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Tensile and impact properties of V–4Cr–4Ti alloy heats 832665 and 832864 ☆

T.S. Bray [a,*], H. Tsai [a], L.J. Nowicki [a], M.C. Billone [a], D.L. Smith [a], W.R. Johnson [b], P.W. Trester [b]

[a] *Argonne National Laboratory, 9700 S. Cass Avenue, Argonne, IL 60439, USA*
[b] *General Atomics, P.O. Box 85608, San Diego, CA 92186, USA*

Abstract

Two large heats of V–4Cr–4Ti alloy were produced in the US in the past few years. The first, 832665, was a 500 kg heat procured by the US Department of Energy for basic fusion structural materials research. The second, 832864, was a 1300 kg heat procured by General Atomics for the DIII-D radiative divertor upgrade. Both heats were produced by Oremet-Wah Chang (previously Teledyne Wah Chang of Albany). Tensile properties up to 800°C and Charpy V-notch impact properties down to liquid nitrogen temperature were measured for both heats. The product forms tested for both heats were rolled sheets annealed at 1000°C for 1 h in vacuum. Testing results show the behavior of the two heats to be similar and the reduction of strengths with temperature to be insignificant up to at least 750°C. Ductility of both materials is good in the test temperature range. Impact properties for both heats are excellent – no brittle failures at temperatures above −150°C. Compared to the data for previous smaller laboratory heats of 15–50 kg, the results show that scale-up of vanadium alloy ingot production to sizes useful for reactor blanket design can be successfully achieved as long as reasonable process control is implemented (H. Tsai, et al., Fusion Materials Semiannual Progress Report for Period Ending 30th June 1998, DOE/ER-0313/24, p. 3; H. Tsai, et al., Fusion Materials Semiannual Progress Report for Period Ending 31st December 1998, DOE/ER-0313/25, p. 3). © 2000 Elsevier Science B.V. All rights reserved.

1. Objective

The objective of this task was to determine the baseline tensile and impact properties of both the 832665 and 832864 heats of V–4Cr–4Ti and to add to the V–4Cr–4Ti property database. In particular, tensile testing of both heats was extended to 800°C to assess the performance of the materials in the high-temperature regime.

2. Background

Vanadium-base alloys are promising candidates for fusion reactor applications because of their low-activation and good thermal–mechanical properties and radiation resistance at high temperature. Two large heats of V–4Cr–4Ti were procured in the US in the last few years from Oremet-Wah Chang (formely Teledyne Wah Chang). Heat 832665 is a 500 kg heat procured by the US Department of Energy for basic fusion structural materials research [3]. Heat 832864 is a 1200 kg heat procured by General Atomics for the DIII-D radiative divertor upgrade project. The procurement purpose for the 832864 heat was to develop knowledge and experience in the design, processing, and fabrication of large-scale V-alloy components and to demonstrate the in-service behavior of vanadium alloys in a typical tokamak environment [4–7]. The nominal compositions of the heats are reported in Table 1.

Susceptibility of vanadium-base alloys to low-temperature embrittlement during neutron irradiation may limit the application of these alloys in low-temperature ($\lesssim$400°C) regimes [8–10]. To extend the service window, it is necessary to assess the performance of the materials in the high-temperature regime, i.e., the ≈700–800°C

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* Corresponding author. Tel.: +1-630 252 9957; fax: +1-630 252 9232.

E-mail address: tbray@anl.gov (T.S. Bray).

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Table 1
Chemical composition of heats 832665 and 832864

Heat	Ingot (kg)	Nom. Comp. (wt%)	Interstitial content (wppm)			
			O	N	C	Si
832665	500	V–3.8Cr–3.9Ti	310	85	80	780
832864	1200	V–3.8Cr–3.8Ti	370	120	30	270

Table 2
Tensile test results for heats 832665 and 832864 [1,2]

Heat	Sample no.	Test temperature (°C)	0.2% OS YS (MPa)	UTS (MPa)	UE (%)	TE (%)
832665	133	600	227	413	9.8	18.6
	134	700	238	428	10.6	17.3
	135	750	233	395	9.6	18.4
	137*	750	230	401	7.4	15.8
	136	800	217	357	7.8	15.2
832864	111	26	315	410	19.3	28.5
	112	280	228	345	16.7	23.2
	113	380	228	355	15.3	22.8
	114	600	199	382	10.0	18.7
	115	700	223	398	12.3	20.9
	116	750	174	388	11.5	16.3
	117	800	173	350	10.5	16.3

* Strain rate of 1.1×10^{-4} s^{-1}.

range. While performance at high temperature may be limited by many factors, including helium effects and creep, adequate tensile properties remain an important consideration.

