TENSILE PROPERTIES OF V-Cr-Ti ALLOYS AFTER EXPOSURE IN HYDROGEN-CONTAINING ENVIRONMENTS*

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OBJECTIVE

The objectives of this task are to (a) determine the hydrogen uptake of V-Cr-Ti alloys as a function of temperature and partial pressure of hydrogen (pH_2) in the exposure environment, (b) examine the microstructural characteristics of surfaces and cross sections of the alloys after exposure, (c) evaluate the influence of hydrogen uptake in low-pH_2 environments on the tensile properties and cracking propensity of the alloys at room and elevated temperatures, and (d) determine the effects of oxygen/hydrogen interactions on the tensile properties of the alloys.

SUMMARY

A systematic study is underway at Argonne National Laboratory to evaluate the performance of several V-Cr-Ti alloys after exposure to environments containing hydrogen at various partial pressures. The goal is to correlate the chemistry of the exposure environment with hydrogen uptake by the samples and the resulting influence on the microstructures and tensile properties of the alloys. At present, the principal effort has focused on the V-4Cr-4Ti alloy of a heat identified as BL-71; however, other alloys (V-5Cr-5Ti alloy of Heats BL-63 and T87, plus a V-4Cr-4Ti alloy from General Atomics [GA]) are also being evaluated. Other variables of interest are the effect of initial grain size on hydrogen uptake and tensile properties, and the synergistic effects of oxygen and hydrogen on the tensile behavior of the alloys. During this period, specimens of Heat BL-71 were exposed for 100 h to pH_2 in the range of 3×10^{-6} to 5×10^{-2} torr (2.7×10^{-5} to 0.45 Pa) at 200 and 350°C. Tensile test results, obtained on specimens exposed for 100 h at 200, 350, and 500°C to pH_2 in the range of 1×10^{-6} to 0.01 torr, showed negligible effect of H_2 on either maximum engineering stress or uniform and total elongation. However, uniform and total elongation decreased substantially when the alloy was exposed at 500°C to 1.0 torr pH_2.

EXPERIMENTAL PROGRAM

The nominal compositions of the heats of vanadium alloys selected for the study were V-5 wt.% Cr-5 wt.% Ti (designated as BL-63 and T87) and V-4 wt.% Cr-4 wt.% Ti (designated as BL-71 and 44 from the GA heat). Detailed chemical analyses of these heats were presented in an earlier report.[1] The tensile specimens were fabricated according to ASTM Standard E8-69 specifications and had a gauge length of ≈19 mm and a gauge width of ≈4.5 mm. Specimens were annealed for 1 h at 1000°C before hydrogen exposure and tensile testing. During this period, tensile specimens of Heat BL-71 were exposed for 100 h at 200 and 350°C to environments with pH_2 levels of 1×10^{-6} and 1×10^{-2} torr; they were subsequently tensile-tested at a strain rate of 1.8×10^{-4} s^{-1} in room-temperature air. The specimens were loaded by means of pins that pass through holes in the grips and the enlarged end sections of the specimen, thus minimizing misalignment. Total elongation was measured with a vernier caliper and load/elongation chart records. The fracture surfaces and longitudinal and axial cross sections of the tested specimens are being examined by scanning electron microscopy. The specimens are also being analyzed for hydrogen content.

RESULTS AND DISCUSSION

The engineering stress/engineering strain plots at room temperature for V-4Cr-4Ti and V-5Cr-5Ti materials in as-annealed condition and after exposure at 500°C in pH_2 levels of 3×10^{-6} and 1 torr were reported in Refs. 1 and 2. The results showed that in the pH_2 range of the present study, BL-

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71 exhibited a small decrease in uniform and total elongation after exposure to hydrogen at 500°C. During this period, additional tensile specimens of V-4Cr-4Ti were exposed for 100 h at 200 and 350°C to pH_2 levels of 1×10^{-6}, 1×10^{-4}, and 5×10^{-2} torr. Engineering stress/engineering strain curves from various tests at room temperature were analyzed to evaluate the tensile properties of the alloy after several exposures to hydrogen. Table 1 shows the values for maximum engineering stress and uniform and total elongation of the alloy after exposure at several pH_2 levels and at various temperatures.

