EFFECT OF OXIDATION ON TENSILE BEHAVIOR OF V-5Cr-5Ti ALLOY*

K. Natesan and W. K. Soppet (Argonne National Laboratory)

OBJECTIVE

The objectives of this task are to (a) evaluate the oxygen uptake behavior of V-5Cr-5Ti alloy 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 in the substrate alloy, (c) evaluate the influence of oxygen uptake on the tensile properties of the alloy at room and elevated temperatures, (d) evaluate oxidation kinetics of the alloy with aluminum-enriched surface layers, and (e) determine the effect of oxygen uptake on tensile behavior of the alloy.

SUMMARY

Oxidation studies were conducted on V-5Cr-5Ti alloy specimens at 500°C in an air environment. The oxidation rates calculated from measurements of thermogravimetric testing are 10, 17, and 25 µm/y at 400, 450 and 500°C, respectively. Uniaxial tensile specimens were oxidized for several time periods in air at 500°C and subsequently tensile-tested at 500°C in air. The hardened layer in each of these oxidized specimens was confined to 75 µm after 1000 h exposure at 500°C. The influence of 1000 h oxidation is to increase the ultimate tensile strength of the alloy by ≈10% while decreasing the tensile rupture strain from 0.23 to 0.14.

INTRODUCTION

Refractory alloys in general and V-alloys in particular are susceptible to pickup of interstitials such as oxygen, carbon, and nitrogen, which can affect the short- and long-term mechanical properties of the materials. The vanadium alloy with a composition of V-5Cr-5Ti contains 5 wt.% Ti (much more stable oxide-former than V and Cr), which can have an even stronger effect on mechanical properties, especially tensile and creep ductility. The degree of influence of interstitials such as oxygen on the alloy's properties will be dictated by alloy grain size (the amount of grain-boundary areas), amount and distribution of oxygen in the alloy, amount and size of second-phase oxide precipitates (such as Ti oxide), and service temperature and time. The purpose of this study is to examine the role of oxygen and oxidation on the tensile properties of the material.

EXPERIMENTAL PROGRAM

The heat of vanadium alloy selected for the study had a composition of V-5 wt.%Cr -5wt.% Ti and had the designation BL-63. Sheet material of the alloy was annealed for 1 h at 1050°C prior to its use in oxidation and tensile testing. Coupon specimens measuring ≈15 x 7.5 x 1 mm were used for the oxidation studies. Oxidation experiments were conducted in air in a thermogravimetric test apparatus. The test temperatures ranged between 300 and 750°C.

Uniaxial tensile tests were conducted at 500°C in air with an Instron machine. The tensile specimens were fabricated according to ASTM specifications and had a gauge length of ≈19 mm and a gauge width of ≈4.5 mm. The specimens were preoxidized in air at 500°C for 24, 250, 600 and 1000 h prior to tensile testing in air at 500°C. Vickers hardness measurements were made on the tested specimens.

RESULTS AND DISCUSSION

Figure 1 shows weight change data for the alloy oxidized in air at several temperatures. The oxidation kinetics followed a parabolic relationship with time. Detailed scanning electron microscopy analysis of the oxidized samples showed the outer layer to be predominantly vanadium-rich oxide and the inner layer to be

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(V,Ti) oxide. Parabolic rate equations were used to calculate oxide scale thicknesses in the specimens, which were in agreement with the values determined by metallography. Figure 2 shows the oxidation rate (based on parabolic kinetics) as a function of temperature in the range 300-575°C. The results show that the oxide will grow at rates of 10, 17, and 25 µm/y at 400, 450, and 500°C, respectively. Even though the oxide thickness values are low at these temperatures, the alloy also exhibits an oxygen-enriched region ahead of the oxide scale, which can lead to hardening of the material and may also embrittle the alloy.

