TENSILE PROPERTIES OF V–(4–5)Cr–(4–5)Ti ALLOYS* H. M. Chung, L. Nowicki, D. Busch, and D. L. Smith (Argonne National Laboratory)

OBJECTIVE

The objective of this work is to provide a data base on the baseline tensile properties of nonirradiated V-(4–5)Cr-(4–5)Ti alloys, including a 500–kg production heat of V–4Cr–4Ti.

SUMMARY

The current focus of the U.S. program of research on V–base alloys is on V-(4-5)Cr-(4-5)Ti that contains 500–1000 wppm Si. In this paper, we present experimental results on baseline tensile properties of two laboratory–scale heats of this alloy and of a 500–kg production heat of V–4Cr–4Ti (Heat 832665) that were measured at 23–700°C. Both the production– and laboratory–scale heats of the reference alloy V–4Cr–4Ti exhibited excellent tensile properties at temperatures up to ≈650°C.

INTRODUCTION

A recently reported comprehensive data base on tensile strength and ductility of several major alloys of the V–Cr–5Ti system includes a 30–kg laboratory heat (BL–47) of the reference alloy V–4Cr–4Ti that has been known to exhibit excellent properties after irradiation with and without He generation.[1] Subsequently, a 500–kg production heat of V–4Cr–4Ti (Heat 832665) and a 15–kg laboratory heat of V–5Cr–5Ti (Heat T87) were fabricated successfully. Excellent impact properties of these new heats have been reported recently.[2–5] This report presents results of tensile tests on the three heats.

MATERIALS AND PROCEDURES

The chemical composition of the three heats of V–(4–5)Cr–(4–5)Ti used in this study is given in Table 1. In the table, electron–beam–melted raw V Heat 820630 was used to melt the ingots of both V–4Cr–4Ti Heat 832665 and V–5Cr–5Ti Heat T87. Final forms of the extruded products were 3.8–, 1.0–, and 0.3–mm–thick plates and sheets. Tensile specimens were machined from 0.7–1.0–mm–thick sheets so that the rolling direction of the sheet was parallel to the uniaxial loading direction.

Table 1. Composition of three heats of V–(4–5)Cr–(4–5)Ti

Heat ID	Alloy Composition (wt.%)	Impurity Concentration (wt. ppm)			
		O	N	C	Si
820630	V	200	62	75	780
BL-47	V–4.1Cr-4.3Ti	350	220	200	870
832665	V–3.8Cr–3.9Ti	310	85	80	783
T87	V–4.9Cr–5.1Ti	380	89	109	545

Typically, the machined and polished specimens were annealed at 1000°C for 1 h in a high–quality vacuum before testing. This annealing condition has been found to produce optimal impact properties in the two new heats T87 and 832665[2–4] and it produced an ≈70% recrystallized structure in Charpy–impact specimens. The only secondary phase in the as–annealed specimen was a Ti(O,N,C) precipitate, ≈300–500 nm in size, which is normally observed in Ti–containing vanadium alloys with O+N+C > 400 wppm. The gauge cross section of each polished specimen was measured individually. Tensile tests were conducted at 23–700°C at a strain rate of 1.1 x 10^{-3} s^{-1}. High–temperature tests were conducted in a quartz cylinder that was evacuated and continuously flushed with flowing Ar. Specimen temperature was

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monitored with two thermocouples spot–welded on the gauge section. Reduction in area was determined from magnified SEM images of the fracture surface that was photographed perpendicular to the tensile axis.

RESULTS AND DISCUSSION

Yield strength, ultimate tensile strength, uniform elongation, total elongation, and reduction in area are shown in Figs. 1–5, respectively. Note that yield strength of the alloys was nearly constant between 200 and 700°C. Ultimate strength appears to be slightly lower at ≈250–300°C than at <200°C or >300°C. At 700°C, the yield and ultimate tensile strengths decreased only slightly.

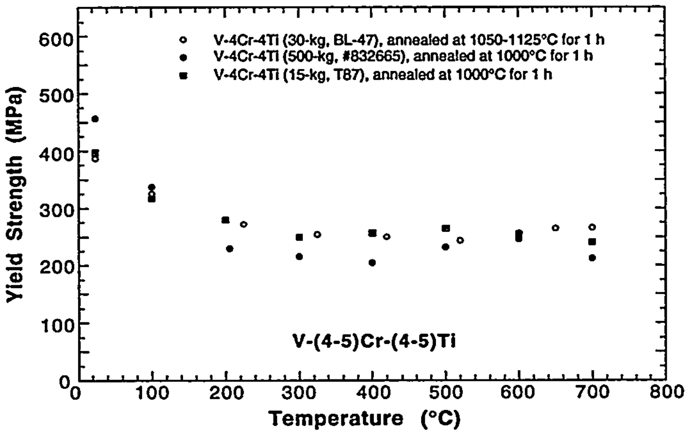

Fig. 1.
Yield strength of three heats of nonirradiated V-(4–5)Cr-(4–5)Ti alloys at 23–700°C.

