TENSILE AND IMPACT PROPERTIES OF GENERAL ATOMICS 832864 HEAT OF V-4Cr-4Ti ALLOY - H. Tsai, L. J. Nowicki, J. Gazda, M. C. Billone, and D. L. Smith (Argonne National Laboratory), W. R. Johnson and P. Trester (General Atomics)

SUMMARY

A 1300-kg heat of V-4Cr-4Ti alloy was procured by General Atomics (GA) for the DIII-D radiative divertor program. To determine the mechanical properties of this alloy, tensile and Charpy tests were conducted on specimens prepared from pieces of 4.8-mm-thick as-rolled plates, a major product form for the DIII-D application. The tensile tests were conducted at three temperatures, 26, 280 and 380°C, the last two being the anticipated peak temperatures during DIII-D boronization and postvent bake-out, respectively. Results from these tests show that the tensile and impact properties of the 832864 heat are comparable to those of the other smaller V-(4-5)Cr-(4-5)Ti alloy heats previously developed by the U.S. Fusion Materials Program and that scale-up of vanadium alloy production can be successfully achieved as long as reasonable process control is implemented.

OBJECTIVE

The objective of this task was to determine the tensile and impact properties of the 832864 heat of V-4Cr-4Ti in the temperature regime of importance to the DIII-D radiative divertor program.

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. To demonstrate the in-service behavior of vanadium alloys in a typical tokamak environment, and to develop knowledge and experience on the design, processing, and fabrication of full-scale vanadium alloy components, GA developed a plan to fabricate a vanadium alloy structure in the DIII-D radiative divertor modification [1,2]. As part of this project, a 1300-kg heat of V-4Cr-4Ti alloy was procured by GA. This heat was produced by Teledyne Wah-Chang of Albany according to specifications developed by GA with input from ANL and ORNL. Particular attention was given to control of impurities in order to meet the immediate goals for the DIII-D radiative divertor program and future goals for development of vanadium alloys used in advanced fusion systems. The requirements included minimization of Nb, Mo, and Ag for low neutron activation; optimization of Si (400-1000 ppm) to suppress neutron-induced swelling; and control of O, N, C and other impurities to avoid grain-boundary segregation and precipitation of embrittling phases [3]. A detailed report on the production of this heat can be found elsewhere [4,5].

GA has conducted six tensile tests on the 832864-heat material at room temperature [6]. The specimens, with gauge dimensions of 4.06 mm (thick) x 6.35 mm (width) x 25.4 mm (length), were machined from either plate stock (4.8 mm thick) or rod stock (10.2 mm dia.). All specimens were annealed at 1000°C for 1 h in vacuum (<1 x 10^{-5} torr, cryopumped) before the tests. The tests were performed with attached gauge extensometers at a strain rate of 5 x 10^{-4}/s. Results of these tests are summarized in Table 1.

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Table 1. Room-temperature tensile properties of Heat 832864 determined by GA

Specimens Made from	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Total Elongation (%)	Reduction in Area (%)
Plate Stock	306	398	41	93
Rod Stock	299	408	42	88

EXPERIMENTAL PROCEDURE

Specimen Preparation

The ANL test specimens were prepared from two 4.8-mm-thick plates supplied by GA. They were the trimmed edges from two as-rolled plates. To avoid altering the as-rolled microstructure, the test specimens were electro-discharge machined with no further rolling of the pieces.

The tensile specimens were of the SS-3 design, which is the de facto standard for the fusion materials program. The nominal dimensions of the gauge were 0.76 (t) x 1.52 (w) x 7.6 (l) mm, and the longitudinal direction of the gauge was parallel to the final rolling direction of the plate.

The Charpy impact specimens were 1/3-size, 3.3 mm (t) x 3.3 mm (w) x 25.4 mm (l), with a 30°, 0.61-mm-deep, 0.08-mm-root radius machined notch. The notch orientation (i.e., crack propagation direction) was perpendicular to the final rolling direction and into the thickness of the plate. This Charpy specimen design is also a de facto standard and has been used extensively in previous fusion materials tests.

