TENSILE PROPERTIES OF V-5Cr-5Ti ALLOY AFTER EXPOSURE IN AIR ENVIRONMENT*

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OBJECTIVE

The objectives of this task are to (a) evaluate the oxygen uptake of V-Cr-Ti alloys as a function of temperature and oxygen partial pressure in the exposure environment, (b) examine the microstructural characteristics of oxide scales and oxygen entrapped at the grain boundaries of the substrate alloys, (c) evaluate the influence of oxygen uptake on the tensile properties of the alloys at room and elevated temperatures, and (d) determine the effect of oxygen uptake on the tensile behavior of the alloys.

SUMMARY

Oxidation studies were conducted on V-5Cr-5Ti alloy specimens in an air environment to evaluate the oxygen uptake behavior of the alloy as a function of temperature and exposure time. The oxidation rates, calculated from parabolic kinetic measurements of thermogravimetric testing and confirmed by microscopic analyses of cross sections of exposed specimens, were 5, 17, and 27 μm per year after exposure at 300, 400, and 500°C, respectively. Uniaxial tensile tests were conducted at room temperature and at 500°C on preoxidized specimens of the alloy to examine the effects of oxidation and oxygen migration on tensile strength and ductility. Correlations were developed between tensile strength and ductility of the oxidized alloy and microstructural characteristics such as oxide thickness, depth of hardened layer, depth of intergranular fracture zone, and transverse crack length.

EXPERIMENTAL PROGRAM

The heat of vanadium alloy selected for the study had a nominal composition of V-5 wt.%Cr -5 wt.%Ti and was designated BL-63. A sheet of the alloy was annealed for 1 h at 1050°C prior to oxidation and tensile testing. Coupon specimens that measured ≈15 x 7.5 x 1 mm were used for the oxidation studies. Oxidation experiments were conducted in air in a thermogravimetric test apparatus at temperatures between 300 and 650°C.

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. The grain size of the specimens was ≈32 μm. The specimens were preoxidized in air at 500°C for 24, 250, 600, 1000, and 2060 h prior to tensile testing in air at 500°C. Similar specimens, preoxidized up to 1000 h at 500°C in air, were also subjected to tensile testing at room temperature. As-annealed (control) specimens were tensile tested on an Instron machine at constant crosshead speeds between 0.0005 and 0.2 cm/min, which correspond to initial strain rates in the range of 4.4×10^{-6} to 1.8×10^{-3} s^{-1}. The preoxidized specimens were tested at a strain rate of 1.8×10^{-4} s^{-1}. The test temperature was maintained within 2°C in all tests performed in air at 500°C. The specimens were loaded by means of pins that pass through holes in the grips and enlarged end sections of the specimen, thus minimizing misalignment. Total elongation was measured with a vernier caliper and by using load/elongation chart records. The fracture surfaces and longitudinal and axial cross sections of tested specimens were examined by scanning electron microscopy (SEM). In addition, Vickers hardness of several tested specimens. Coupon specimens of the alloy that were oxidized with the tensile specimens were analyzed for bulk oxygen content by a vacuum-fusion technique.

RESULTS AND DISCUSSION

Oxidation Behavior

Oxidation of the alloy followed parabolic kinetics with respect to time. Detailed SEM analysis (with both energy-dispersive and wavelength-dispersive analysis) of the oxidized samples showed that the outer layer was predominantly vanadium-rich oxide and the inner layer was (V,Ti) oxide. Furthermore, X-ray diffraction of the oxides showed the outer oxide to be V_2O_5; no nitrogen or nitride phases were detected.

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The thickness of the oxide scale of the specimens, calculated from a parabolic rate equation, was in good agreement with the values determined by microscopy. The results were discussed in earlier reports (1, 2). Secondary-ion mass spectrometry was used to obtain depth profiles for oxygen in the tested specimens.

