EFFECTS OF ATMOSPHERIC ENVIRONMENTAL CONDITIONS ON FATIGUE CRACK GROWTH RATES

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Corrosion has a significant impact on the fatigue of aging aircraft. In service, an airframe will be exposed not only to a spectrum of mechanical loading due to variations in flight profile and mission types, but also to a spectrum of environmental conditions. The detrimental influence of chlorides on fatigue performance for metallic materials has been well-documented in mechanical tests typically performed in an aqueous solution. In studying aircraft alloys, however, the environmental influence is that of a multifarious non-stationary gaseous atmosphere, making an aqueous exposure a poor predictor of in-service corrosion phenomena. Temperature, humidity, atmospheric gas composition, salt concentration, pollution, and UV light exposure all vary as a complex function of geographical location, seasonal weather patterns, diurnal cycle, and flight mission profiles. Research in accelerated corrosion testing has resulted in noteworthy advances in understanding the kinetics of atmospheric corrosion. Current test methodologies, such as the salt fog described in ASTM B117, often correlate poorly with field exposure. The addition of ozone, UV light, and control of relative humidity was shown to create corrosion in highly pure Ag samples similar to outdoor exposures due to the formation of reactive oxidizing species. AA 5083 and carbon steel samples demonstrated similar discrepancies between lab simulated and actual field exposures that were mitigated in lab testing with the addition of ozone and UV light. Chlorides in conjunction with strong oxidizers like ozone react to create species that attack the substrate material. Furthermore, the aerosols that deposit chlorides on field exposure samples can vary in size, composition and acidity. These variations have proven in recent experiments to influence corrosion morphologies and rates. When considering environmental influences on fatigue crack growth rates (FCGR), investigations have focused on a more limited set of parameters. The effects of water vapor on FCGR have been examined in tests under vacuum, partial vacuum, dry inert gas, lab air, and at climatic low temperatures by numerous investigators. At low temperatures, air has little capacity to hold water. Indeed, experiments with AA 2024-T3 and AA 7075-T6 at -75°C demonstrated FCGR much lower than that at room temperature. Similar results were obtained with AA 2024-T351 and AA 7475-T7651 at room temperature and at -54°C though the FCGR difference was clearly sensitive to stress ratio, R, and stress intensity factor range, ΔK. Further evidence for the role of water vapor was demonstrated by research exhibiting decreasing FCGR with decreasing relative humidity and tests exhibiting the same behavior with decreasing water vapor pressure, both with AA 7075-T651. Since systems to apply and control multiple environmental parameters in conjunction with mechanical loading are not readily available, such a system has been developed to apply and control relative humidity (2% to 100%), specimen temperature (-57°C to 121°C), ozone (30 ppb to 50 ppm), salt spray (NaCl, CaCO3, NaHCO3), background gas (CO2 and N2) and UV light. The chamber is designed to fit 245 kN and some larger servo-hydraulic test frames. The current test program is designed to elucidate the effects of the individual environmental parameters before moving onto combinations of parameters to enable a better understanding of the underlying mechanisms. Baseline FCGR tests are underway on center-cracked AA 7075-T651 specimens at a range of R values between -1 and 0.9. Constant amplitude sine wave decreasing ΔK, increasing ΔK tests are used to generate full FCGR curves to characterize behavior from threshold to stable tearing, but constant K-gradient test control will be investigated as a means of accelerating testing efforts. Tests at various ozone levels and chloride loading levels are to follow. The effects of ozone levels at 1-3 orders of magnitude higher (0.5 – 50 ppm) than typical ground level ozone values will be examined to determine at what combinations of ozone concentration and testing frequency an effect can be seen. Salt loading will focus primarily on the effects of relative humidity variations near the deliquescence point. There is some evidence to suggest that FCGR may decrease at relative humidity levels above the deliquescence point presumably due to significant corrosion products influencing crack closure. These effects will be of significant interest. Testing will eventually transition into the simultaneous application of a spectrum of environmental conditions with a mechanical loading spectrum. The resulting test data will ultimately be used to improve fatigue life prediction models that typically rely upon laboratory air FCGR data.

UNDERSTANDING DIFFERENT FACTORS AFFECTING SUPERSONIC PARTICLE DEPOSITION (SPD) REPAIRED AL 7075-T651 PLATE FOR STRUCTURAL RESTORATION