3. Experimental procedure

The reference tensile specimen design for the US Fusion Materials Program has gauge dimensions of $0.76(t) \times 1.52(w) \times 7.6(l)$ mm. The Charpy V-notch impact specimens used were 1/3-size with dimensions of $3.33(t) \times 3.33(w) \times 25.4(l)$ mm with a 30° 0.61 mm deep, 0.08 mm root radius machined notch. For the 832864 heat, sheets of the correct thickness were not available; therefore, an electric discharge machine was used to slice the sheets to the correct thickness to avoid altering the as-rolled microstructure. All specimens were annealed in an ion-pumped vacuum ($<1 \times 10^{-7}$ Torr) at 1000°C for 1 h before testing.

The room-temperature tensile test was conducted in air; elevated-temperature tests were conducted in high-purity flowing argon with a titanium foil impurity getter in a radiant furnace. The tests were performed with an Instron tensile machine; corrected cross-head displacement was used to determine the strain. Strain rates for testing were 1.1×10^{-3} s^{-1} for all tests except for one conducted at 1.1×10^{-4} s^{-1} to investigate strain-rate effects.

The Charpy V-notch impact tests were conducted in air with a Dynatup drop-weight tester. Specimen temperature during the test was measured by a thermocouple that was spot-welded to the end of the specimen. For above-ambient-temperature tests, a hot-air blower provided heating; for below-ambient-temperature tests, liquid nitrogen was used to provide cooling.

4. Results and discussion

The results of the tensile tests are presented in Table 2 and are shown in Figs. 1–3. The current data from the

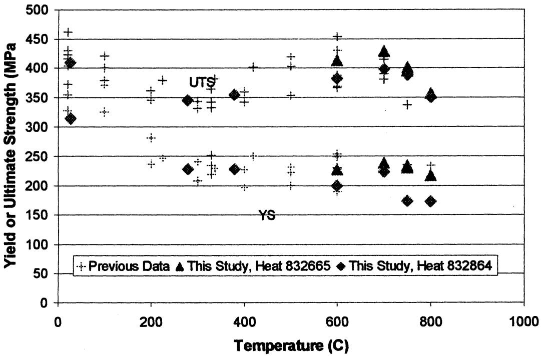

Fig. 1. Ultimate tensile strength and yield strength data for heats 832665 and 832864 [1,2,11–17].

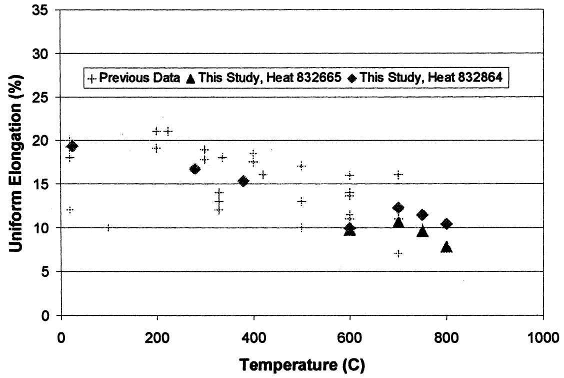

Fig. 2. Ultimate elongation data for heats 832665 and 832864 [1,2,11–17].

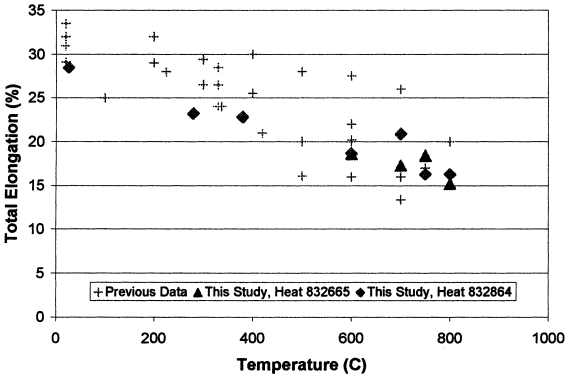

Fig. 3. Total elongation data for heats 832665 and 832864 [1,2,11–17].