Figure 1 shows the engineering stress-engineering strain curves for V-4Cr-4Ti alloy specimens that were exposed to various pH_2 levels at 200, 350, and 500°C and subsequently tensile tested at room temperature air. Figure 2 shows the maximum engineering stress values as a function of hydrogen concentration for the alloy at 200, 350, and 500°C. The results show that pH_2 levels in the range of the present study have little or no effect on the maximum engineering stress for the alloy. The uniform and total elongation values for the alloy are 0.14-0.20 and 0.19-0.31, respectively, at pH_2 levels of 1×10^{-6} to 5×10^{-2} torr. After exposure at a pH_2 of 1 torr at 500°C, the alloy showed a significant decrease in uniform and total elongation, indicating that this pH_2 level may be the threshold for embrittlement of the alloy. Figures 3 and 4 are plots of uniform and total elongation values as a function of H_2 concentration for the alloy exposed at 200, 350, and 500°C and tested at room temperature. The hydrogen concentration in the alloy after exposure for 100 h at 500°C in 1 torr pH_2 was 358 wppm. Examination of the fracture surfaces and specimen cross sections, and measurements of hardness profiles are in progress, and the results will be used to correlate the microstructure, hydrogen concentration, and hardness data with the tensile properties of the alloys.

Table 1. Effects of 100-h hydrogen exposure at 200, 350, and 500°C on room-temperature tensile properties of V-Cr-Ti alloys, initially annealed for 1 h at 1050°C in vacuum

Exposure temperature (°C)	pH_2 in exposure environment (torr)	Maximum engineering stress (MPa)	Uniform elongation	Total elongation
200	3×10^{-6}	421	0.199	0.302
	1×10^{-4}	420	0.178	0.313
	5×10^{-2}	419	0.138	0.207
350	3×10^{-6}	434	0.133	0.184
	1×10^{-4}	525	0.182	0.242
	5×10^{-2}	460	0.183	0.294
500	-	424	0.186	0.322
	3×10^{-6}	440	0.174	0.263
	1×10^{-4}	467	0.154	0.227
	1×10^{-4}[a]	491	0.148	0.206
	1×10^{-2}	459	0.169	0.263
	5×10^{-2}	477	0.142	0.191
	1	468	0.0016	0.0016

