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EFFECT OF HEAT TREATMENT AND IMPURITY CONCENTRATION ON SOME MECHANICAL PROPERTIES V-15Cr-5Ti ALLOY*

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EFFECT OF HEAT TREATMENT AND IMPURITY CONCENTRATION ON SOME MECHANICAL PROPERTIES OF V-15Cr-5Ti ALLOY*

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The effects of heat treatment and O, N, C, Si, and S impurity level on the yield strength, ductility, and fracture mode for specimens from four different heats of the V-15Cr-5Ti alloy are presented. The heat treatments for the alloy consisted of annealing as-rolled material for one hour at either 950, 1050, 1125, or 1200°C. The total oxygen, nitrogen, and carbon impurity concentration ranged from 400 to 1200 wppm. The Si concentration ranged from 300 to 1050 wppm, and the S concentration ranged from 440 to 1100 wppm. The yield strength and ductility for the alloy, regardless of impurity concentration, exhibited minimum and maximum values, respectively, for the 1125°C anneal. The primary mode of failure for the tensile specimens was transgranular fracture.

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1. Introduction

Observations of the microstructure in ion-irradiated V-15Cr-5Ti specimens by transmission electron microscopy have shown that irradiation-induced dimensional change, i.e., swelling due to voids or gas-filled cavities, in a V-15Cr-5Ti structural material will not be a major concern during the lifetime of a magnetic fusion reactor (MFR). However, these observations also suggest that the ductility of the alloy may be decreased substantially by the presence of a high density of irradiation-produced, disc-shape precipitates in the vicinity of grain boundaries and intrinsic precipitates [1].

The ductility of the irradiated alloy may be improved with a suitable pre-irradiation heat treatment and a maximum concentration of impurities in the alloy. In this paper the yield stress, ductility, and hardness are presented for unirradiated V-15Cr-5Ti alloys with a range of O, N, C, Si, and S concentration and with different heat treatments.

2. Materials and Procedure

The V-15Cr-5Ti alloys (Table 1) were obtained from the Fusion Materials Inventory (FPP) at Oak Ridge National Laboratory and the ANL materials inventory (ANL) at Argonne National Laboratory. Experimental data from an earlier study on a relatively pure V-15Cr-5Ti alloy (TID) are also presented for comparison [2]. Sheet tensile specimens with a nominal thickness of 0.4

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mm and a guage length and width of 7.6 mm and 1.5 mm, respectively, were machined from the as-rolled material. The tensile specimens (wrapped in tantalum foil) were annealed in quartz tubes containing high-purity argon for one hour at either 950, 1050, 1125, or 1200°C and quenched in the capsules in water. The annealed specimen surfaces were subsequently polished to a 0.3-μm finish. Load versus elongation curves for the tensile specimens were obtained at ambient room temperature using a strain rate of 1.1 x $10^{-3}s^{-1}$. The V-15Cr-5Ti alloys were also examined for constituent distribution in the microstructure by use of auger electron spectroscopy (AES), energy dispersive x-ray spectroscopy (EDXS), and scanning auger microprobe (SAM) techniques.

3. Results

The microstructures for the annealed specimens are shown in Figs. 1 and 2. It can be noted in Fig. 1 that precipitates were uniformly distributed in the matrix of the CAM 835-4 (Fig. 1b) and ANL AM 274 (Fig. 1d) alloys, which was not the case for the CAM 834-6 (Fig. 1a) and ANL AM 114 (Fig. 1c) alloys. The TEM microstructures (Fig. 2) show that the grain boundaries in these alloys were relatively free of precipitates regardless of the O, N, C, Si and S concentration in the alloy. The average grain diameters in the recrystallized alloys after the one-hour anneal at 1125°C are listed in Table 2. Since the fabrication history for these alloys could not be documented, the grain diameters in Table 2 may not be directly related to the different O, N, C, Si and S concentrations in the alloys. Nevertheless, the higher purity materials had the largest grain diameter.

The yield stress, total elongation, and hardness of the V-15Cr-5Ti alloys after anneals at 950, 1050, 1125, and 1200°C are shown in Figs. 3, 4, and 5, respectively. The yield stress for the alloys was taken as the stress at the upper yield point. These results show that the V-15Cr-5Ti alloy had a minimum yield stress, maximum total elongation, and minimum hardness after the one-hour anneal at 1125°C. On the basis of these data, the recrystallization temperature for the V-15Cr-5Ti alloy was ~1125°C. The anneals at 1200°C resulted in significant solution hardening of the alloy for total O, N, and C concentrations greater than ~300 wppm. There did not appear to be a simple relationship between the yield stress and total elongation and the impurity concentration in the alloy. The ANL alloys exhibited substantially less total elongation than the CAM alloys after anneals at 1125°C and 1200°C. The primary mode of failure for the tensile speicmens, regardless of impurity concentration, was transgranular fracture with accompanying secondary intergranular cracking.