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One of the main challenges in maintaining aging aircraft is to find a reliable, effective and economic repair process, for both non-structural and structural repairs. Supersonic particle technology (SPD) aka Cold Spray (CS) has proved to be an effective geometry restoration technology and has the potential to repair/restore/enhance the airworthiness of aging aircraft. Al 7075-T651 is highly susceptible for stress crossing cracking compared to –T7351 temper. Mechanism involved in environment assisted cracking (EAC) such as corrosion fatigue primarily in conventional product forms such as rolled plate, extrudate or forging in Al 7075 is complex. Fundamental research concerning the driving force and micro-mechanism involved in EAC is still not matured, and, not completely understood in Al alloys. In addition, the effect of different factors such as high strain rate deformed layers, residual stress in the coating and substrate and presence of micro defects makes more complex in understanding the EAC in SPD repair subjects. In light of the complex nature of the SPD structure, systematic evaluation was carried out to determine various factors affecting the EAC behavior of the SPD repair. Thus, this presentation focuses on a brief overview on the application of this technology for corrosion repair followed by experimental study and fractographic analysis of SPD repaired Al 7075-T651 0.25” plate aimed at restoring the structural functionality. To study the structural behavior of the SPD coated 7075 Al, both static and fatigue performance were evaluated in ambient and humid environment. The study involves simulating a 20% thickness loss by milling Al 7075 master plates (9.1” x 8.75”) followed by depositing Al 7075 spray atomized powder using SPD process. Test coupons were extracted from this master plate; orientation and location of the individual test specimen origin were tracked. The presentation includes factors affecting the quality of the SPD coating specifically for structural application and how to exploit these factors in qualifying a SPD coating. Test results are validated and supported by detailed fractographic studies. Emphasis will be given to failure modes and mechanism involved on these SPD coated specimens tested under cyclic loads, and, under ambient and humid environments will be discussed.

IN SITU THREE DIMENSIONAL STUDY OF CORROSION FATIGUE CRACK INITIATION AND GROWTH OF CORRODED 7075 ALUMINUM ALLOYS

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Corrosion fatigue crack initiation in aluminum alloys can have significant effects on part life. An improved understanding of the mechanisms governing corrosion and corrosion fatigue damage of Al alloys is necessary. Alloy design and environmental chemistry have significant effects on corrosion fatigue crack initiation and growth. Influential alloy design features include alloy chemistry, precipitate structure, and grain structure. Environmental factors such as environmental chemistry and preexisting corrosion damage can also effect the corrosion fatigue behavior of the alloys. To investigate the effects of environment and precipitate size on corrosion fatigue of aluminum alloys, the *in situ* corrosion fatigue testing of corroded peak-aged and overaged 7075 Al alloys in 3.5 wt% NaCl solution will be presented.

For this study, rolled 7075 Al alloy was heat-treated to peak-aged, overaged, and highly overaged conditions. The samples were machined, mechanically polished, masked, and then soaked in 3.5 wt.% NaCl solution for fifteen days to yield significant corrosion damage in a region of interest. The corroded specimens were fatigue tested *in situ* in 3.5 wt.% NaCl using synchrotron X-ray tomography to gain three dimensional information regarding fatigue crack initiation and growth characteristics. Hydrogen bubbles were observed within the crack during propagation, indicating chemical changes in the sample during corrosion fatigue. The crack initiation, growth, and bubble evolution were quantified and discussed. A relationship was observed between the bubble volume and crack surface area as the test progressed, which suggested an effect from stress at the crack tip. Ultimately, this in situ study provided new insights regarding the localized processes occurring during the corrosion fatigue cracking of aluminum alloys which previous post-mortem and two dimensional studies were unable to discover.

NUMERICAL AND THEORETICAL MODELS TO PREDICT FATIGUE LIFE IN AGGRESSIVE ENVIRONMENTS FROM EXPERIMENTAL DATA

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Key Words: FCGR, Environment Assisted Cracking, Corrosion Fatigue, Ti-6Al-4V

Corrosion fatigue produce sensible effects in the fracture mechanics of structural materials. Aggressive environments in presence of dynamic fatigue load are indeed responsible of multiple effects, regarding crack nucleation and propagation rates. Considering Ti-6Al-4V in air, inert paraffin oil and 3.5 wt.% NaCl mixture, environmental effects are sensible in terms of acceleration of Fatigue Crack Growth Rate – i.e. d*a*/d*N* vs. stress intensity factor Δ*K*. Several literature studies dealt with the topic in the past years. However, research has been focused mainly on the FCGR description, and the prediction of number of cycles to failure in aggressive environments is not addressed. In the presented poster, a methodology to obtain a numeric model which reconstruct d*a*/d*N* vs Δ*K* from experimental results, including crack length and applied stress, is presented and compared against literature data. Results are related to *R* = 0.1 axial test involving smooth and notched flat dogbone specimens, with varying notch radius. The proposed model is used to reconstruct the number of cycles to failure of the tested specimens, resulting in a satisfactory correlation with experimental data. Comparison with other literature models highlights the necessity to develop a proper numerical model with each test case.

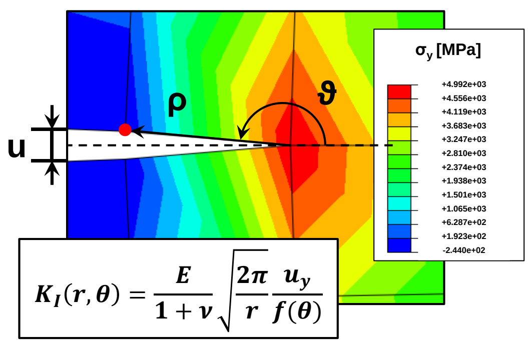

Fig. 1: FE numerical model and reconstruction of the stress intensity factor from crack tip opening.

