# 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 has been initiated 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 the hydrogen uptake in the samples and its influence on the microstructure and tensile properties of the alloys. At present, four heats of alloys (BL-63, BL-71, and T87, plus 44 from General Atomics) are 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. Experiments conducted thus far on specimens of various V-Cr-Ti alloys exposed to $pH_2$ levels of 0.01 and $3 \times 10^{-6}$ torr showed negligible effect of $H_2$ on either maximum engineering stress or uniform/total elongation. Further, preliminary tests on specimens annealed at different temperatures showed that grain size variation by a factor of ≈2 had a negligible effect on tensile properties.

## EXPERIMENTAL PROGRAM

The heats of vanadium alloy selected for the study had nominal compositions of 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 GA heat). Detailed chemical analyses of these heats are given in Table 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 1050°C prior to hydrogen exposure and tensile testing. Some of the specimens of BL-63 and BL-71 heats were also annealed for 2 h at 1200°C to obtain a larger grain size before hydrogen exposure.

Tensile samples of the four alloys were exposed for 100 h at 500°C to environments containing $H_2$ at partial pressures of $3 \times 10^{-6}$ and 0.01 torr and subsequently tensile-tested at a strain rate of $1.8 \times 10^{-4}\ s^{-1}$ in room-temperature air. 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 load/elongation chart records. The fracture surfaces and longitudinal and axial cross sections of the tested specimens are being examined by scanning electron microscopy.

## RESULTS AND DISCUSSION

Figure 1 shows 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 to $H_2$ at partial pressures of $3 \times 10^{-6}$ and 0.01 torr. The results indicate that in the $H_2$ pressure range of the present study, BL-63 exhibited negligible effect of $H_2$ on tensile properties. BL-71 exhibited a small decrease in uniform and total elongation after $H_2$ exposure. Table 2 shows the values for maximum engineering stress and uniform and total elongation for all four heats of material. The results also show that for the

Table 1. Chemical compositions of several heats of V-Cr-Ti alloys used in hydrogen studies

| Element[a] | BL-63 (832394) | T87 | BL-71 (832665 | GA heat (832864) |
|---|---|---|---|---|
| Cr | 4.45 | 4.94 | 3.8 | 3.8 |
| Ti | 5.0 | 5.06 | 3.97 | 4.0 |
| V | Bal[b] | Bal[b] | Bal[b] | Bal[b] |
| B | <5 | <5 | <5 | <5 |
| C | 75 | 110 | 79 | 45 |
| H | 3 | 17 | - | 5 |
| N | 28 | 90 | 85 | 135 |
| O | 410 | 380 | 320 | 370 |
| P | <30 | <30 | <30 | <30 |
| S | 25 | <20 | <10 | 15 |
| Al | 200 | 160 | 190 | 170 |
| Nb | <50 | <100 | <50 | 90 |
| Si | 305 | 545 | 780 | 340 |
| Fe | - | 67 | 230 | 210 |
| Cu | - | 67 | <50 | <50 |
| Mo | - | 520 | 290 | <50 |
| Ta | - | <36 | <20 | <30 |
| W | - | <5 | 25 | - |

[a]Concentrations for Cr, Ti, and V are in wt.%; all others are in wt ppm.
[b]Indicates balance.

Table 2. Effects of 100 h hydrogen exposure at 500°C on room-temperature tensile properties of V-Cr-Ti alloys, initially annealed for 1 h at 1050°C in vacuum

| $pH_2$ in exposure environment (torr) | Maximum engg. stress (MPa) | | | | Uniform elongation | | | | Total elongation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BL-63 | T87 | BL-71 | GA | BL-63 | T87 | BL-71 | GA | BL-63 | T87 | BL-71 | GA |
| - | 469 | - | 424 | - | 0.165 | - | 0.186 | - | 0.303 | - | 0.322 | - |
| $3 \times 10^{-6}$ | 437 | - | 440 | - | 0.189 | - | 0.174 | - | 0.313 | - | 0.263 | - |
| $1 \times 10^{-2}$ | 445 | 501 | 459 | 462.5 | 0.194 | 0.178 | 0.169 | 0.151 | 0.313 | 0.296 | 0.263 | 0.224 |