The lineal SAM analyses suggested that the Cr and Ti concentration in the annealed alloys had a quasi-periodic (~0.1 mm) variation with the variations being more evident for the ANL alloys. The AES analyses have shown significant concentrations (0.1-0.2 w/o) of Si and S in the near-surface layer (~10 nm) of the specimens annealed at 1125°C. However, the concentrations of these impurities in the near-surface layers were not significantly different for the different alloys. The EDXS analyses have shown the presence of high concentrations of Si and S (0.5-1.0 w/o) in the vicinity of grain boundaries in the V-15Cr-5Ti specimens annealed at 1125°C. However, the large variation (0.5-1.0 w/o) in the concentration of these impurities in different grain boundary regions for a particular alloy precluded a correlation of impurity concentration with the yield stress and ductility of the different alloys.

4. Discussion of results

The experimental results obtained in this study suggest that the ductility of the V-15Cr-5Ti alloy can be increased by limiting the heat treatment temperature for the alloy to ~1125°C. An unexpected result from this study was the absence of an obvious relationship between the impurity concentration and the yield stress and total elongation for the alloy. Because of the substantial difference between the total elongation for the CAM alloys and the ANL alloys, there may have been an additional factor that was important for determining the total elongation. Different fabrication schedules for the CAM alloys and the ANL alloys may have contributed to their different response to tensile deformation.

5. Conclusions

1. The recrystallization temperature for the rolled V-15Cr-5Ti alloy was ~1125°C.
2. The mechanical properties of the V-15Cr-5Ti alloy were not determined solely by the O, N, C, Si, and S impurity concentration.
3. The fabrication schedule for the V-15Cr-5Ti alloy may have a major impact on the mechanical properties of this alloy.

6. References

1. B. A. Loomis and D. L. Smith, in Alloy Development for Irradiation Performance, DOE/ER-0045/13, U. S. Department of Energy, (1984) p. 85.
2. J. C. La Vake and C. T. Wang, "Vanadium Purification", CEND-3742-356, UC-25, Metals, Ceramics, and Materials, TID-4500, 54th Edition, November 1969.

Table 1. Impurity concentrations in V-15Cr-5Ti alloys containing a nominal 15 w/o Cr and 5 w/o Ti.

V-15Cr-5Ti Source	Concentration (wppm)				
	C	N	O	Si	S
FPP CAM 834-6	320	460	310	700	1100
FPP CAM 835-4	170	520	230	1050	880
ANL AM 114	195	16	205	670	500
ANL AM 274	230	138	810	500	440
TID-4500	130	90	100	300	--

Table 2. Average grain diameter in recrystallized V-15Cr-5Ti alloys.

Alloy	Average Grain Diameter(mm)
	1125°C
FPP CAM 834-6	0.020
FPP CAM 835-4	0.015
ANL AM 114	0.050
ANL AM 274	0.020
TID-4500	0.080

Figure Captions

Fig. 1. Microstructure for V-15Cr-5Ti alloys after the 1125°C anneal: (a) CAM 834-6, (b) CAM 835-4, (c) ANL AM 114, (d) ANL AM 274.

Fig. 2. TEM microstructure for V-15Cr-5Ti alloys after the 1125°C anneal: (a) CAM 834-6, (b) CAM 835-4, (c) ANL AM 274, (d) ANL AM 114.

Fig. 3. Yield stress of V-15Cr-5Ti alloys.

Fig. 4. Total elongation of V-15Cr-5Ti alloys.

Fig. 5. Hardness of V-15Cr-5Ti alloys.