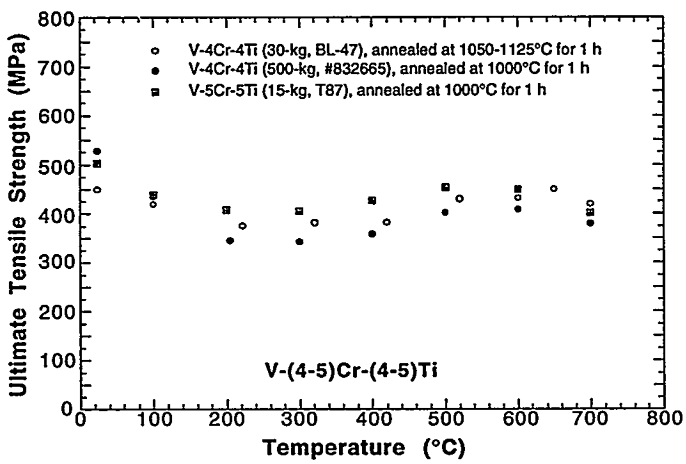

Fig. 2.
Ultimate tensile strength of three heats of nonirradiated V-(4–5)Cr-(4–5)Ti alloys at 23–700°C.

At all test temperatures in the previous studies, yield and ultimate strength of V–Cr–(4–5)Ti increased monotonically for increased chromium content, indicating the predominant effect of Cr on the tensile strength of the alloy system.[1] The results shown in Figs. 1 and 2 appear to be consistent with the findings of the previous studies, that is, for similar annealing conditions, the strength of T87 (V–4.9Cr–5.1Ti) was higher than that of 832665 (V–3.8Cr–3.9Ti). Tensile specimens of BL–47 (V–4.1Cr–4.3Ti) were annealed at temperatures somewhat higher than those of 832665. Note that the strength of BL–47 is slightly higher than that of 832665. It is not clear if this is because of the higher annealing temperature or the higher combined content of Cr and Ti (i.e., 8.4 vs. 7.7 wt.%) of BL–47.

The yield strength of V–Cr–Ti alloys at room temperature and 420–600°C could be correlated well with combined content of Cr and Ti, as shown in Fig. 6. The strength of the two new heats of V–(4–5)Cr–(4–5)Ti alloys is also consistent with the correlation shown in Fig. 6. The excessive alloying addition of Cr

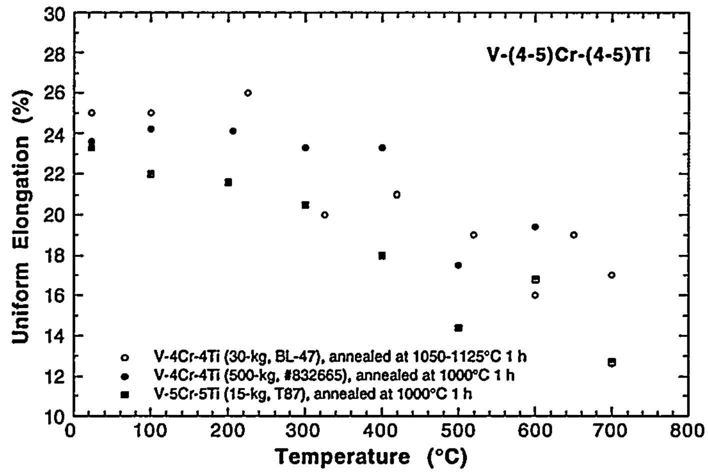

Fig. 3.
Uniform elongation of three heats of nonirradiated V-(4–5)Cr-(4–5)Ti alloys at 23–700°C.

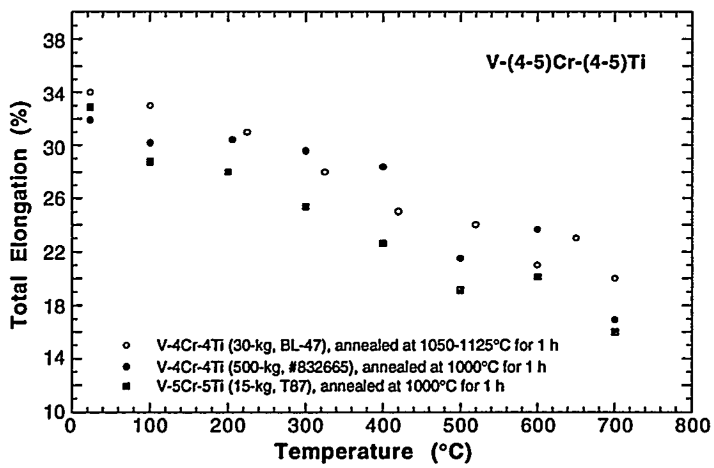

Fig. 4.
Total elongation of three heats of nonirradiated V-(4–5)Cr-(4–5)Ti alloys at 23–700°C.

