HIGH TEMPERATURE TENSILE PROPERTIES OF V-4Cr-4Ti — S. J. Zinkle, A. F. Rowcliffe and C. O. Stevens (Oak Ridge National Laboratory)

OBJECTIVE

The objective of this report is to summarize recent high temperature data on the tensile properties of V-4Cr-4Ti.

SUMMARY

Tensile tests have been performed on V-4Cr-4Ti at 750 and 800°C in order to extend the data base beyond the current limit of 700°C. From comparison with previous measurements, the yield strength is nearly constant and tensile elongations decrease slightly with increasing temperature between 300 and 800°C. The ultimate strength exhibits an apparent maximum near 600°C (attributable to dynamic strain aging) but adequate strength is maintained up to 800°C. The reduction in area measured on tensile specimens remained high (~80%) for test temperatures up to 800°C, in contrast to previous reported results.

PROGRESS AND STATUS

Introduction

The maximum operating temperature limit for vanadium alloys in fusion reactor design studies is typically assumed to be ~700°C [1,2]. Alternatively, it was recently suggested that vanadium alloys might be capable of operation at temperatures up to 750°C [3]. Although the maximum operating temperature will likely be determined by creep (thermal and irradiation), helium embrittlement, or corrosion effects, there are no known tensile data for V-4Cr-4Ti alloys at temperatures above 700°C. High temperature tensile data would be beneficial to help guide planned thermal creep experiments on V-4Cr-4Ti, and may provide some insight into the maximum allowable operating temperature based on mechanical strength considerations.

Experimental Procedure

The specimens were prepared from the 500 kg US fusion program heat of V-4Cr-4Ti (heat 832665). A 50% cold-rolled plate (6.4 mm thickness) supplied by Teledyne Wah Chang Albany was annealed at 1000°C for 2 h and then cross-rolled to a thickness of 3.81 mm (40% cold work). Type SS3 miniature sheet tensile specimens (nominal gage dimensions 0.76 × 1.52 × 7.6 mm) were electrodischarge machined and subsequently annealed at 1000°C for 2 h in a vacuum of ~2×10^{-7} torr. The specimens were engraved with ID codes (RC and RD series) prior to annealing. The tensile specimens were tested in vacuum (~2×10^{-7} torr) at a constant crosshead speed of 0.46 mm/minute, which corresponds to an initial strain rate of 1.0×10^{-3} s^{-1}. The specimens were held at the test temperature for 20 to 30 minutes prior to the start of the tensile test. Data were digitally acquired at an acquisition rate of 20 points per second. Following tensile testing, the fracture surfaces were examined in a scanning electron microscope in order to determine the reduction in area.

Results and Discussion

The tensile properties of the V-4Cr-4Ti specimens are listed in Table 1, and the load-elongation tensile curves are shown in Fig. 1. Slight yield drops were observed at all three test temperatures, similar to what was previously observed at test temperatures up to 700°C [4]. The difference between the upper and lower yield points was approximately 10 MPa in all three cases. The

Table 1. Summary of tensile data on V-4Cr-4Ti specimens.

Test temperature	Yield strength	Ultimate strength	Uniform elongation	Total elongation	Reduction in area
600°C	228 MPa	387 MPa	11.5%	22%	—
750°C	235 MPa	397 MPa	10.0%	17%	77%
800°C	234 MPa	337 MPa	10.5%	20%	82%

Luders band elongation was less than 2% at all three temperatures. The yield strength was determined at the lower yield point, which occurred at 0.2-0.5% plastic extension. Serrations in the stress-strain tensile curves were observed in specimens tested at temperatures up to 750°C, although the amplitude of the serrations observed at 750°C was much smaller than that observed at 600-700°C [4]. The amplitude of the serrations was very small (~1 MPa) at a test temperature of 800°C. The Portevin-Le Chatelier serrations fell below the general level of the stress-strain curve (Type C behavior [4]) at all three test temperatures.

The present tensile data are plotted along with previously reported tensile data [4-6] in Figs. 2-4. The strength data shown in Fig. 2 were fitted to a 4th order polynomial, and the resulting equations are given in the figure. The yield strength is nearly independent of test temperature between 300 and 800°C. The ultimate strength exhibits a local maximum at test temperatures near 600°C, and begins to significantly decrease at 800°C. As shown in Fig. 3, the uniform and total elongation decrease slowly with increasing temperature. High tensile elongations are observed at all temperatures up to 800°C. The reduction in area measured in the present study (Fig. 4) was ~80% at both 750 and 800°C. Ductile dimple fracture surfaces were observed at