Effect of Oxidation on Tensile Properties

To evaluate the effect of oxide scale formation and oxygen penetration into the substrate alloy, tensile behavior of the alloy was examined as a function of oxygen ingress and oxide scale formation. Specimens were exposed to air for 24-2060 h at 500°C and then tensile tested in air at either room temperature or 500°C at a strain rate of 1.8 x 10^{-4} s^{-1}. Figure 1 shows the engineering stress/engineering strain curves at 500°C for specimens after oxidation for several exposure times up to 2060 h. Stress/strain behavior of the alloy is virtually unaffected by 24 h of exposure in air at 500°C. As exposure time increases to 250 h, alloy strength increases, with some loss in tensile ductility. In the exposure range of 250-1000 h, the alloy essentially has the same ultimate tensile strength but showed substantial reduction in tensile ductility. Further exposure of the alloy to air at 500°C causes loss of strength and tensile ductility, as evidenced by the stress/strain curve for the specimen that was preoxidized for 2060 h.

Figure 2 shows engineering stress/engineering strain curves obtained at room temperature for specimens after oxidation for several exposure times up to 1000 h. A significant increase in tensile strength and a moderate decrease in tensile ductility of the alloy occurs after 24 h of oxidation. However, the effect of oxidation on ductility was more severe as oxidation time increased to 260 h and beyond.

The load-displacement curves were reanalyzed by drawing lines parallel to the initial portion of the loading curve at the points of maximum load and rupture load. The intersects of these lines with the displacement axis are used to calculate the uniform and total elongation for the specimens subjected to various oxidation treatments. The present approach accounts for the stiffness, or lack of it, in the loading fixture of the tensile machine and, as a result, yields elongation values that are more representative of the gauge section of the tensile specimen; the values are generally lower than those in the last report (3).

Figures 3 and 4 show the variations in maximum engineering stress and uniform and total eleongation as a function of preoxidation time in air at 500°C for tests conducted at room temperature and 500°C.

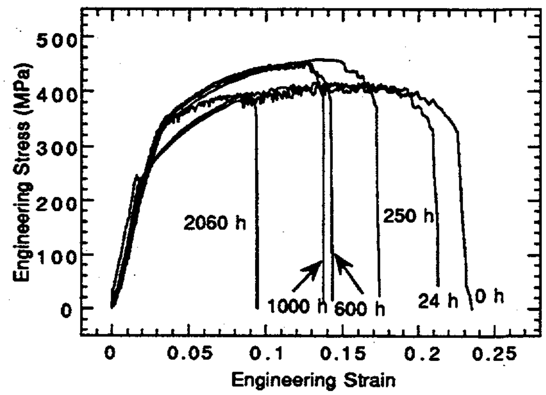

Figure 1. Effect of preoxidation at 500°C on stress/strain behavior of V-5Cr-5Ti alloy tested at 500°C in air at a strain rate of 1.75 x 10^{-4} s^{-1}.

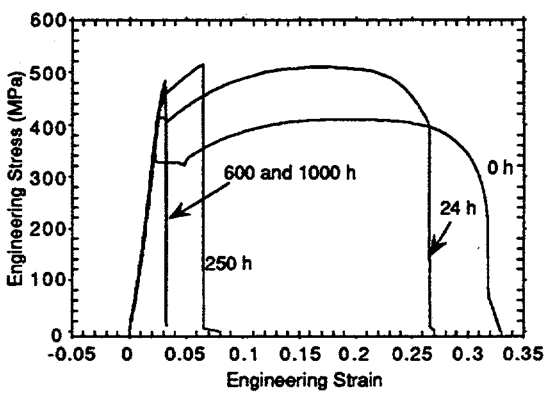

Figure 2. Effect of preoxidation at 500°C on stress/strain behavior of V-5Cr-5Ti alloy tested at room temperature in air at a strain rate of 1.75 x 10^{-4} s^{-1}.

