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CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

TRIP REPORT

SUBJECT: 2001 The Minerals, Metals and Materials Society (TMS) Annual Meeting Symposium on Chemistry and Electrochemistry of Corrosion and Stress Corrosion Cracking: A Symposium Honoring the Contributions of Roger W. Staehle
Charge No. 20.01402.571
AI 01402.571.006

DATE/PLACE: February 11–15, 2001
New Orleans, Louisiana

AUTHOR: Gustavo A. Cragnolino

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PERSONS PRESENT: The annual meeting was attended by approximately 2,600 people and the symposium by approximately 60–80 people, including attendees from several countries of Europe, Asia and South America.

BACKGROUND AND PURPOSE OF TRIP:

The main purpose of the trip was to attend and present an invited talk in the Symposium on Chemistry and Electrochemistry of Corrosion and Stress Corrosion Cracking: A Symposium Honoring the Contributions of Roger W. Staehle. G. Cragnolino presented the paper titled "The Critical Potential for the Stress Corrosion Cracking of Fe-Cr-Ni Alloys and Its Mechanistic Implications," coauthored by D.S. Dunn, Y.-M. Pan and N. Sridhar, and chaired the session on Stress Corrosion of Waste Container Materials and other topics.

SUMMARY OF PERTINENT POINTS:

The symposium began on Monday, February 11 and continue through Thursday, February 15 with 8 sessions covering the following topics: Mechanisms and Modeling; Pitting, Crevice Corrosion, and Crack Initiation; Stress Corrosion Cracking of Iron and Nickel Based Alloys; Corrosion and Stress Corrosion of Lightweight Alloys; and Stress Corrosion of Waste Container Materials and Other Topics. There were thirty-eight papers presented in the various sessions, in addition to the keynote lecture by R.W. Staehle titled "Bases for Predicting the Earliest Failures Due to Stress Corrosion Cracking", which initiated the symposium. The Proceedings of the Symposium, edited by R.H. Jones, have been published by TMS.

R.W. Staehle (Consultant and University of Minnesota Adjunct Professor) discussed the bases for predicting the earliest failures (those which occur with a probability of 10^{-4} to 10^{-2}) in a set of subcomponents such as heat exchanger tubes or piping welds when the mode of failure is stress corrosion cracking (SCC). The basic approach developed by Staehle consists in connecting the physical description of SCC, in terms of the effect of the main material, environment and electrochemical variables on failure time or crack penetration, with the Weibull distribution. In order to develop predictions of the earliest failure, both the mean and the Weibull scale and shape parameters should be known. After a lengthy discussion with many examples from the available

literature and an extensive database, Staehle concluded that there is no solid theoretical bases for the estimation of the value of the shape parameter β despite its importance in predicting the earliest failure. If β is assumed to be equal to 1, which corresponds to a Poisson type of distribution for a random process in space and time, a conservative estimate of earliest failure is obtained. On the other hand, values of β larger than 4, corresponding to certain types of accumulation processes, may lead to longer failure times for a low probability of occurrence. However, these cases of large shape parameter may lead to incorrect prediction of earliest failure if the data arises from accelerated tests in which values close to the mean failure time are generally used.