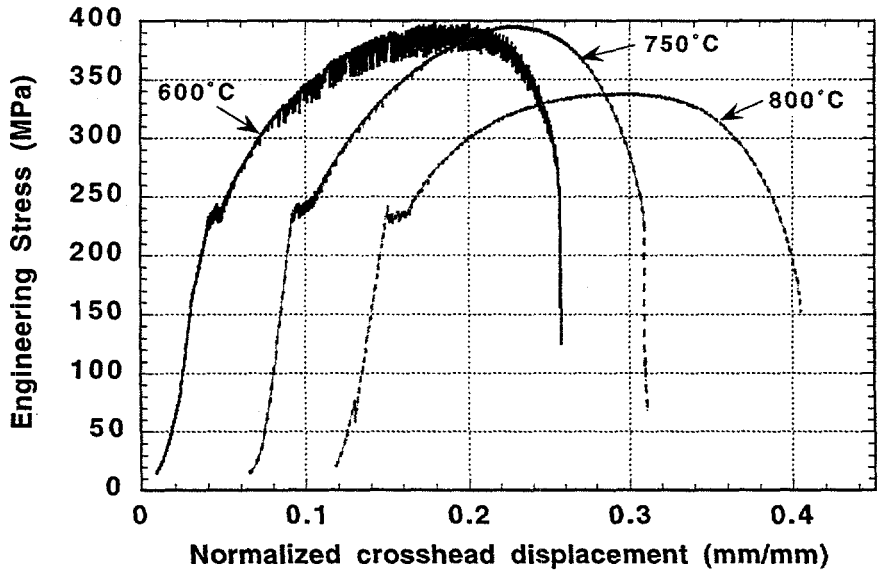

Fig. 1. Load-elongation curves for V-4Cr-4Ti tensile specimens tested at 600-800°C. The tensile curves have been horizontally offset for clarity.

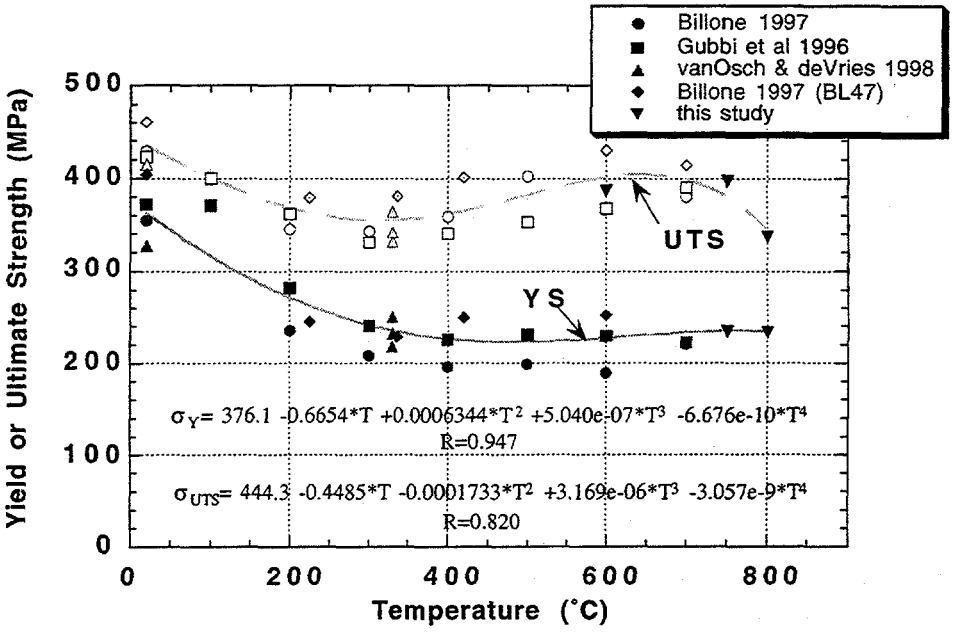

Fig. 2. Temperature dependence of the tensile strength of V-4Cr-4Ti [4-6]. Unless otherwise indicated, all of the data were obtained on the US Fusion program heat #832665.