[a]Repeat

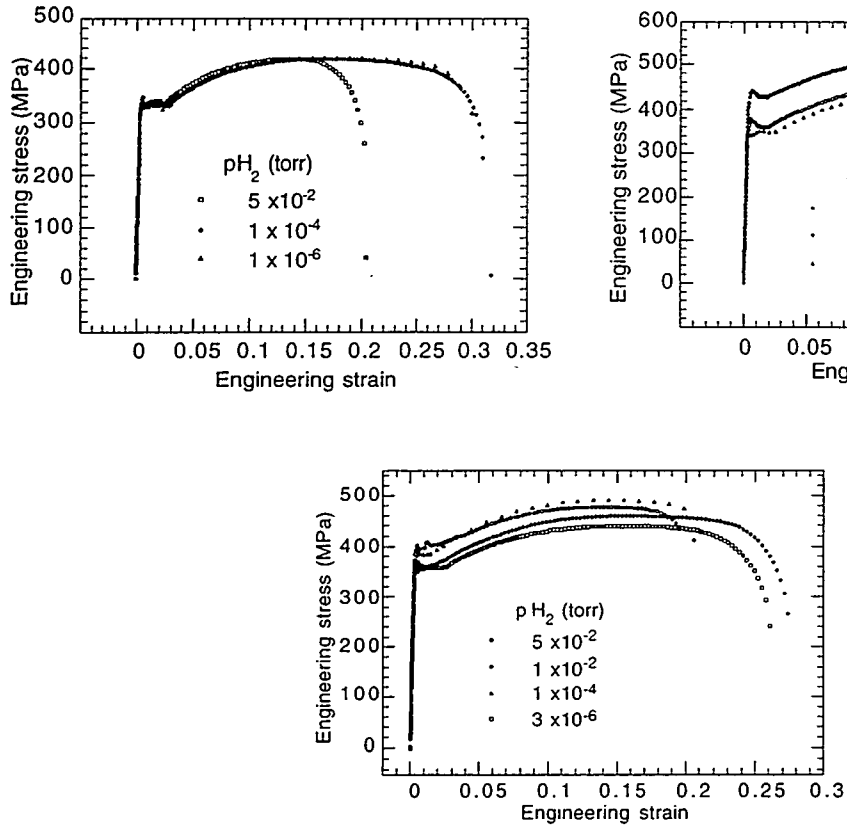

Figure 1. Engineering stress/engineering strain curves for V-4Cr-4Ti alloy at room temperature after 100 h exposure to hydrogen at 200°C (top left), 350°C (top right), and 500°C (bottom).

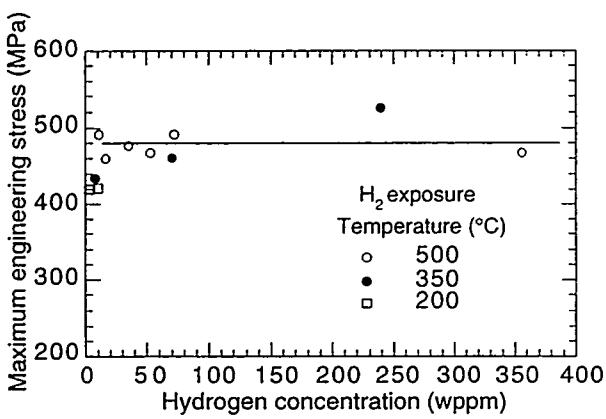

Figure 2. Maximum engineering stress as a function of hydrogen concentration for V-4Cr-4Ti alloy tested at room temperature

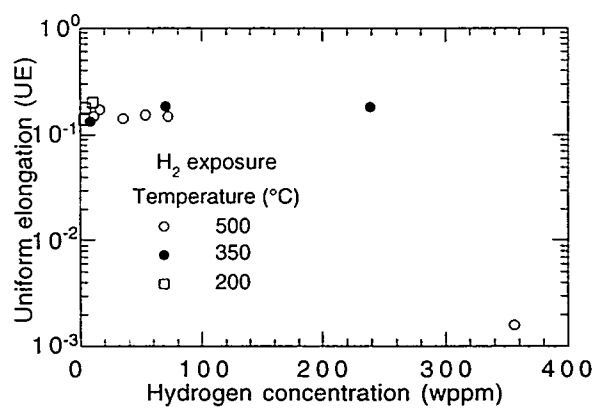

Figure 3. Uniform elongation as a function of hydrogen concentration for V-4Cr-4Ti alloy tested at room temperature

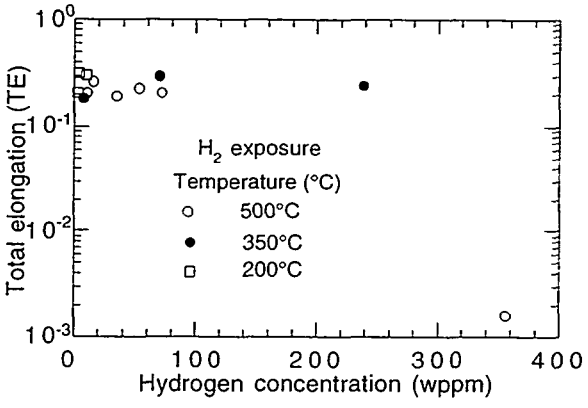

Figure 4. Total elongation as a function of hydrogen concentration for V-4Cr-4Ti alloy tested at room temperature

REFERENCES

1. K. Natesan and W. K. Soppet, "Tensile Properties of V-Cr-Ti Alloys after Exposure in Hydrogen-Containing Environments," Fusion Reactor Materials Progress Report for the Period Ending December 31, 1997, Argonne National Laboratory, DOE/ER-0313/23, p. 127, March 1998.

2. K. Natesan and W. K. Soppet, "Tensile Properties of V-Cr-Ti Alloys after Exposure in Hydrogen-Containing Environments," Fusion Reactor Materials Progress Report for the Period Ending June 30, 1998, Argonne National Laboratory, DOE/ER-0313/24, p. 68, September 1998.