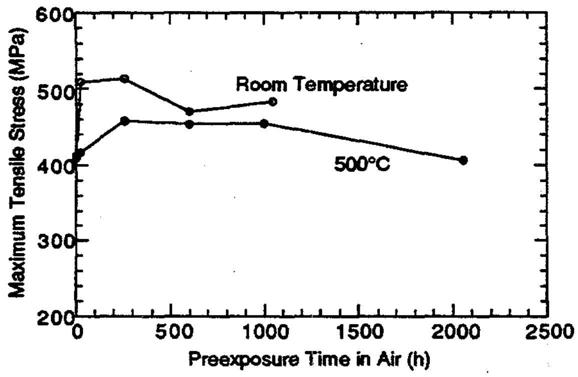

Figure 3. Maximum tensile stress as a function of preexposure time in air for specimens of V-5Cr-5Ti alloy tested in air.

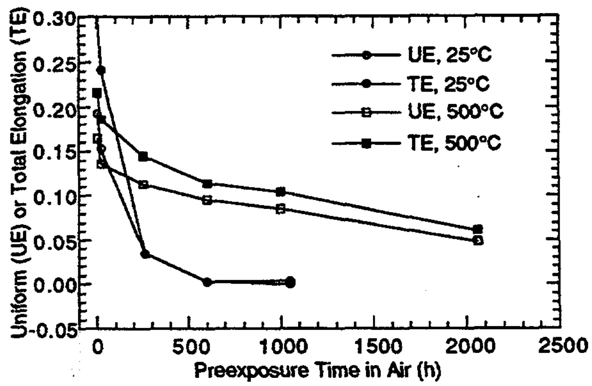

Figure 4. Rupture strain as a function of preexposure time in air for specimens of V-5Cr-5Ti alloy tested in air.

Table 1 lists the calculated and measured thickness of oxide layers, depth of hardened layers (from Vickers hardness measurements), thickness of intergranular fracture zones, and transverse crack length for specimens as-annealed, preoxidized, and tensile-tested at room temperature and 500°C. The results indicate that the specimens that were oxidized for 600 and 1000 h at 500°C registered only 0.003 and 0 uniform elongation at room temperature.

Additional exposures as a function of oxygen partial pressure in the exposure environment, as well as tensile tests at other temperatures on oxidized specimens, are underway to establish alloy performance in an oxygen-containing environment.

Table 1. Oxidation, hardness, and fracture data for V-5Cr-5Ti alloy

Exposure time (h)	Calculated oxide thickness[a] (µm)	Measured oxide thickness (µm)	Depth of hardened layer after exposure at 500°C (µm)	Intergranular-fracture zone (µm)		Measured crack length (µm)		Uniform elongation[c]		Total elongation[c]	
				RT[b]	500°C	RT[b]	500°C	RT[b]	500°C	RT[b]	500°C
0	0	0	0	0	0	0	10	0.193	0.164	0.301	0.216
24	1.4	1.2	<25	d	25	24	22	0.153	0.136	0.241	0.186
250[e]	4.6	5.0	45	>500	65	f	50	0.035	0.113	0.035	0.145
600	7.1	7.1	68	>500	100	f	90	0.003	0.095	0.003	0.114
1000[e]	9.1	9.0	80	>500	120	f	110	0	0.085	0.004	0.104
2060	13.1	14.0	120	NT[g]	165	NT[g]	160	NT[g]	0.048	NT[g]	0.061

[a]Values were calculated with an equation developed from a parabolic fit of all the oxidation data.
[b]RT = room temperature.
[c]Values that were recalculated by following the revised procedure discussed above.
[d]Fracture is partially ductile and no transition is noted from ductile to brittle fracture.
[e]Exposure times were 260 and 1050 h for the samples tested at room temperature.
[f]Specimen fully embrittled.
[g]NT=not tested.

REFERENCES

1. K. Natesan and W. K. Soppet, "Effect of Oxidation on Tensile Behavior of V-Cr-Ti Alloys," Fusion Reactor Materials Progress Report for the Period Ending March 31, 1995, Argonne National Laboratory, DOE/ER-0313/18, p. 247, July 1995.

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3. K. Natesan and W. K. Soppet, "Effect of Oxygen and Oxidation on Tensile Behavior of V-5Cr-5Ti," Fusion Reactor Materials Progress Report for the Period Ending December 31, 1995, Argonne National Laboratory, DOE/ER-0313/19, p. 50, April 1996.