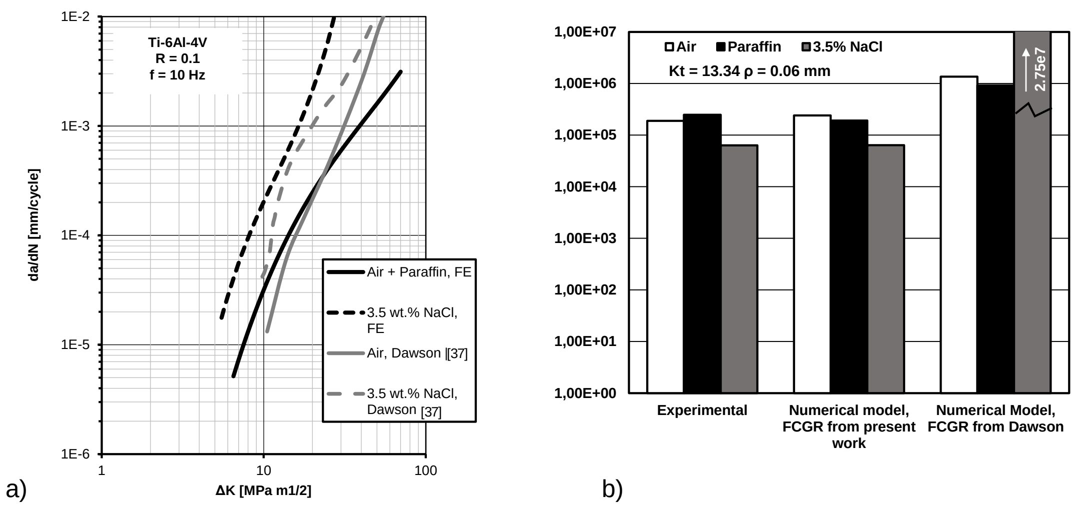

Fig. 2: FCGR obtained from numerical reconstruction of actual experiments vs. literature data (a); predictions in terms of number of cycles obtained from present numerical reconstruction, vs. prediction based on literature FCGR data.

A METHOD FOR CORROSION-FATIGUE LIFE PREDICTION

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It is well recognized that environment has significant effects on the failure of cyclically loaded members/structures Existing experimental data indicates that fatigue life is much shorter in corrosive environment that in more inert environment such as a dry air or vacuum. This paper presents a method and strategy to predict/estimate life under corrosion-fatigue. A corrosion fatigue factor k_{corr} is defined as the ratio of the fully-reversed stress amplitude in air, $(\sigma_a)_{air}$, over that in corrosive environment, $(\sigma_a)_{corr}$, for a given fatigue life in terms of a number of cycles to failure, N_f, i.e. $k_{corr} = (\sigma_a)_{air}/(\sigma_a)_{corr}$ at the same N_f. The corrosion fatigue factor resembles the widely used fatigue notch factor k_f. The proposed strategy requires the S-N curve in air and the corresponding k_{corr} factor. Experimental data for three materials, namely 7075-T651, 6161-T561 and 4140 steel tested in laboratory air and 3.5% of NaCl solution were used to illustrate and validate the proposed method. A fairly good agreement is demonstrated in terms of the correlation among air and corrosion-fatigue data.

NUMERICAL INVESTIGATION OF A GALVANIC STRUCTURAL JOINT SUBJECTED TO A MECHANO-ELECTROCHEMICAL LOADING

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Here, we present for the first time, an experimentally validated numerical model for a galvanic couple subjected to a mechano-electrochemical process. The model is capable of tracking moving boundaries of the corroding constituent of the couple by employing Arbitrary Langrangian Eulerian (ALE) method. Results show that, when an anode is under a purely elastic deformation, there is no apparent effect of mechanical loading on the electrochemical galvanic process. However, when the applied tensile load is sufficient to cause a plastic deformation (local internal stress gradient), the local galvanic corrosion activity at the vicinity of the interface is increased remarkably. The effect of other factors, such as electrode area ratios, electrical conductivity of the electrolyte and depth of the electrolyte, are studied. It is observed that the conductivity of the electrolyte significantly influences the surface profile of the anode, especially near the junction.

INVESTIGATION OF ALKALI METAL EMBRITTLEMENT OF ALUMINUM LITHIUM ALLOYS USING FIRST PRINCIPLES CALCULATIONS AND DISLOCATION THEORY

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Segregation of alkaline earth metals at grain boundaries is investigated as a cause of grain boundary embrittlement in Aluminum alloys. Auger spectroscopy shows that grain boundary segregation of Na occurs in an AlLi alloys. In addition, Aluminum extracted from bauxite bring in alkali impurities. First-principles simulation allows us to understand the energetics of Na segregation at grain boundaries and model the decreased grain boundary cohesive energy. Using this data within the concomitant dislocation theory based on our recent work, we study the effect of Na segregation on static and fatigue fracture of Al-Li alloys. Using DFT calculations, we describe how the presence of alkali impurities could possibly enhance hydrogen embrittlement.