After the machining and cleaning, all specimens were annealed in an ion-pumped vacuum (<1 x 10^{-7} torr) at 1000°C for 1 h before the testing.

Test Procedure

One tensile test each was conducted at room temperature, 280, and 380°C, the last two being the anticipated peak temperatures during the DIII-D boronization and postvent bake-out, respectively. The room-temperature test was conducted in air; the elevated-temperature tests were conducted in high-purity flowing argon. The tests were performed with an Instron machine without an extensometer attached to the specimen gauge. Extensions due to slack in the grip and deformation of the load frame were subtracted from the crosshead displacement to obtain the correct gauge-section extension. The strain rate for all tests was 1.1 x 10^{-3}/s, which is the reference used in many previous fusion materials tensile tests.

All Charpy impact tests were conducted in air with a Dynatup drop-weight tester. Specimen temperature during the impact test was measured with a thermocouple spot-welded to the end of the specimen. For the above-ambient-temperature tests, a hot-air blower was used to provide the heating. For the below-room-temperature tests, liquid nitrogen was used to chill the specimens.

RESULTS AND DISCUSSION

Tensile Tests

The results of the tensile tests are summarized in Table 2 and Fig. 1. The individual tensile curves are shown in Fig. 2. Reduction-in-area measurements and fractographic examinations have not yet been conducted.

Table 2. Tensile properties of 832864 heat determined at ANL

Test Temp. (°C)	Yield Strength[a] (MPa)	Ultimate Tensile Strength (MPa)	Uniform Elongation (%)	Total Elongation (%)
26	315	410	19.3	28.5
280	228	345	16.7	23.2
380	228	355	15.3	22.8

[a] Lower yield point.

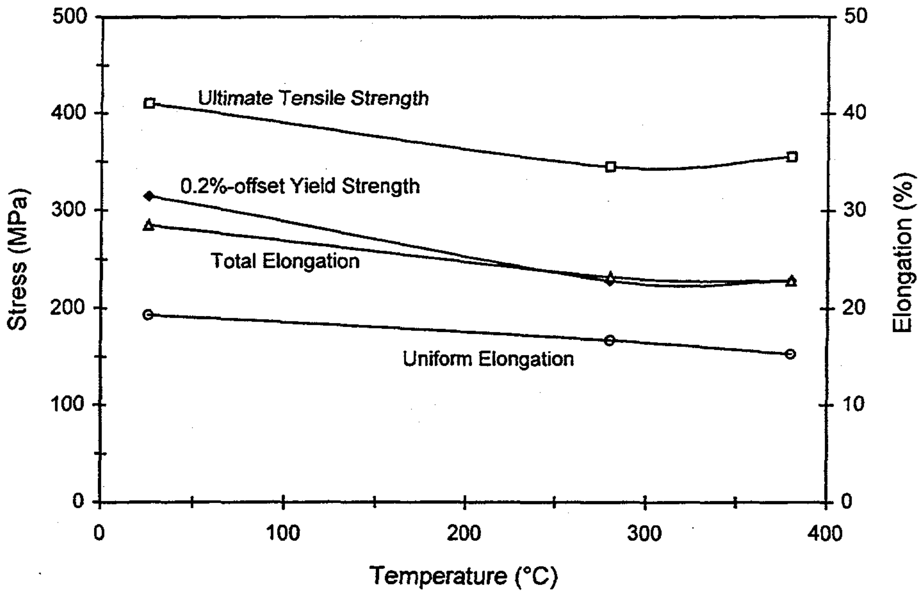

Fig. 1. Tensile properties of Heat 832864 as functions of test temperature

Compared to the data determined by GA (Table 1), the agreement in the room-temperature strengths is good. The slight difference in strain rates (1.1 x 10^{-3}/s in the ANL tests and 5 x 10^{-4}/s in the GA tests) appeared to be a nonfactor, as previous studies have indicated [7]. The room-temperature total elongation data from the ANL test, however, were notably lower than those from the GA tests, ≈29 vs. 41%. The cause of this discrepancy is probably related to differences in specimen size and geometry but has not been fully determined.

