Effects of the ENVIRONMENT on the Initiation of CRACK GROWTH

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Foreword

This publication, *Effects of the Environment on the Initiation of Crack Growth*, contains papers presented at the symposium of the same name held in Orlando, Florida, on 20-21 May 1996. The symposium was sponsored by ASTM Committee E-08 on Fatigue and Fracture, G01 on Corrosion of Metals, and Subcommittees E08.06 on Crack Growth Behavior and G01.06 on Stress Corrosion Cracking and Corrosion Fatigue. The symposium was chaired by W. Alan Van Der Sluys, Babcock & Wilcox; Robert S. Piascik, NASA Langley Research Center, and Robert Zawierucha, Praxair, Inc. They also served as editors of this publication.

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Overview

The initiation stage of environmentally assisted cracking can have a profound effect on the life of a component. Little is known about the damage mechanisms that occur during the important early stages of crack formation, e.g., nucleation and small crack growth, compared to the crack propagation regime. This Special Technical Publication reviews current understanding on the effects of the environment on the initiation of crack growth relating to specific areas, including: (1) mechanistic modeling, (2) life prediction, (3) nuclear industry environmental cracking, and (4) recent aging aircraft durability issues. The following is a brief overview of the symposium papers included in this topical volume.

Session I: Stress Corrosion Cracking Initiation

Akid discussed the role of stress-assisted localized corrosion on the development of short fatigue cracks. Corrosion experiments were conducted under cyclic and static stress, using low and high strength steels and stainless steels in chloride environments. Surface film breakdown, pit development and growth, pit/crack transition, and environment-assisted Stage I and Stage II crack growth were monitored. Each process is considered to be of primary importance during the early stages of stress corrosion and corrosion fatigue cracking.

Chen, Liao, Wan, Gao, and Wei assess two proposed pit to crack transition criteria: (1) the stress intensity factor for an equivalent crack, equal, or exceeded the threshold stress intensity factor for corrosion fatigue crack growth (CFCG), and (2) the time-based CFCG rate exceeded the pit growth. Validation of a proposed pitting corrosion/fatigue crack nucleation criterion is presented and discussed in terms of open hole alloy 2024-T3 experiments conducted in 0.5M NaCl solution.

Leis and Colwell studied the processes leading to the formation of crack-like features as well as early crack growth of stress-corrosion cracking on the exterior of gas transmission piping. Observations show that cracks with dense spacing tend towards dormancy, whereas the sparsely spaced cracks continue to grow. Fracture mechanics based analysis is used to rationalize the crack pattern observations.

Session II: Crack Initiation in Aging Aircraft

Kolman and Scully examined the effects of a sharp notch or crack tip on cation accumulation—hydrolysis—acidification, potential drop in solution and resulting hydrogen production, and localization on dynamic strain in titanium alloys exposed to 0.6 *M* NaCl. It was shown that the drop in potential down a sharp crack is severe enough to enable hydrogen production, even when the applied potential is more positive than the reversible potential for hydrogen production. The effects of a sharp notch on the interplay of mechanics, film rupture, and hydrogen uptake are also examined.

Schmidt, Crocker, Giovanola, Kanazawa, Shockey, and Flournoy investigated the processes that influence the transition from salt water corrosion pit development to fatigue crack formation in Alcad 2024-T3. Results suggest that the nucleation of corrosion fatigue cracks involves two competing mechanisms: hydrogen effects in the cladding and electrochemical dissolution at constituent particles in alloy 2024. Cracks do not necessarily nucleate at the largest corrosion pit, suggesting that a contributing factor to crack nucleation from a pit may be the creation of a local region of weakness.

Bray, Bucci, Colvin, and Kulak evaluate the effect of prior corrosion on the S/N fatigue performance of 1.60 and 3.17-mm-thick aluminum sheet alloys 2524-T3 and 2024-T3. The fatigue strength of alloy 2524 was approximately 10% greater and the lifetime to failure, 30 to 45% longer than alloy 2024. Two main factors are believed to have contributed to the better performance of 2524: less damaging configuration of corrosion pits and its better fatigue crack growth resistance.

Session III: Stress Corrosion Crack Initiation in Nuclear Environments

Parkins and Mirzai provide a database that will allow prediction of stress corrosion cracking failures in nuclear reactor components exposed to the radiolysis of moist air which produce nitric acid environments. Constant strain stress corrosion tests, at 50 or 100% yield stress, were conducted on welded nickel based steel samples exposed to a mixed nitrate solution for various times. Selective attack at relatively short exposure times was observed where grain boundaries intersected the specimen surfaces.

