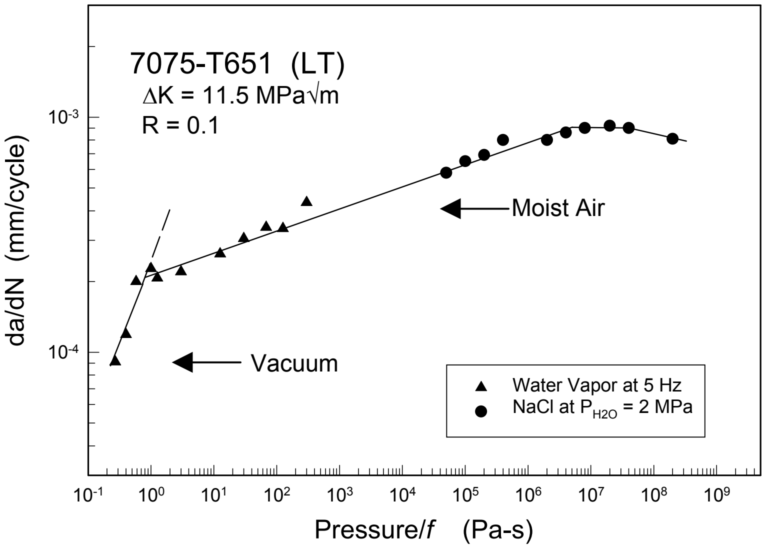

Figure 1. The environmental exposure dependence of da/dN for a 7000-series aluminum alloy in pure water vapor or a chloride bearing electrolyte.

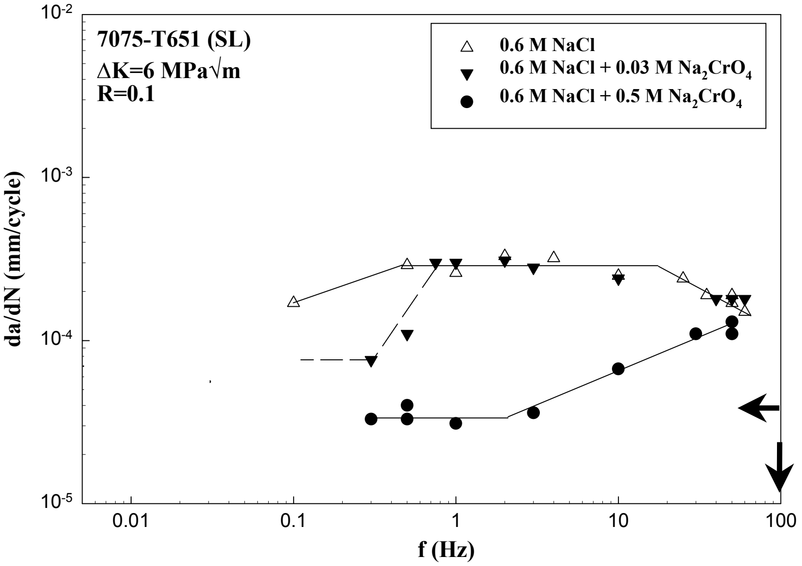

Figure 2. The inhibiting effect of chromate ion addition on time dependent fatigue crack growth rates for peak aged AA7075 in aqueous chloride solution and at constant ΔK and R. The arrows show da/dN for humid air (horizontal) and ultrahigh vacuum (vertical).

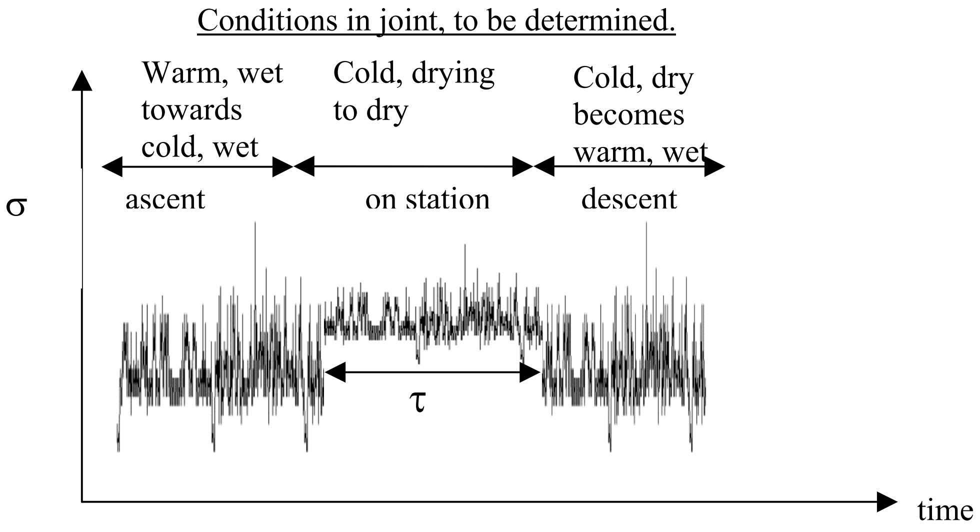

Figure 3. Overlay of stress schematic with likely lap joint environment conditions

References

1. G. Clark, “Fatigue Damage Evolution From Corrosion,” Fatigue 2002: not paginated

2. K. Ferrer, “Determination of the Role of Bicarbonate in the Corrosion of Aircraft Lap Splice Joints,” University of Virginia, Dissertation. (2002)

3. B. Hinton, et al., “The Protection Performance of Corrosion Prevention Compounds on Aluminum Alloys in Laboratory and Outdoor Environments,” Victoria, Australia, Defence Science and Technology Organisation, Aeronautical and Maritime Research Laboratory, (2000)