Possibly the most insightful assessment of the 832864 heat is to compare its properties with those of the previous V-4Cr-4Ti heats that have been extensively studied. In this regard, the 832864 heat appears to be fairly similar to the other heats, as described below.

In Fig. 3, ultimate tensile strength of the 832864 heat is compared to that in the existing V-4Cr-4Ti data base. The 832864 data are near the center of the established data band. The data also display the characteristic upturn with temperature in the ≈300-600°C range.

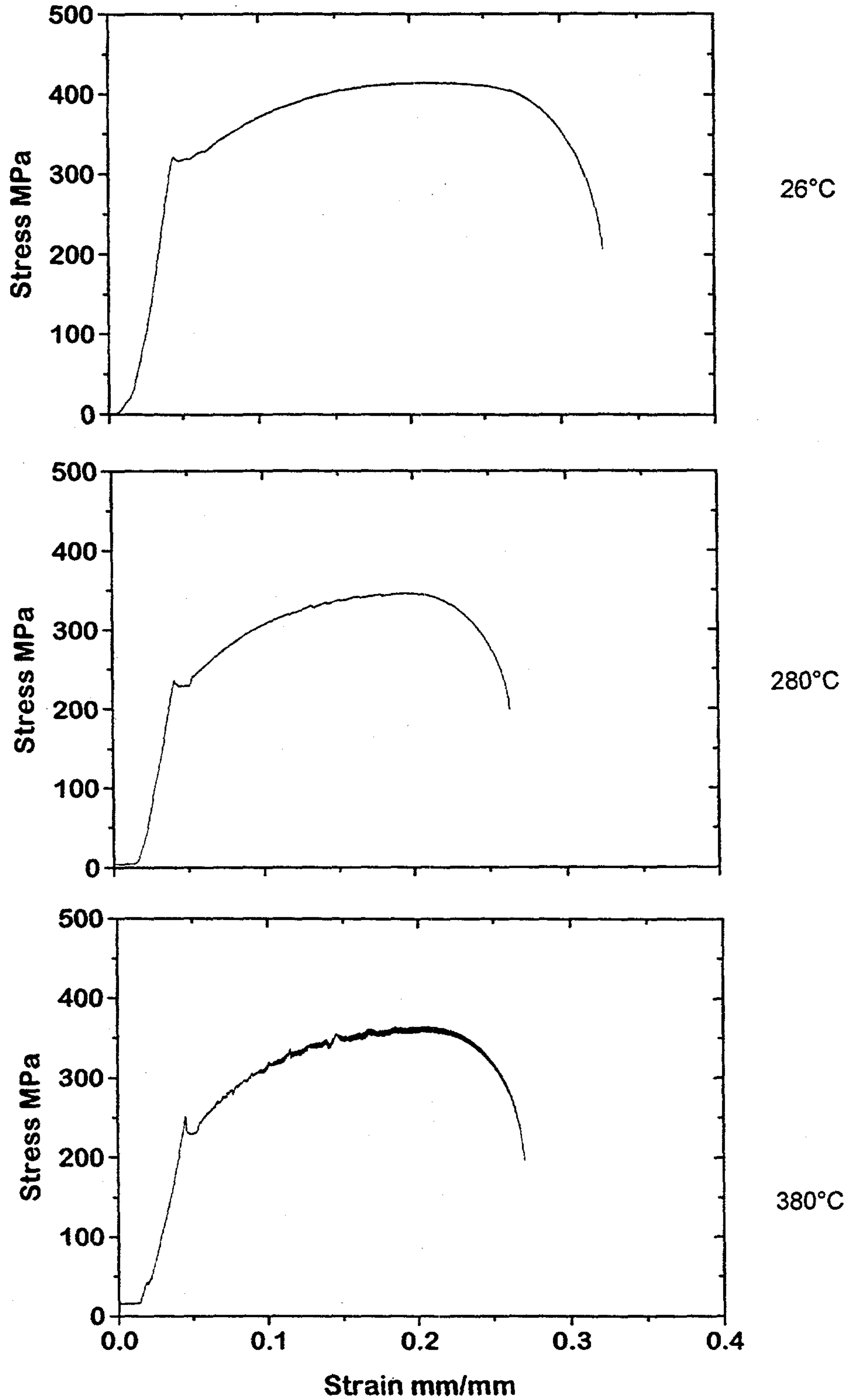