Kondo, Bodai, Takei, Sugita, and Inagaki studied environmentally assisted cracking of 3.5NiCrMoV low alloy steel under cyclic straining in water at 60°C. Test results showed that higher strain range, lower strain rate, longer strain hold times, and higher electric conductivity caused increased charge transfer, which resulted in shorter crack initiation life. A prediction model for crack initiation life was proposed based on observed charge transfer.

Soloman, DeLair, and Unruh investigated the fatigue crack initiation of WB36, a German low alloy steel (LAS), tested in high-temperature high-purity water. The tests were performed at 177°C, in water containing 8 ppm O_2. H_2SO_4 additions were also used in some tests to raise the conductivity of the water from 0.06 to 0.4-0.5 μS/cm. The crack initiation and growth data are correlated with water chemistry.

Akashi and Nakayama investigated the initiation of stress corrosion cracking in boiling water reactor materials. They suggest that stress corrosion cracking can be divided into six (three deterministic and three stochastic) separate processes. The paper examines the influence of three stochastic processes: (1) nucleation of corrosion pits, (2) initiation of micro cracks, and (3) the coalescence of microcracks, on the stress corrosion cracking initiation process.

Session IV: Modeling

Hall and Symons showed that the initiation of stress corrosion cracking in alloy X-750 exposed to high-temperature-deaerated water occur at a variable distance from the notch or crack tip. The initiation site varies from very near the crack tip, for loaded sharp cracks, to a site that is one grain diameter from the notch, for lower loaded, blunt notches. The existence of hydrogen gradients, which are due to strain-induced hydrogen trapping in the strain fields of the notch and crack tips of the SCC test specimens, is argued to be responsible for variation in the crack initiation site.

O. Jonas presented a corrosion model for iron-based alloys. Interactions of aqueous environments in cracks are expressed as relative bonding energies for individual molecules and other parameters. The results indicate relative aggressiveness of environments, types of chemical/corrosion reactions, and the rate of mass transport to the crack-tip.

Session V and VI: Crack Initiation in Corrosion Fatigue

Atkinson, Zhao, and Yu investigated the effect of dynamic strain aging (DSA) on stress corrosion cracking of reactor pressure vessel steels exposed to 250°C water. Results support the coincidence of temperature and strain rate between the DSA hardening and the susceptibility to environment-assisted cracking of reactor pressure steels. The mechanistic role of DSA and its interpretation with other influential variables in the enhancement of stress corrosion cracking are discussed.

Higuchi, Iida, and Asada studied the effect of strain rate on the fatigue life of carbon steel exposed to high-temperature water containing dissolved oxygen. A series of strain-controlled fatigue tests were conducted with strain rate changed stepwise or continuously. A method using the product of the environmental effect and the strain increment within a unit time interval in a transient period is integrated from the minimum strain to the maximum. This modified strain rate approach method is discussed in detail.

Nakao, Higuchi, Kanasaki, Iida, and Asada investigated the fatigue design of pressure vessel components. They show that decreased fatigue life of STS410 carbon in simulated boiling water reactor water is dependent on temperature and dissolved oxygen. An environment parameter ratio, R_p, is proposed for the estimate of the fatigue life at a certain temperature and dissolved oxygen content.

Chopra and Shack summarized the available data on the effects of various material and loading variables such as steel type, dissolved oxygen level, strain range, strain rate, and sulfur content on the fatigue life of carbon steel and low-alloy steels. The data have been analyzed to define the threshold values of the five critical parameters. Methods for estimating fatigue lives under actual loading histories were discussed.

Kanasaki, Hirano, Iida, and Asada performed strain controlled low cycle fatigue tests of a carbon steel in oxygenated high-temperature water. The corrosion fatigue life prediction method was proposed for changing temperature conditions. The method is based on the assumption that the fatigue damage increased linearly with the fatigue cycle strain increment. The fatigue life predicted by this method was in good agreement with the test results.

Kishida, Umakoshi, and Asada proposed a method for evaluating the environmental fatigue lives for the Class I reactor pressure. A revised simplified method is developed for the determination of a fatigue usage factor for a component in which loading transients include variation of temperature, strain rate, and oxygen content in addition to the strain range. A number of examples are presented in which an environmental effect correction factor is determined for components in a nuclear pressure boundary.

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