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LOCALIZED CORROSION AND STRESS CORROSION CRACKING BEHAVIOR OF
AUSTENITIC STAINLESS STEEL WELDMENTS CONTAINING
RETAINED FERRITE

ANNUAL PROGRESS REPORT

for the period June 1, 1979 through March 31, 1980

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ABSTRACT

Localized corrosion and stress corrosion cracking experiments have been performed on single phase 304 stainless steel alloys and autogeneous weldments containing retained delta ferrite as a second phase. The results of the pitting experiments show that the presence of delta ferrite decreases localized corrosion resistance with pits initiating preferentially at delta ferrite-gamma austenite interphase boundaries. This increased susceptibility is reversible with elevated temperature heat treatments which revert the metastable ferrite phase to the equilibrium austenite phase. Experiments have also been conducted as functions of surface preparation, pH, Cl^- concentration and temperature from 20°C to 290°C . These experiments indicate that pitting tendency for both single phase and two phase alloys is controlled by the physical properties of the passive films which are naturally forced.

The results of the SCC experiments have shown that, for two phase alloys at temperatures from 20°C to 290°C , the ferrite phase also significantly affects stress corrosion resistance. At low temperatures and low pH the ferrite phase is preferentially dissolved, while at intermediate temperatures and pH's the δ/γ interface is the preferred crack path. At high temperatures cracking is associated with pitting, and depends sensitively on O_2 concentration of the environment. Additionally, the addition of $\text{SO}_4^{=}$ to chloride containing environments has a marked inhibitive effect on SCC.

TECHNICAL PROGRESS REPORT

Localized Corrosion

Dr. P. E. Manning has completed the requirements for the Ph.D. degree and is currently associated with the corrosion research group of the Stellite Division of Cabot Corporation. The results of his dissertation have been and are being published in Corrosion, Corrosion Science, the Welding Journal and Scanning Electron Microscopy. Preprints of these publications have been forwarded to the Division of Physical Research as they have become available and, accordingly are not attached. However, in accordance with progress reporting requirements, a list of these publications is appended. Mrs. W. Cieslak has recently joined the program as a research assistant and is in the process of familiarizing herself with the experimental techniques associated with localized corrosion in the temperature range of 5-300°C. Her suggested program is outlined in the proposed work for 1980-81.

Stress Corrosion Cracking

The results of stress corrosion cracking progress is single phase and duplex stainless steels can be summarized as follows:

I. Stress Corrosion Cracking in Deaerated Solutions Containing Chloride.

a. No stress corrosion cracking of annealed, welded or sensitized Type 304 stainless steel is observed in solutions containing up to 1000 ppm chloride unless dissolved oxygen is introduced or applied potentials are impressed.

b. The threshold potential for stress corrosion cracking in deaerated solutions can be expressed as a function of chloride in the following way (on the Ag/AgCl scale at 290°C):

$$\phi_p = -0.085 \log (\text{ppm Cl}^-) + 0.02 \text{ V}$$

c. The threshold potential for stress corrosion cracking is identical to the critical pitting potential, and crack initiation occurs at pits. The dependence of the threshold potential on the concentration of chloride is in agreement with the results of other investigations conducted at room temperature and 290°C. The threshold potential shifts in the active direction when a strain rate of 10^{-6} s^{-1} is applied.

d. The repassivation kinetics increase with temperature. At temperatures below approximately 125°C, repassivation occurs too slowly to maintain passivity when the specimen is strained at 10^{-6} s^{-1} , as measured by potentiodynamic polarization. Thus sensitized Type 304 stainless steel is predictably susceptible to intergranular stress corrosion cracking resulting from a selective dissolution process, as has been observed by others.

e. For annealed-sensitized or welded-sensitized Type 304 stainless steel, the threshold cracking potential is several hundred millivolts active to the pitting potential, with an approximate value of -0.45 V vs. Ag/AgCl at 290°C.

II. Stress Corrosion Cracking in Aerated Solutions.

a. Aerated or oxygenated pure water will induce stress corrosion cracking in Type 304. The apparent threshold strain rate for cracking is 10^{-6} s^{-1} .

b. In solutions containing dissolved oxygen and chloride ion, Type 304 is susceptible to severe transgranular stress corrosion cracking. This is associated with pitting which occurs when dissolved oxygen shifts the corrosion potential over the pitting potential. This could reasonably occur at oxygen concentrations of 50 ppb in solutions containing 1000 ppm

chloride, and at 0.5 ppm in solutions containing 10 ppm chloride.

c. The distinction between these two types of cracking is reinforced by cathodic polarization experiments in solutions containing dissolved oxygen and chloride ion. Polarization below the pitting potential dramatically reduces the severity of cracking, however cracking is observed at potentials as low as -0.40 V. This value approximately agrees with the corrosion potential corresponding to the minimum level of dissolved oxygen at which transgranular stress corrosion cracking occurs in annealed Type 304 at 10^{-6} s^{-1} .