Fig. 2. Tensile plots for individual tests. Note occurrence of dynamic strain aging at 380°C.

Comparison of the yield strength and uniform elongation of the 832864 heat with those in the existing V-4Cr-4Ti data base is shown in Fig. 4. Again, the data for the 832864 heat are comparable with those of the previous heats. The yield strength of the 832864 heat is slightly lower than the group average, possibly because of its lower impurity and Si contents.

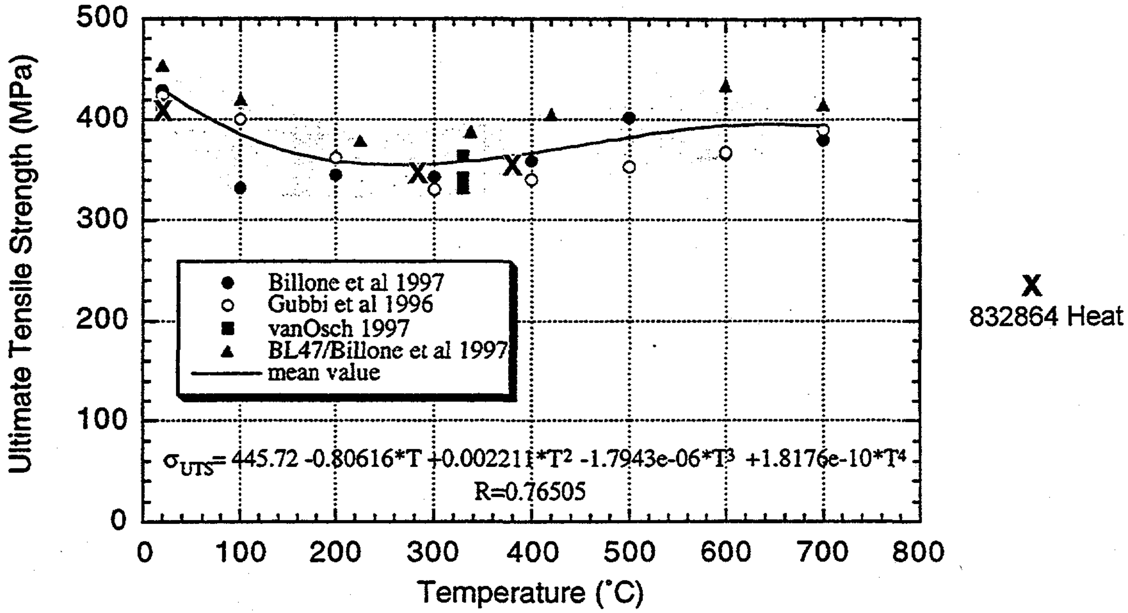

Fig. 3. Comparison of ultimate tensile strength of 832864 heat with that in existing data base [8].