The session on Mechanism and Modeling I continued with papers presented by Gilman, Galvele, Magnin, Andresen and Cragnolino. Gilman (University of California at Los Angeles) presented a theoretical paper using quantum chemistry concepts but mostly applicable to non-electronic conductive materials such as glass, polymers and ceramics. Galvele (Comision Nacional de Energia Atomica, Argentina) followed with a discussion on the role of vacancies in SCC mechanisms to support his own mechanism of surface mobility of ad-atoms inducing vacancy creation as a means of propagating a crack in a lattice only elastically stressed in the vicinity of the crack tip. He also compared his model with others such as the selective dissolution vacancy creep model by Saario et al. and the vacancy dislocation interaction model by Meletis et al., stressing the point that the surface mobility model provides better correlation with experimental data. Magnin (Ecole Nationael Superieure des Mines, France) presented an elaborated discussion on his corrosion enhanced plasticity model for SCC and numerical simulations of hydrogen-dislocation interactions at the crack tip and molecular dynamics and Monte Carlo simulation of hydrogen segregation at grain boundaries. Nevertheless, he recognized the limitations for calculating crack velocities from atomistic calculations. It appears, however, that hydrogen-induced SCC is more amenable to atomistic modeling than SCC promoted through anodic processes. Andresen (General Electric Corporation) questioned all the mechanistic interpretations of SCC based on threshold values for parameters such as stress intensity, corrosion potential, temperature, high-energy neutron fluence, etc. claiming that high-sensitivity crack growth measurements (using the potential drop method) reveal crack propagation below certain threshold values. Most of his experimental observations have been made in high temperature, high pressure aqueous environments typical of the boiling water reactor (BWR), but he also included data for Ti Grade 7 obtained in air saturated, concentrated groundwater (pH 10) at 110 °C showing a crack growth rate of 1.25×10^{-8} mm/s under constant load conditions (30 $MPa\cdot m^{1/2}$). However, the value of the corrosion potential and the effect of potential on the crack growth rate was not reported. Cragnolino presented a paper in which the prevailing SCC models, including those of Andresen and Ford, and Galvele, were critically reviewed emphasizing their limitations for long-term prediction. Experimental data supporting the concept of a critical potential for SCC of Fe-Cr-Ni alloys in hot, chloride solutions and its relationship with the repassivation potential was presented. A lively discussion among several attendees and the presenter followed because there is concern about the possibility of crack growth below the repassivation potential once a crack is initiated even for stainless steel such as 316L.

The second session on mechanisms and modeling had a paper by P. Scott (Framatome, France) on the secondary side SCC of pressurized water reactor (PWR) steam generator tubing. One of the principal aspects addressed by Scott was the chemical composition of the solutions formed in the crevice areas and the modeling attempts conducted in recent years. Bruemmer (Pacific Northwest National Laboratory) presented a careful study of samples containing cracks along grain boundaries conducted with the high resolution analytical transmission electron microscope. Whereas stainless steel samples exhibited significant plastic deformation along the crack path, no extensive plasticity was observed on Alloy 600 specimens where cracks contain polycrystalline oxides. G. Was (U. of Michigan) presented an extended review of his work

on grain boundary sliding related to intergranular stress corrosion cracking (IGSCC) of Alloy 600 in PWR environments. J Lumsden (Rockwell) showed Auger composition profiles for films formed on Alloy 600 under conditions that promote IGSCC and intergranular corrosion in high temperature caustic solutions identifying potential regions for dealloying or formation of a duplex nickel oxide/spinel passive film. M. Speidel (Swiss Federal Institute of Technology) presented his approach to the prediction of SCC in service based on crack growth rate laboratory data for alloy/environment systems of interest in the power generating industry. D.D. Macdonald (Pennsylvania State University) discussed in detail his interpretation of the role of coupling between the internal and external environment in SCC using a zero resistance ammeter to obtain electrochemical noise (current) data for type 304 SS in BWR environments and 4340 steel in caustic solutions.

In the last session on mechanisms and modeling, D. Duquette (Rensselaer Polytechnic Institute) presented a paper on the SCC of carbon steels in carbonate solutions discussing the role of local carbon distribution along grain boundaries on the basis of experiments with steels of different carbon contents. J. Conglenton (University of Newcastle, United Kingdom) described his work on the SCC of iron-base alloys in high temperature aqueous environments in which the dominant effect of potential and the existence of threshold potentials were clearly illustrated. P. Sofronis (University of Illinois at Urbana-Champaign) presented a interesting paper on the numerical modeling of hydrogen induced microscale shear localization in uniaxially loaded specimens in support of the hydrogen enhanced localized plasticity mechanism for hydrogen embrittlement. The session was closed by R. Wei (Lehigh University) with an extensive review of his work on localized corrosion (pitting) and corrosion fatigue of aluminum alloys using a mechanistically based probabilistic model to predict the performance of aging airframes.

