CRACKING OF ZIRCONIUM ALLOYS IN NEUTRAL AND ACIDIC ENVIRONMENTS

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The United States (US) Congress has recently proposed the Yucca Mountain site, near Las Vegas, Nevada to be the nation's geologic repository to contain spent nuclear fuel (SNF) and defense high-level waste should the US Nuclear Regulatory Commission grants license to do so. Cladding is the primary structural barrier that prevents the release of radionuclides contained in SNF. SNF cladding used in most US commercial reactors is made of zirconium (Zr) alloys such as Zircaloy-2 (Zr-2) and Zircaloy-4 (Zr-4). There are indications in the open literature(1) that these alloys may become susceptible to stress corrosion cracking (SCC), hydrogen embrittlement (HE), and localized (pitting and crevice) corrosion in the event of breeching and moisture contamination that may produce acidic aqueous environments. This paper presents the results of SCC and localized corrosion studies of Zr-2 and Zr-4 in neutral (pH: 6-7) and acidic (pH: 2-3) aqueous solutions at temperatures ranging from ambient to 90°C. The susceptibility of smooth cylindrical tensile specimens of both alloys to SCC was determined by using constant-load and slow-strain-rate (SSR) testing techniques. For constant-load testing, a calibrated proof ring was used to apply tensile load based on the material's yield strength (YS) value for a maximum period of 30 days. During SSR testing, the specimen was continuously strained until fracture at a strain rate of 3.3×10^{-6} sec^{-1}. The susceptibility to localized corrosion was evaluated by cyclic potentiodynamic polarization (CPP) method at a potential scan rate of 0.17 mV/sec using a potentiostat. The morphology of cracking was analyzed by scanning electron microscopy (SEM).The results indicate that neither alloy exhibited cracking in constant-load tests even at applied stresses up to 95 percent of their YS values. The results (Table 1) of SSR testing indicate that the true fracture stress (σ_f) was reduced in both environments at 90°C. However, the percent elongation (%El), the percent reduction in area (%RA), and the time-to-failure (TTF) were generally increased at 90°C indicating enhanced ductility, as shown in Table 1. The results (Figure 1) of CPP experiments at ambient temperature indicate that both the corrosion potential (E_{corr}) and the critical pitting potential (E_{pit}) became more active (negative) in the acidic solution compared to those in the neutral solution. A similar observation has been made elsewhere(2). SEM micrographs of the primary fracture faces of both alloys revealed dimples (Figure 2) that are characteristics of ductile failures. SCC tests under cathodic charging, and CPP experiments at elevated temperatures are ongoing.

References:
(1)Lawrence Livermore National Laboratory, UCID-20172, September 1984
(2)Corrosion Science, Vol. 33, No. 11, 1992

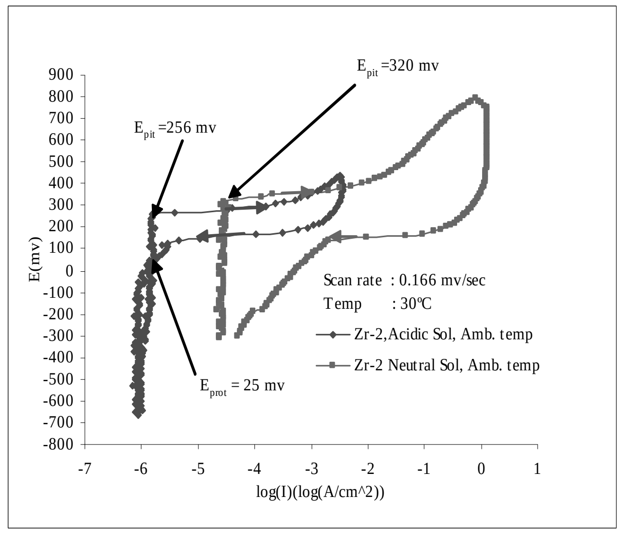

Figure 1. CPP Plot for Zr-2 in Neutral and Acidic Solutions at Ambient Temperature

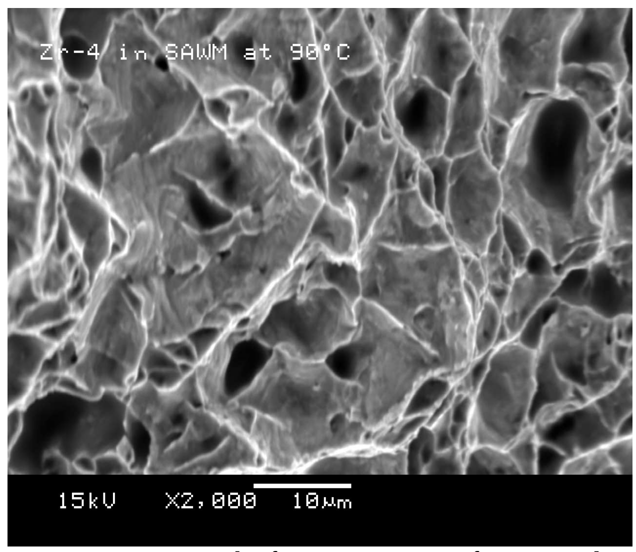

Figure 2. Micrograph of Zr-4 Fracture Surface in Acidic Solution at 90ºC

Table 1.
Results of SSR Testing

Alloy	Environment	σ_f (ksi)	% El	% RA	TTF (hr)
Zr-2	Neutral, RT	89.50	26.07	47.47	24.97
	Neutral,90°C	83.81	32.55	54.53	28.87
	Acidic, RT	92.38	25.38	48.78	24.86
	Acidic, 90°C	67.97	30.98	50.43	28.93
Zr-4	Neutral, RT	89.24	31.26	49.62	28.59
	Neutral,90°C	87.56	36.75	52.48	32.76
	Acidic, RT	95.78	30.10	51.76	28.10
	Acidic, 90°C	68.64	35.54	52.11	21.60

Key to Abbreviations:
RT : Room temperature
σ_f : True Failure stress
TTF : Time To failure
%RA : % Reduction in area
%El : % Elongation