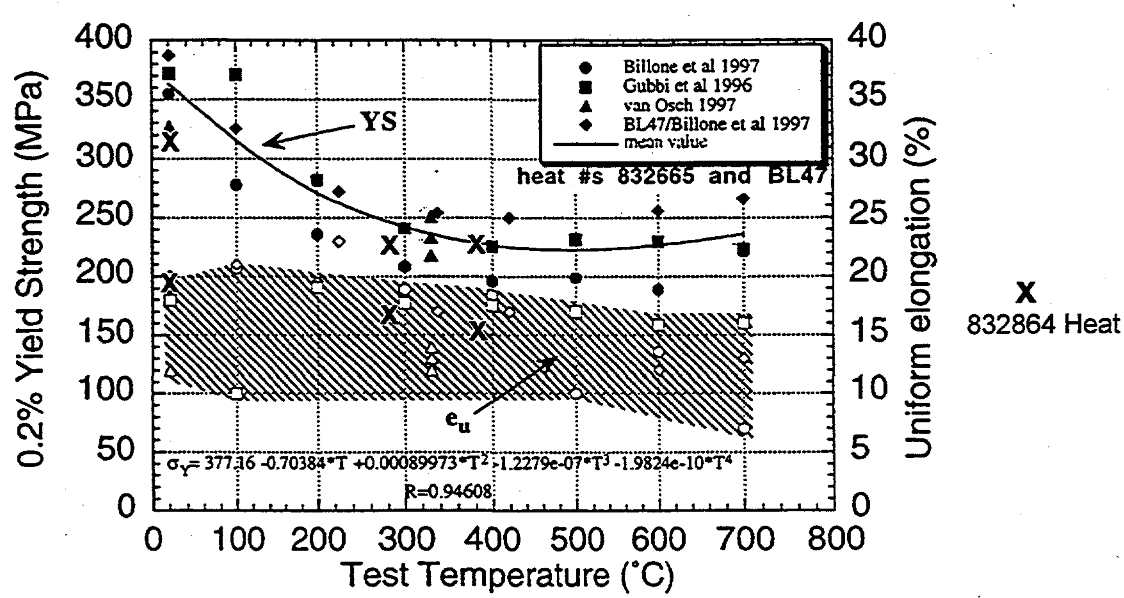

Fig. 4. Comparison of yield strength and uniform elongation of 832864 heat with those in existing database [8].

Likewise, comparison of total elongation data (Fig. 5) revealed no significant differences between 832864 and the other heats.

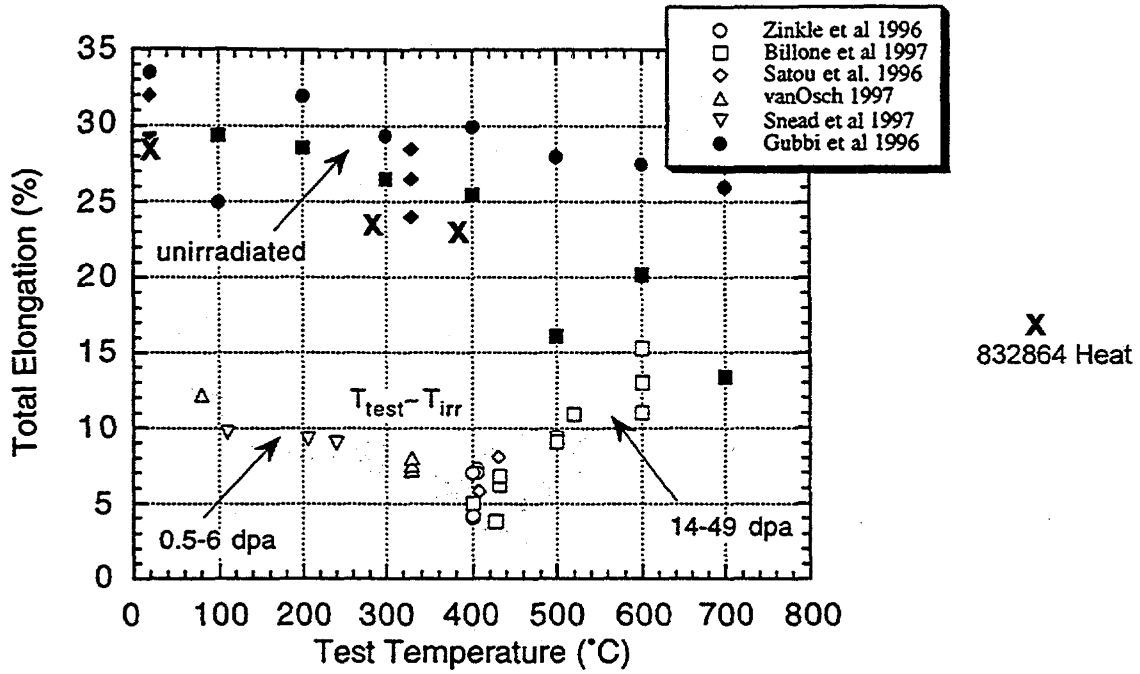

Fig. 5. Comparison of total elongation of 832864 heat with that in existing data base [8]. Neglect open-symbol irradiated data in lower part of chart.