The sessions on pitting, crevice corrosion and crack initiation had interesting papers presented by S. Smialowska (Ohio State University), N. Sato (Hokkaido University, Japan), H. Bohni (Swiss Federal Institute of Technology), H. Pickering (Pennsylvania State University), and S. Tsujikawa (University of Tokyo, Japan) covering several aspects of pitting and crevice corrosion initiation and growth. From the point of view of our program, the most interesting presentation was done by Tsujikawa on the crack initiation from crevices rather than pits for the SCC of Fe-Cr-Ni alloys in chloride solutions. The results presented, though some of them already known to us from previous publications, clearly support the concept of a critical potential as discussed in our paper, emphasizing the competition between dissolution rate and crack growth rate in defining the electrochemical conditions for SCC.

The remaining list of papers presented is attached in the form of the Table of Contents of the Proceedings. In the final session on Stress Corrosion of Waste Container Materials and Other Topics, the paper by R D. McCright and J. Farmer (Lawrence Livermore National Laboratory) titled " Stress Corrosion Cracking of a High Performance Nuclear Waste Containment Material" was cancelled. M. Akashi (Ishikawa-Harima Heavy Industries, Japan) presented an interesting paper on the SCC of α-Ti alloys promoted by hydrogen charging in the potential region corresponding to the hydrogen evolution reaction. The behavior of commercial purity Ti (Ti Grade 1) and Ti -0.06Pd (Ti Grade 17), which are considered as potential candidate container materials for disposal of high level radioactive waste, was compared. Akashi reported that Ti grade 17 exhibits a thicker hydride layer than Ti Grade 1 under identical hydrogen charging conditions. A model for initiation and propagation of cracks through the discontinuous, localized fracture of the hydride layer was developed. Using this model and measurements of the passive current density, the authors concluded that no failure due to hydride embrittlement can be expected over a disposal time of 1,000 years.

SUMMARY OF ACTIVITIES:

None.

IMPRESSION/CONCLUSIONS:

Overall, the attendance was beneficial because the meeting reflected the current state of knowledge in the field of SCC. It was useful for discussing our ideas regarding prediction of SCC under repository conditions among people specialized in this subject area. It is apparent that long-term predictions remain a very controversial issue in the field of SCC specially in cases in which a large database is not available and uncertainties exist on environmental conditions. However, our participation in this symposium enhanced the confidence within the corrosion community on the work conducted at the CNWRA that is intended to provide a reliable technical assessment of the proposed engineering barriers design.

PROBLEMS ENCOUNTERED:

None.

PENDING ACTIONS:

None.

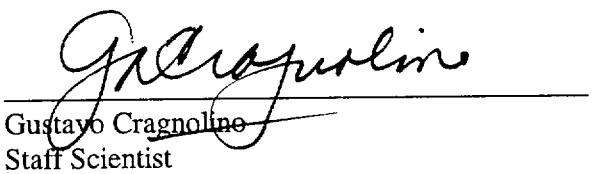
RECOMMENDATIONS:

Future attendance to topical meetings should be evaluated mostly in terms of the importance of the topic in relation to the NRC program. Attendance contributes to the visibility and recognition among peers of the corrosion related activities conducted at the CNWRA.

REFERENCES:

The Proceedings of the Symposium is available upon request from the authors.

SIGNATURES:



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Staff Scientist

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Date

Vijay Jain
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3/30/01
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CONCURRENCE:

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Attachment

GC:jg

Chemistry and Electrochemistry of Corrosion and Stress Corrosion Cracking: A Symposium Honoring the Contributions of R.W. Staehle

Proceedings of Symposium sponsored by the Structural Materials Division (SMD), Corrosion and Environmental Effect Committee (Jt. ASM-MSCTS), and Nuclear Materials Committee (Jt. ASM-MSCTS) of TMS (The Minerals, Metals & Materials Society).

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