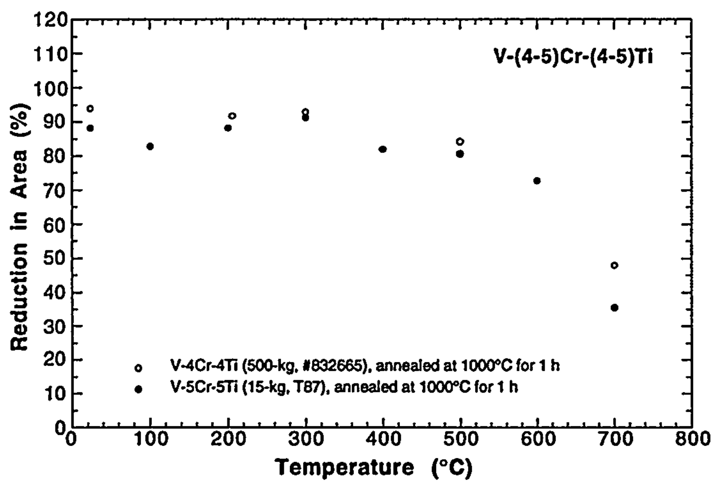

Fig. 5.
Reduction in area of V-4Cr-4Ti and V-5Cr-5Ti alloys at 23–700°C.

(≥6 wt.%) is undesirable from the standpoint of irradiation–induced degradation of material toughness. Likewise, excessive addition of titanium (≥9 wt.%) is believed to be undesirable from the standpoint of higher ductile–brittle transition temperature and, probably, thermal creep.

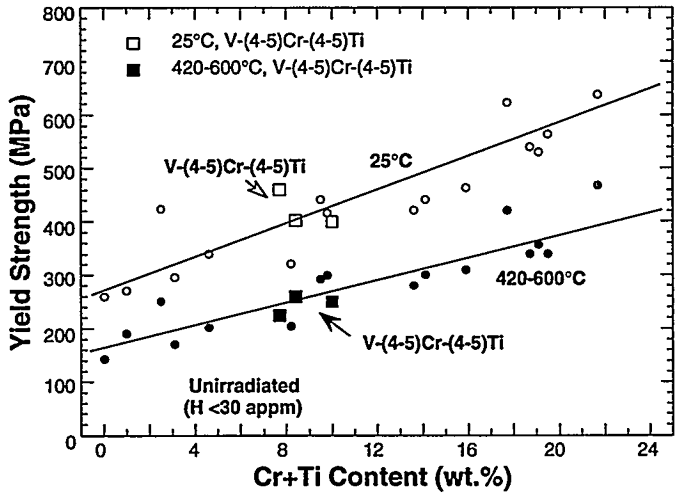

Fig. 6.
Yield strength of non–irradiated V, V–Ti, V–Cr–Ti, and V–Ti–Si alloys at 25°C and 420–600°C as function of combined Cr and Ti content.

Within the limits of data scattering, uniform and total elongation of the laboratory and production heats of V–4Cr–4Ti (Figs. 3 and 4) is similar at 20–700°C, i.e., 15–26 and 20–34%, respectively. However, uniform (12–23%) and total (16–35%) elongation of the laboratory heat of V–5Cr–5Ti is somewhat lower than that of V–4Cr–4Ti for the similar temperature range. Uniform and total elongation decreases monotonically with increasing temperature.

Reflecting the high elongation, reduction in area (Fig. 5) of the production heat of V–4Cr–4Ti and the laboratory heat of V–5Cr–5Ti was significantly large, i.e., ≈80% at 20–600°C. However, reduction in area decreased significantly to <40% at 700°C.

CONCLUSIONS

1. Baseline tensile properties of one production– and two laboratory–scale heats of V–(4–5)Cr–(4–5)Ti alloy were determined at 23–700°C. Yield strength of the alloys was nearly constant at 200–280 MPa at 200–700°C, whereas ultimate strength (330–530 MPa) was slightly lower at ≈200–250°C than at <150°C or >350°C. Yield strength of the V–(4–5)Cr–(4–5)Ti alloys at room–temperature and 420–600°C was consistent with a previously developed correlation between yield strength and the combined content of Cr and Ti of the V–(0–15)Cr–(0–20)Ti alloys.

2. Uniform and total elongation of the laboratory and production heats of V–4Cr–4Ti was similar, i.e., 15–26 and 20–34%, respectively. However, uniform (12–23%) and total (16–35%) elongation of the laboratory heat of V–5Cr–5Ti was somewhat lower than that of V–4Cr–4Ti. Uniform and total elongation decreased monotonically with increasing temperature.

3. Reduction in area of the production heat of V–4Cr–4Ti and the laboratory heat of V–5Cr–5Ti was significantly large, i.e., ≈80% at 20–600°C. However, reduction in area decreased significantly to <40% at 700°C.

4. The reference alloy V–4Cr–4Ti, identified as the most promising candidate alloy for a fusion reactor first–wall structure on the basis of its excellent resistance to irradiation–induced embrittlement, swelling, creep, and microstructural evolution, exhibited excellent baseline tensile properties at temperatures up to ≈650°C. The ratio of uniform to total elongation of the alloy remained constant at ≈0.8 regardless of test temperature, whereas the ratio of yield to ultimate tensile strength decreased monotonically from ≈0.9 at room temperature to ≈0.6 at 700°C, indicating more pronounced work hardening of the alloy at higher temperatures.

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