<u>Charpy Impact Tests</u>

The results of the Charpy tests are shown in Fig. 6 along with prior data from the 832665 sibling heat of V-4Cr-4Ti. The upper-shelf energy of ≈10-12 J of the 832864 heat is slightly lower than that of the 832665 heat. Again, this may be due to differences in impurity contents. A transition from upper-shelf to lower-shelf, in good agreement with the data trend, appears to occur at a low temperature, ≈ -180°C. From Fig. 6, we can concluded that the impact properties of the 832864 heat are good and comparable to those of the sibling 832665 heat.

FUTURE ACTIVITIES

Fractographic examination of the test specimens will be completed to determine the fracture mode and reduction-in-area data.

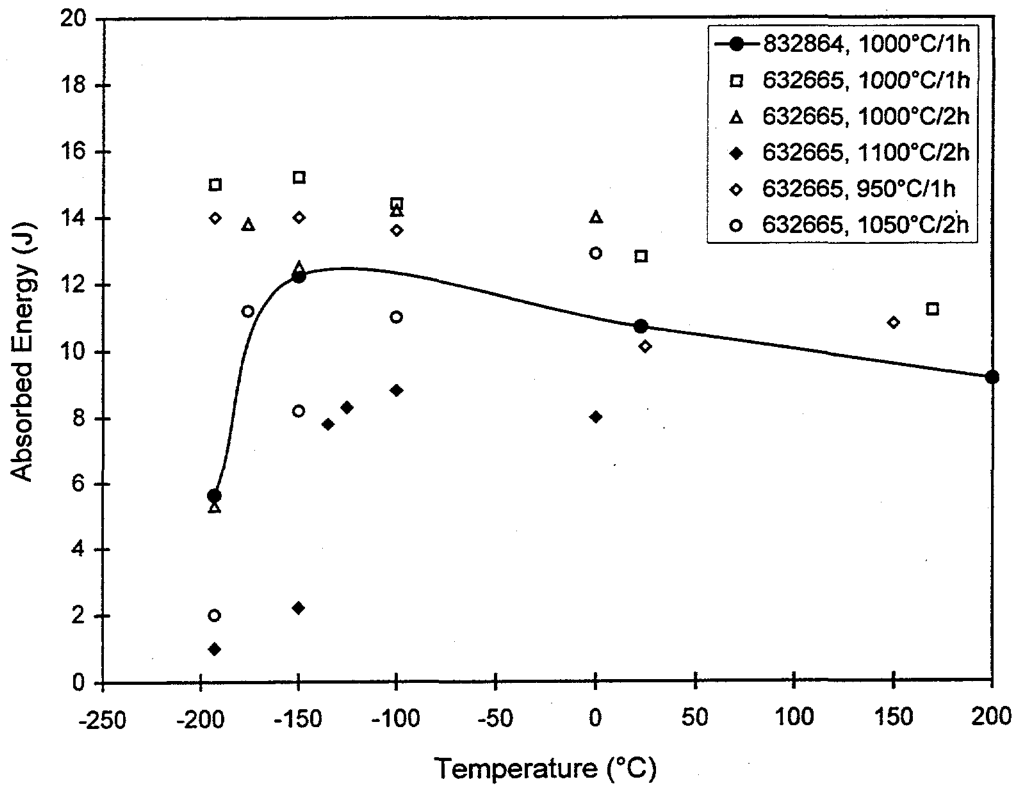

Fig. 6. Comparison of Charpy impact properties of 832864 heat with existing data base [9,10].

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