To evaluate the effect of oxidation and oxide penetration into the substrate alloy, several tests are in progress to examine the tensile behavior of the alloy as a function of oxygen ingress and oxide scale

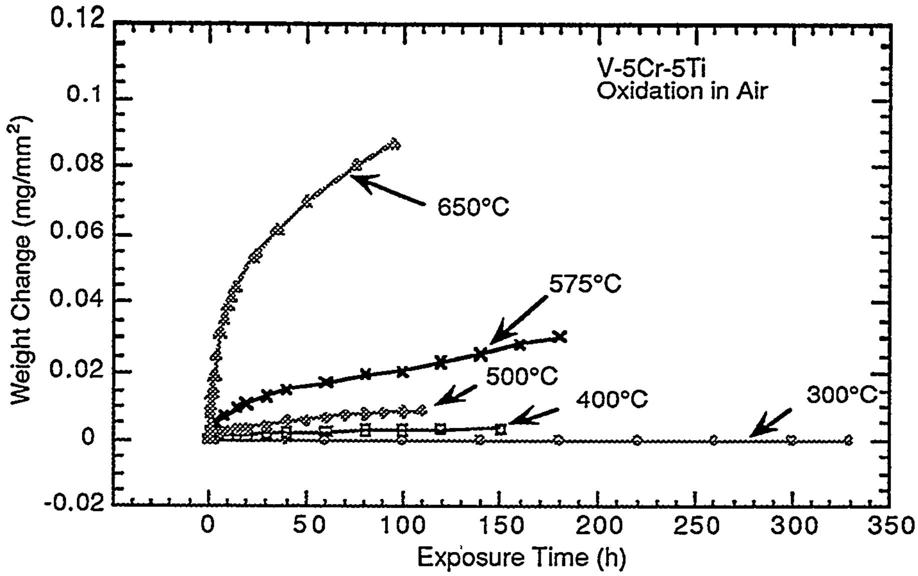

Figure 1. Weight change data for oxidation of V-5Cr-5Ti alloy in air at several test temperatures.

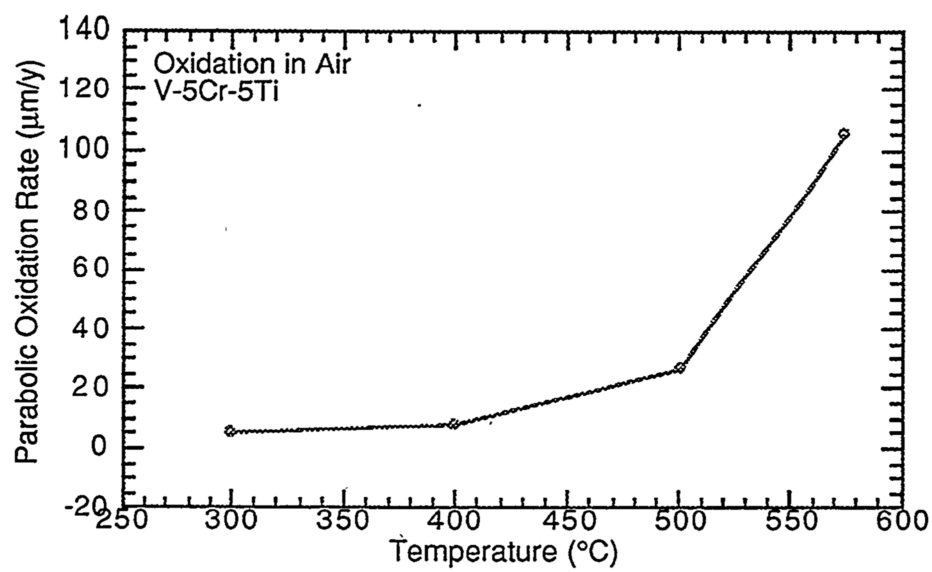

Figure 2. Parabolic rate (for first year) for oxidation of V-5Cr-5Ti alloy in air as a function of exposure temperature.

formation. In the first series of tests, tensile specimens were exposed to air for 24 to 1000 h in air at 500°C and then tensile-tested in air at the same temperature. Most of the tests were conducted at a strain rate of 1.75×10^{-4} s^{-1}, while a few specimens were tested at lower strain rates to evaluate the strain rate effect on tensile properties. Figure 3 shows the Vickers hardness profile of the specimens exposed to air for different times at 500°C. Oxide scale thickness is ≈10 µm but the hardness increase is noted to a depth of 50-70 µm, indicating an oxygen-enriched zone ahead of the oxide scale. Detailed analysis of this oxygen-enriched zone is in progress.