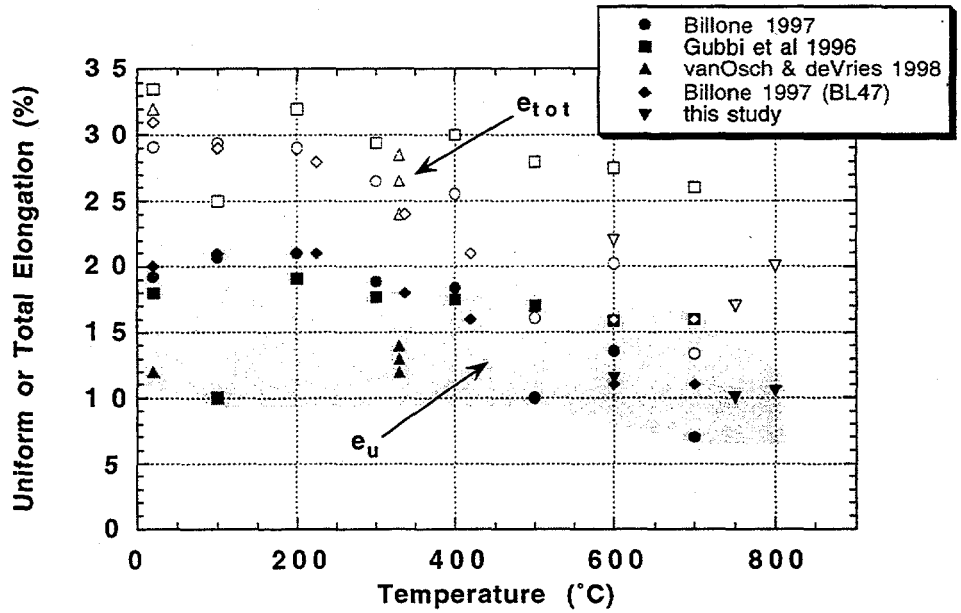

Fig. 3. Temperature dependence of the tensile elongations of V-4Cr-4Ti [4-6]. Unless otherwise indicated, all of the data were obtained on the US Fusion program heat #832665.

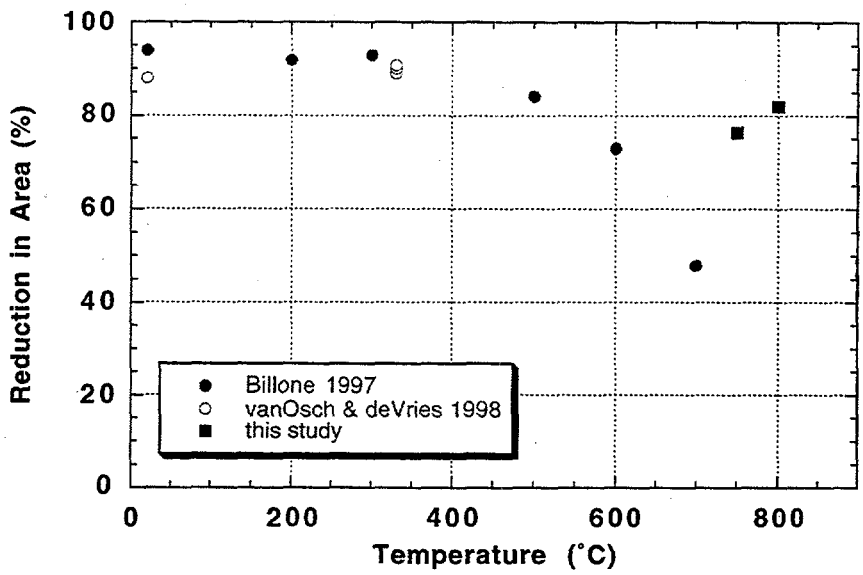

Fig. 4. Temperature dependence of the reduction in area of the US Fusion program heat (#832665) of V-4Cr-4Ti tensile tested at ~1 × 10^{-3} s^{-1} [5,6].

all temperatures investigated in this study. Previous studies [5,6] reported that the reduction in area for V-4Cr-4Ti was nearly constant between 20 and 500°C with a value of ~90%, and decreased rapidly at temperatures above 600°C. The reason for the apparent discrepancy in high temperature reduction in area values between the present study and the values summarized in ref. [5] is uncertain. Differences in the quality of the testing vacuum may be one possibility.

ACKNOWLEDGEMENTS

The authors thank A. M. Williams for providing the scanning electron microscopy measurements.

REFERENCES

1. D. L. Smith et al., Argonne National Laboratory Report ANL/FPP-84-1 (1984).
2. H. Matsui et al., Fusion Technology 30 (1996) 1293.
3. D. L. Smith et al., 8th Int. Conf. on Fusion Reactor Materials, Sendai, J. Nucl. Mater. (1998) in press.
4. A. N. Gubbi, A. F. Rowcliffe, W. S. Eatherly and L. T. Gibson, in Fusion Materials Semiannual Progress Report for Period ending June 30, 1996, DOE/ER-0313/20 (Oak Ridge National Lab, 1996) p. 38.
5. M. C. Billone, in Fusion Materials Semiann. Prog. Report for period ending Dec. 31 1997, DOE/ER-0313/23 (Oak Ridge National Lab, 1997) p. 3.
6. E. V. van Osch and M. I. de Vries, 8th Int. Conf. on Fusion Reactor Materials, Sendai, J. Nucl. Mater. (1998) in press.