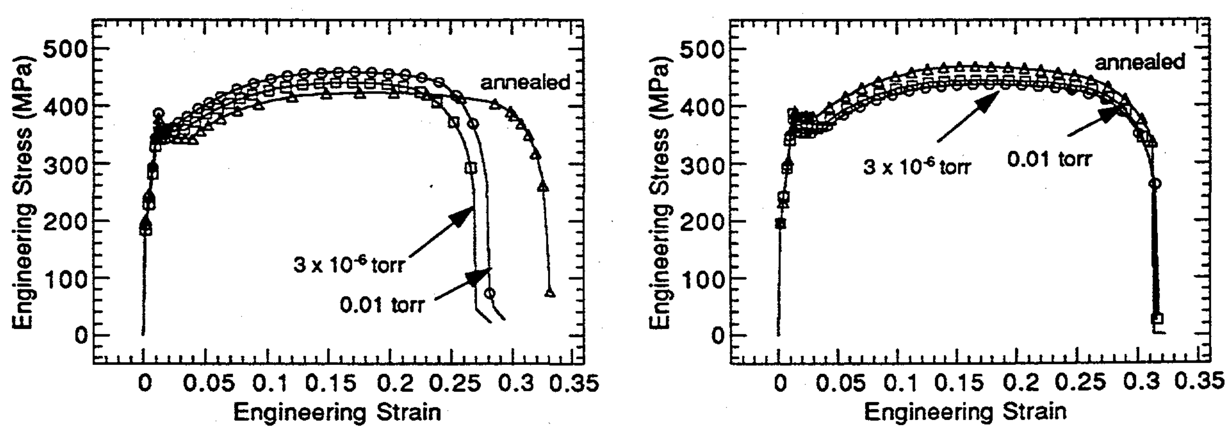


Figure 1. Engineering stress/engineering strain plots for BL-71 (left) and BL-63 (right) heats of material in as-annealed condition and after 100 h exposure at 500°C to various $pH_2$ levels.

same exposure condition of 0.01 torr $pH_2$, the BL-71 and GA heats exhibited almost similar strength properties, while the T87 heat showed somewhat higher strength than the BL-63 heat (see Figure 2). However, the total elongation values are similar for BL-63 and T87, while that for the GA heat was significantly lower than that for the BL-71 heat. Additional $H_2$ exposures and post-exposure tensile-testing are in progress to quantify the effects of $H_2$ on the tensile behavior of these alloys.

To examine the effect of initial grain size on subsequent $H_2$ uptake and tensile properties, specimens of BL-71 and BL-63 were annealed for 2 h at 1200°C, which increased the grain size of the alloys by at least a factor of 2 over those annealed for 1 h at 1050°C. Figure 3 shows the engineering stress/engineering strain curves for large- and small-grain materials after 100 h exposure at 500°C to a $pH_2$ of 0.01 torr. With the increased grain size, both alloys exhibited some increase in strength and some decrease in elongation. Similar effects were observed when the specimens were exposed for 100 h at 500°C to a $pH_2$ of $3 \times 10^{-6}$ torr (see Table 3). Additional experiments at other $pH_2$ levels are in progress to quantify the grain-size effect (if any) on $H_2$ uptake and tensile properties.

Table 3. Effects of 100 h hydrogen exposure at 500°C on room-temperature tensile properties of enlarged-grain V-Cr-Ti alloys, initially annealed for 2 h at 1200°C in vacuum

| $pH_2$ in exposure environment (torr) | Maximum engg. stress (MPa) | | Uniform elongation | | Total elongation | |
|---|---|---|---|---|---|---|
| | BL-63 | BL-71 | BL-63 | BL-71 | BL-63 | BL-71 |
| $3 \times 10^{-6}$ | 515 | 472 | 0.144 | 0.159 | 0.250 | 0.225 |
| $1 \times 10^{-2}$ | 524 | 479 | 0.160 | 0.153 | 0.244 | 0.227 |

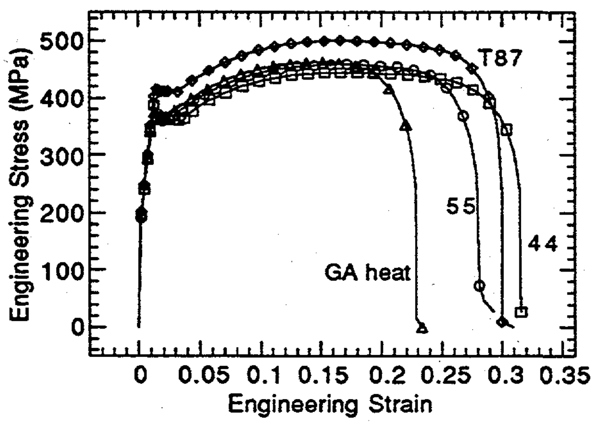


Figure 2. Engineering stress/engineering strain curves at room temperature for four heats V-Cr-Ti alloys after 100 h exposure at 500°C to 0.01 torr $H_2$.

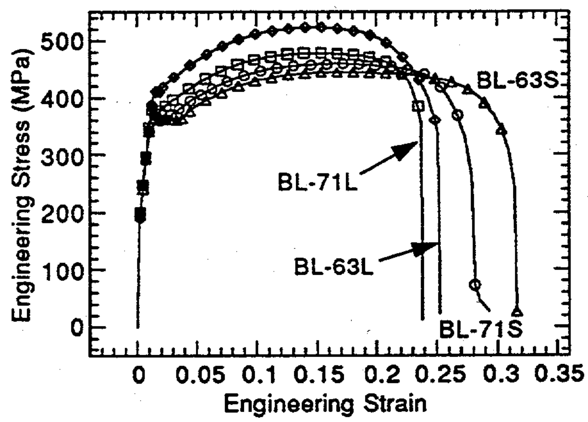


Figure 3. Engineering stress/engineering strain curves at room temperature for various grain size BL-71 and BL-63 materials after 100 h exposure at 500°C to 0.01 torr $H_2$. L and S indicates large- and small-grain materials, respectively.