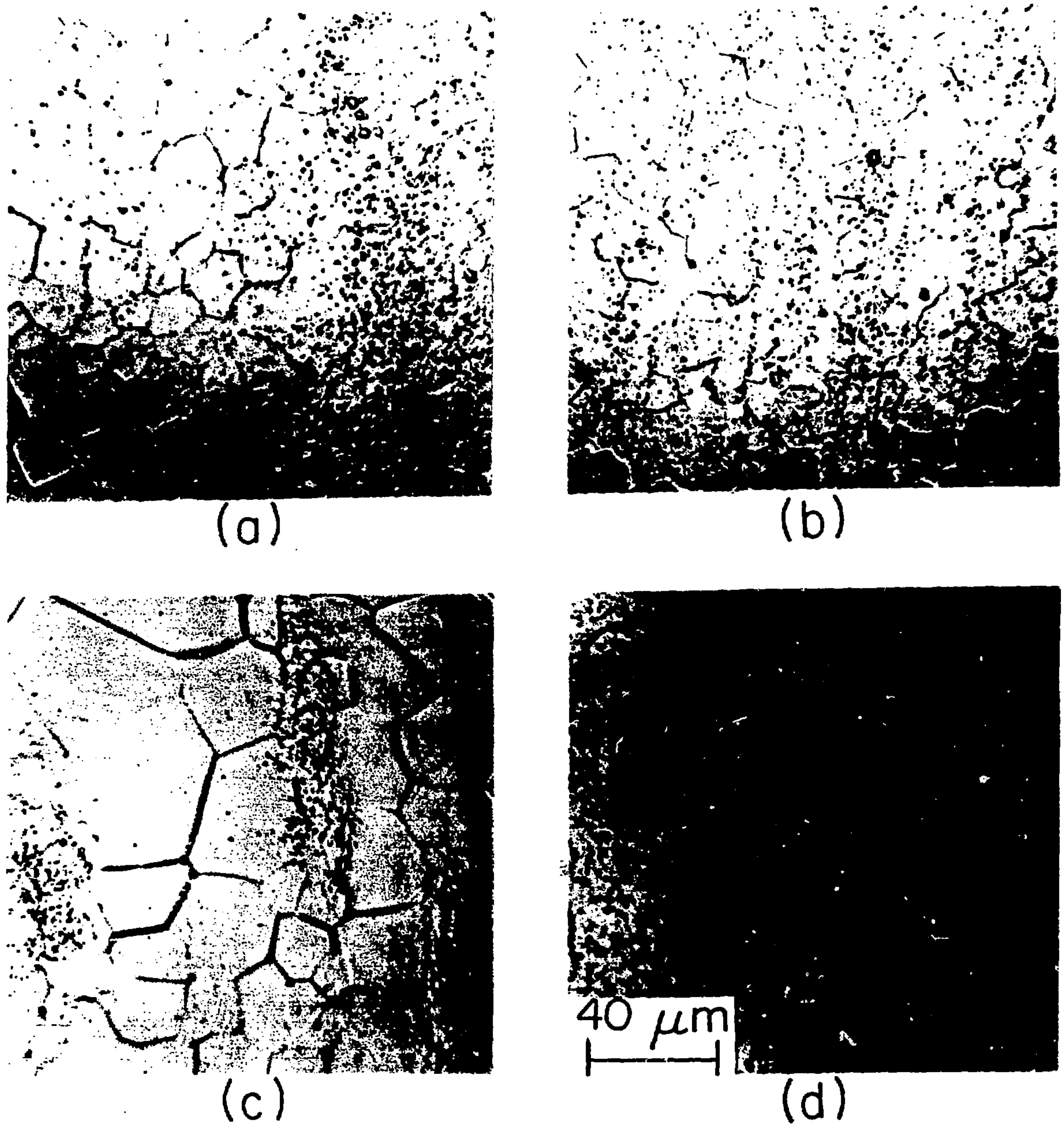

Fig. 1. Microstructure for V-15Cr-5Ti alloys after the 1125°C anneal: (a) CAM 834-6, (b) CAM 835-4, (c) ANL AM 114, (d) ANL AM 274.