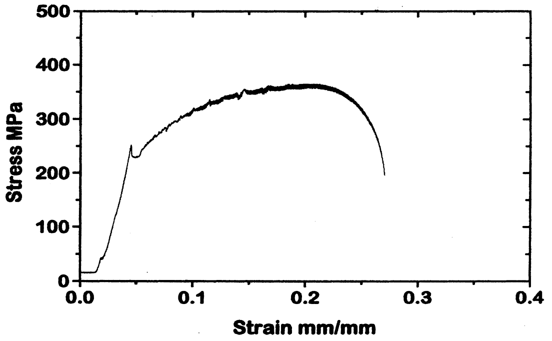

Fig. 4. Stress–strain curve for heat 832864 sample 113.

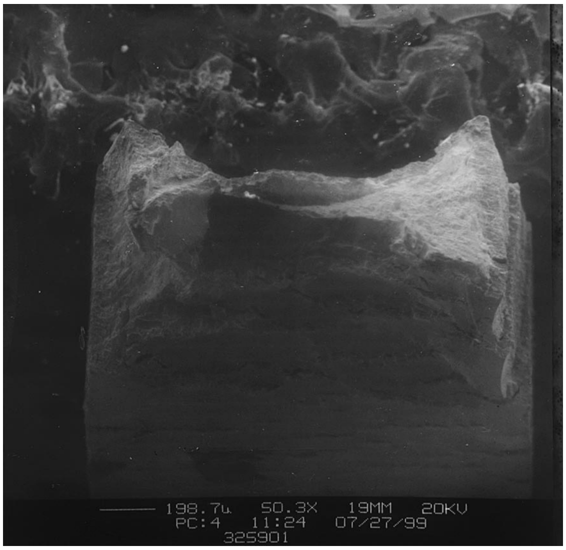

Fig. 5. SEM photograph of tensile specimen 137, heat 832665, showing ductile failure (ET325901).

two heats are compared to previous data for trending purposes. The overall database indicates that degradation of the tensile properties due to high temperatures appears not to be an issue, even approaching 800°C. All specimens display substantial ductility, with uniform elongation ranging from 7.4% to 19.3% and total elongation from 15.2% to 28.5%. The data obtained compare and agree well with previously reported data. Yield strength of the 832864 heat is slightly lower than the group average, possibly because of its lower impurity and silicon content. Not unexpectedly, the 832864 heat exhibits slightly greater ductility. Serrations in the load curve, due to dynamic strain aging, were observed in both materials at 600°C and in the 832864 heat at 380°C. The stress–strain curve for sample 113 of the 832864 heat is shown in Fig. 4. At higher test temperatures, serrations could not be identified. Finally, there appear to be no significant strain-rate effects on tensile properties.

Fractography results show that all failures are ductile; an example of a ductile failure is shown in Fig. 5. Reductions in area for the 832665 samples range from 59% to 73%. Reductions in area for samples 114–117 of 832864 range from 68% to 71%. The results are shown in Table 3.

Table 3
Tensile specimens, reductions in area

Heat	Sample no.	Area reduction (%)
832665	133	64
	134	63
	135	73
	136	70
	137	59
832864	114	68
	115	71
	116	70
	117	68

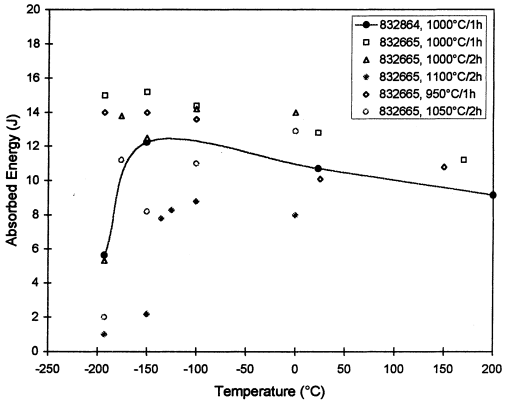

Fig. 6. The Charpy V-notch impact test results.

The impact properties of the two heats are good and comparable. The upper-shelf energy of ≈10–12 J in the 832864 heat is slightly lower than that of the 832665 heat. The transition from upper-shelf to lower-shelf, in good agreement with the data trend, appears to occur at ≈−180°C. Results of the impact tests are presented in Fig. 6 along with previous data [1,18,19].

5. Conclusions

Tensile properties of the 832665 and 832864 heats are good even at temperatures approaching 800°C. Ultimate tensile strength ranged from 350 to 428 MPa. Offset yield strength was 173–315 MPa. Both heats displayed substantial ductilty, with the 832864 heat displaying a slightly greater value. Uniform elongations were 7.4–19.3% and total elongation was 15.2–28.5%. Reductions in area measured from 50% to 73% for both heats. Impact results between the two heats are good and comparable with the transition from upper-shelf to lower-shelf occurring at ≈−180°C.

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