Figure 4 shows the engineering stress/engineering strain curves for specimens in oxidized condition and

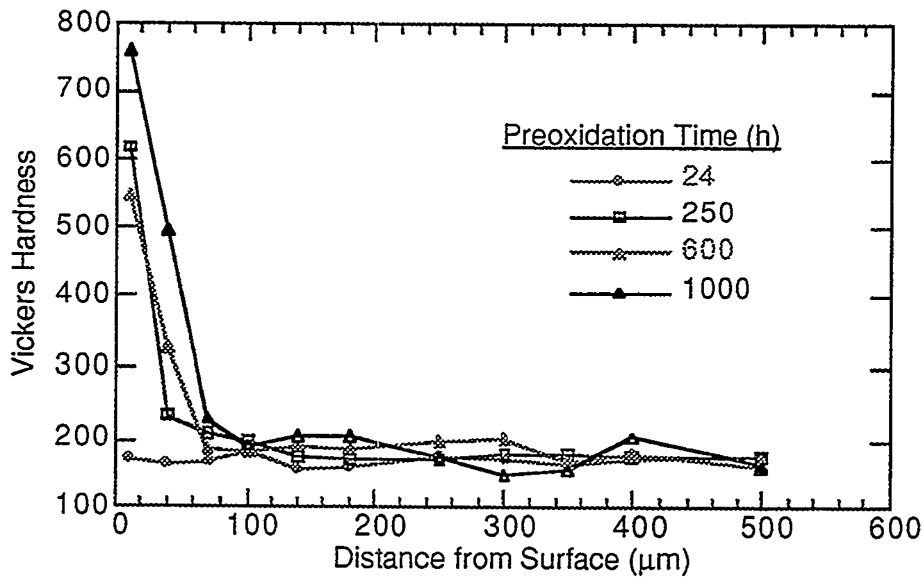

Figure 3. Vickers hardness data for specimens of V-5Cr-5Ti alloy oxidized at 500°C in air for different times.

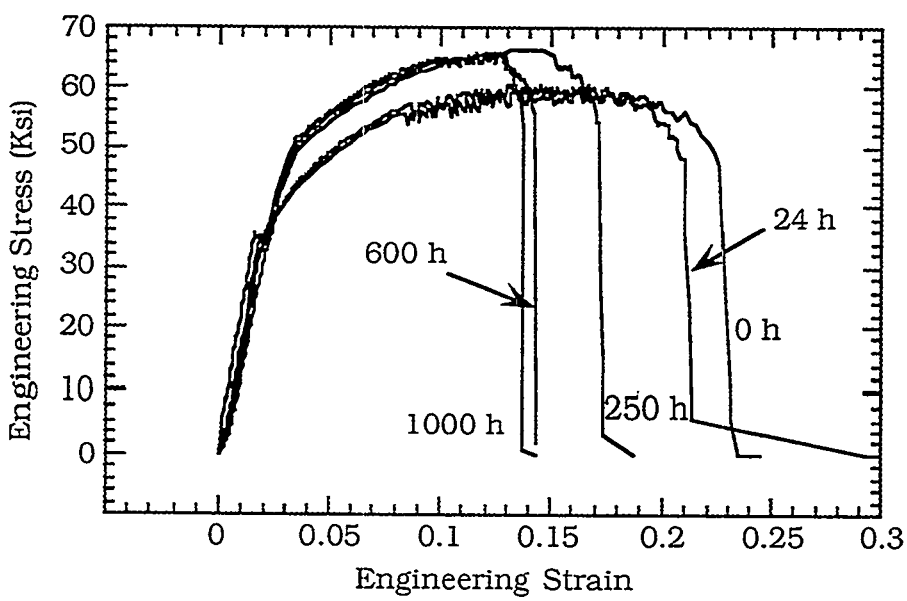

Figure 4. Effect of preoxidation at 500°C on stress-strain behavior of V-5Cr-5Ti alloy tested at 500°C in air at a strain rate of 1.75×10^{-4} s^{-1}.

after preoxidation for 24, 250, 600, and 1000 h in air at 500°C. The results show that air exposure for 24 h at 500°C has a negligible effect on tensile properties. The ultimate tensile strength value was ≈60 ksi for the specimens with and without 24 h exposure. Tensile strain decreased from 0.23 to 0.21 as a result of the 24h oxidation treatment. Air exposures of 250, 600, and 1000 h resulted in some increase in ultimate tensile strength of the material, but strength seemed to saturate at 67 ksi after 1000 h. Tensile strain decreased to 0.175, 0.145, and 0.14 after 250, 600, and 1000 h, respectively. Results to date indicate that the material is not subject to catastrophic embrittlement due to oxygen ingress into the material. Additional exposures as a function of oxygen partial pressure in the exposure environment, as well as tensile tests at lower temperatures, are in progress to establish the performance envelope for the alloy in an oxygenated environment.