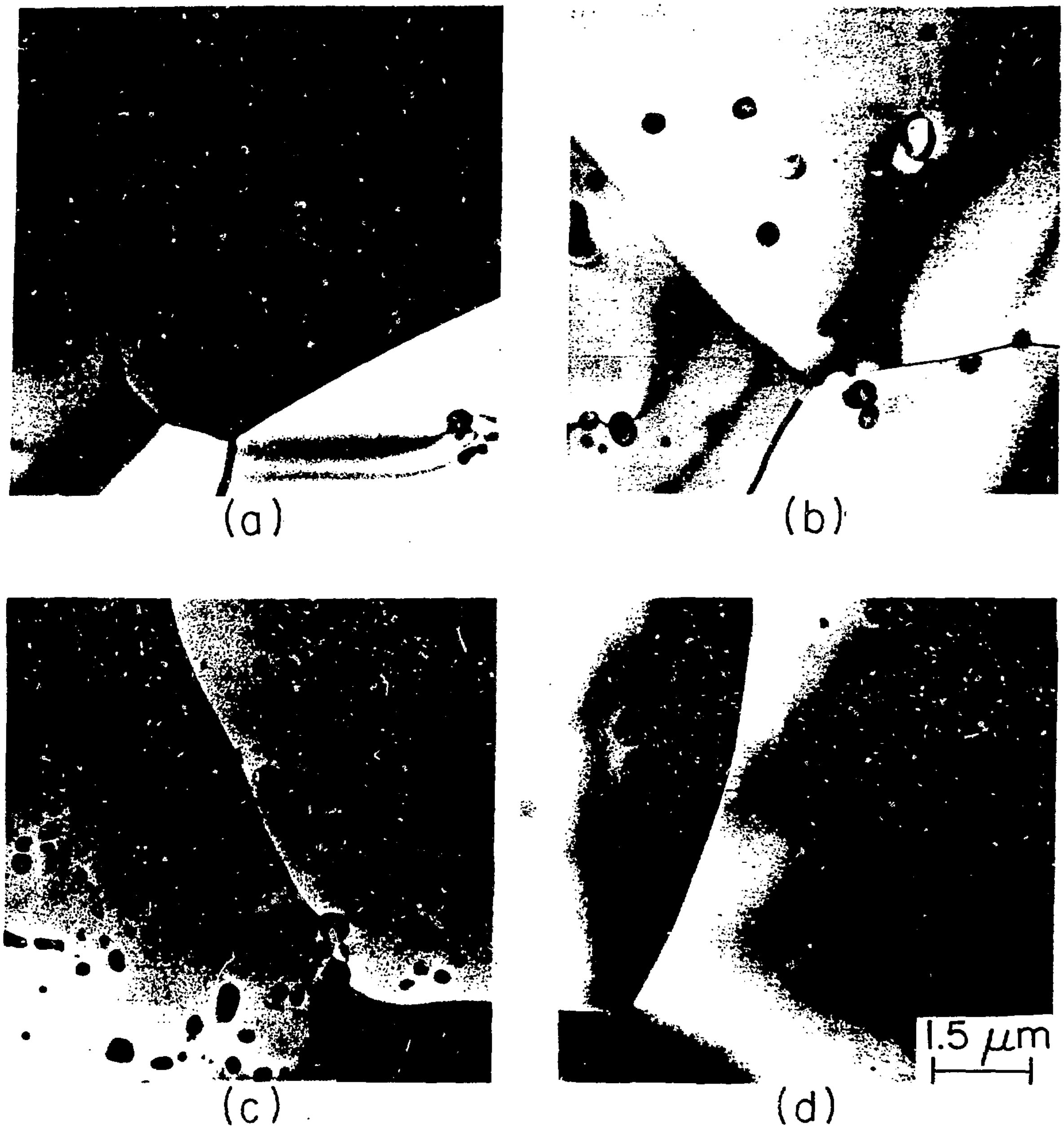

Fig. 2. TEM microstructure for V-15Cr-5Ti alloys after the 1125°C anneal: (a) CAM 834-6, (b) CAM 835-4, (c) ANL AM 274, (d) ANL AM 114.