III. General Conclusions.

a. Annealed and welded Type 304 stainless steels exhibit substantially similar pitting and stress corrosion cracking behavior in solutions containing chloride at temperatures above 200°C .

b. The temperature effects on the corrosion and pitting potentials are such that, based on the proximity of the two potentials, susceptibility to cracking under conditions of static strain is highest at 175°C .

c. Under potentiodynamic polarization, no anodic loop is observed, and passivity is maintained up to the pitting potential. Under conditions of no load or constant load, this is true at all temperatures between 25°C and 290°C , while at a strain rate of 10^{-6} s^{-1} stable passivity occurs only above 130°C .

d. Once over the pitting potential, crack initiation and propagation occur very rapidly. Stress corrosion failures in environments containing chloride are therefore best controlled by preventing crack initiation.

e. The fracture appearances are sufficiently distinctive to enable categorization and failure analysis. Crack morphologies become crystallo-

graphic in nature as the electrochemical driving force increases and the stress intensity decreases.

f. From a pitting and stress corrosion cracking standpoint, the properties of the passive film degrade as temperature increases. Above 220°C where the film is predominantly n-type, very little difference is observed between straining electrode tests and static strain tests, and pitting/cracking potentials are relatively constant with temperature.

g. A model based on dissolution best explains the intergranular and intercellular cracking in sensitized and welded structures. A model based on adsorption of chloride best describes the critical potential for pitting and transgranular stress corrosion cracking observations.

PERSONNEL DATA

Currently Assigned to Program

D. J. Duquette, Professor of Metallurgical Engineering
W. F. Savage, Professor of Metallurgical Engineering
C. E. Lyman, Assistant Professor of Metallurgical Engineering
S. Levy, Research Assistant
W. Cieslak, Research Assistant
A. Posnansky, Research Assistant

Degrees Awarded

E. Tsao, M.S. May 1979
P. A. Andresen, Ph.D. May 1979

Publications resulting from research performed under DOE Contract #DE-AS02-76ER02462

1. Previously Reported.

"Slow Strain Rate SCC of Type 304 Stainless Steels" Corrosion 33, 67 (1977), F. Stalder and D. J. Duquette.

"Stress Corrosion Cracking in Duplex Stainless Steel Weldments," Welding Journal, 57(6) 1978, p. 175, W. A. Baeslack III, W. F. Savage and D. J. Duquette.

"STEM Microanalysis of Duplex Stainless Steel Weld Metal," Scanning Electron Microscopy, 1, 213 (1978), C. E. Lyman, P. E. Manning, D. J. Duquette and E. Hall.

"The Effect of Test Method and Surface Condition in Pitting Potential of Single and Duplex Phase 304L Stainless Steel," Corrosion, 35, 151 (1979), P. Manning, D. J. Duquette and W. F. Savage.

"Slow Strain Rate Stress Corrosion Testing at Elevated Temperatures and High Pressures," to be published Corrosion Science, 1980, P. Andresen and D. J. Duquette.

2. Publications for 1979-80.

"Effect of Nitrogen on the Microstructure and Stress Corrosion Cracking of Stainless Steel Weld Metals," Welding Journal, 58(3), 835, (1979), W. A. Baeslack III, W. F. Savage and D. J. Duquette.

"The Effect of Strain Rate on SCC in Duplex Type 304 Stainless Steel Weld Metal," Met. Trans., 10A, 1429 (1979), W. A. Baeslack III, W. F. Savage and D. J. Duquette.

"The Effect of Temperature (25° - 290° C) in Pit Initiation in Single Phase and Duplex 304L Stainless Steels in 100 ppm Cl^{-} Solution," to be published, Corrosion Science, 1980, P. E. Manning and D. J. Duquette.

"The Effect of Retained Ferrite on Localized Corrosion in Duplex 304L Stainless Steel," submitted to Welding Journal, P. E. Manning, D. J. Duquette and W. F. Savage.

"The Role of Sulfide Inclusion Dissolution Kinetics in Pit Initiation of Several 300 Series Stainless Steels," to be published, Corrosion, 1980, P. E. Manning, D. J. Duquette and W. F. Savage.

"Effect of Chloride-Ion Concentration and Applied Potential on the SCL Behavior of Type 304 Stainless Steel in Deaerated High Temperature Water," Corrosion, 36, 85 (1980), P. A. Andresen and D. J. Duquette.

"The Effects of Dissolved Oxygen, Chloride Ion and Applied Potential on the SCL Behavior of Type 304 Stainless Steel in 290° C Water," to be published, Corrosion, 1980, P. A. Andresen and D. J. Duquette.

"Sulfur and Phosphorus Segregation in Duplex Stainless Steel Weld Metal," Mickobeam Analysis Ed. D. Newbury, p. 135, (1979), C. E. Lyman.