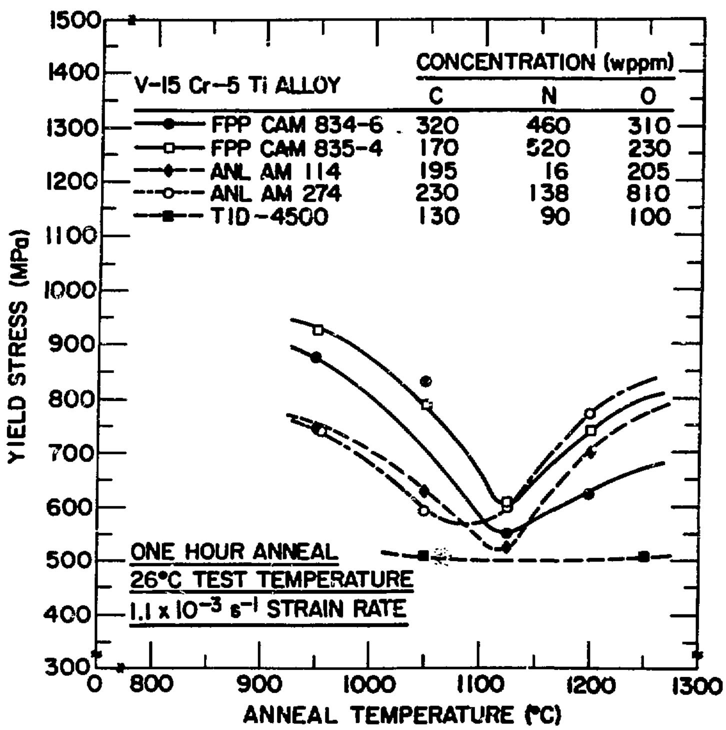

Fig. 3. Yield stress of V-15Cr-5Ti alloys.

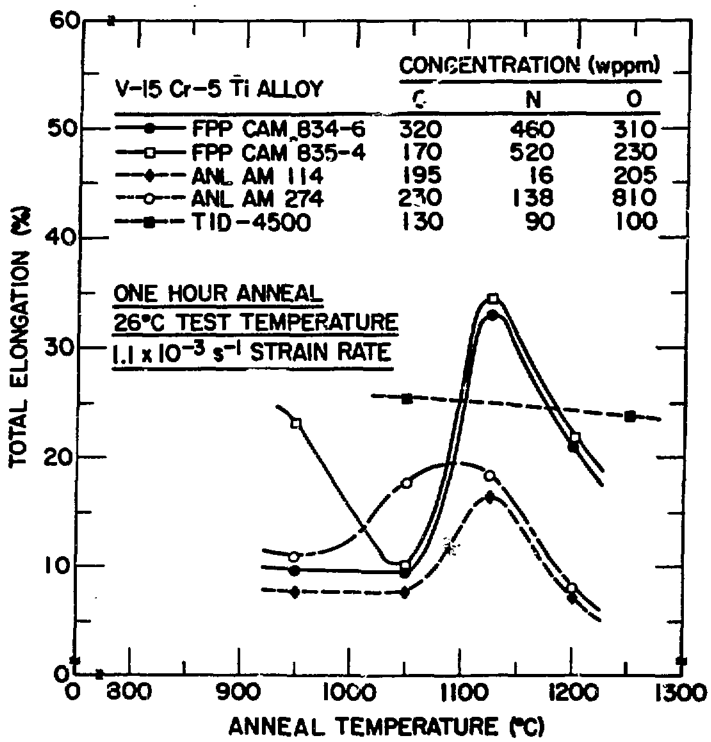

Fig. 4. Total elongation of V-15Cr-5Ti alloys.

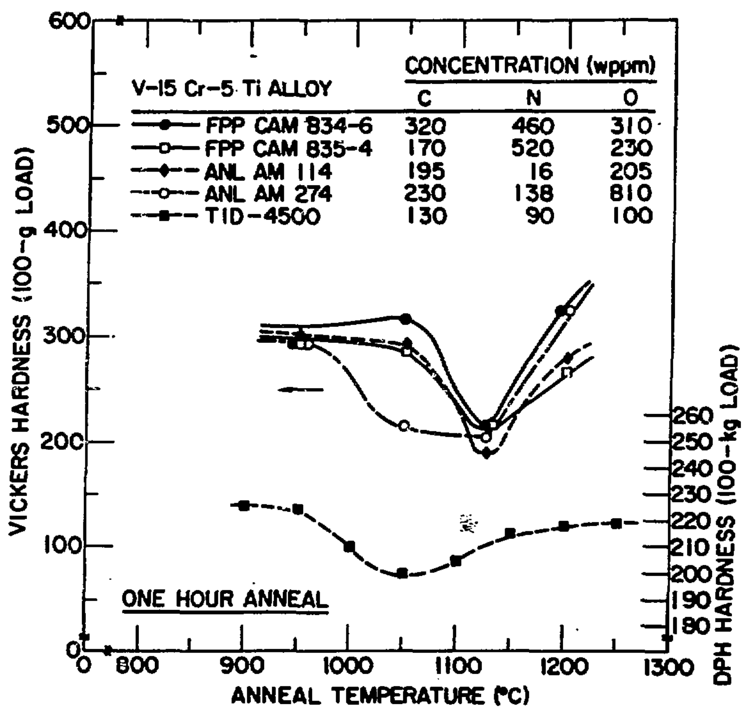

Fig. 5. Hardness of V-15Cr-5Ti alloys.