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Effect of Helium Implantation on Tensile Properties of V-Ti-Cr-Si Type Alloy

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Helium implantation of 50at.ppmHe by cyclotron accelerator was adopted to study helium effect on tensile properties of the V-5Ti-5Cr-1Si-Al-Y type alloy. Tensile tests were conducted at temperatures ranging from room temperature to 850 °C with strain rates from 6.7×10^{-5} to 6.7×10^{-3}/s. Increase of yield stress was not appreciable in helium-implanted specimens except for 450 °C. Intergranular fracture mode was observed specimens tested at temperatures above 450 °C. Decrease of elongation was observed at all testing temperatures. Relationship between tensile strength and decrease of elongation was discussed.

KEYWORDS: Vanadium alloy, fusion materials, low activation materials, helium embrittlement, tensile propertie

1. Introduction

Vanadium alloys are considered to be candidate structural materials for fusion reactor, because of their advantages, such as low induced radio-activity, high-heat loading capability, good mechanical properties at high temperatures, low swelling under irradiation at high-neutron fluence, good compatibility with liquid lithium.[1] In fusion reactor environment, helium generation by (n,α) reaction is considered to be about 500at.ppmHe for vanadium after 10MWy/m^2 operation. Helium may segregate at grain boundary and reduce its strength. It is important to understand the helium effects on the mechanical properties of the vanadium alloy. The V-Ti-Cr-Si type alloys containing Al and Y were developed as proof-oxidation and irradiation resistant materials for fusion reactor applications[2].[3] Various techniques have been adopted to study helium effects on mechanical properties of the alloy.[4] In this paper, the results of implantation experiment with relatively high amount of helium compared to displacement damage are described in order to study the resistance against helium embrittlement of the alloy.

2. Experimental

The chemical composition of the V-5Ti-5Cr-1Si-Al-Y alloy is given in table 1. The preparation procedure of the alloy was described earlier.[5] Tensile specimens and disks for transmission electron microscopy were punched out from 0.25mm thick sheets. The tensile specimen had a gauge section of 5mm long and 1.2mm wide. These specimens were annealed at 1100 °C for 3.6ks in a vacuum of 5×10^{-3}Pa to obtain a fully recrystallized condition with grain size of about 20μm. Specimens of pure vanadium, with the grain size of about 30μm after annealing at 900 °C for 1.8ks, were also examined for comparison.

Helium ion of 36MeV was implanted by Tohoku University cyclotron accelerator using the materials irradiation chamber. To obtain uniform helium distribution along the implanted direction, the tandem-type energy degrader with foils of 525 steps was used.[6] Total amount of helium calculated from implanted fluence in the specimen was evaluated about 50 at.ppmHe with displacement of about 0.02 dpa. The helium ion beam was scanned by 1Hz horizontally and 10 Hz vertically. Specimens of 8 tensile ones and 14 disks were fixed on a water-cooled holder by indium solder. Therefore, the specimen temperature during implantation was kept below melting point of the solder i.e. 156 °C. Tensile tests were carried out at temperatures ranging from room temperature to 850 °C and at strain rates from 6.7×10^{-5} to 6.7×10^{-3}/s in a vacuum less than 2×10^{-3}Pa after implantation. Fracture mode was characterized by a scanning electron microscope(SEM). Reduction in area and fraction of intergranular fracture surface were measured by computerized digitizing system. Microstructures of as-implanted specimen or post-implantation annealed specimens i.e. 650 or 850 °C for 3.6ks, were observed by a transmission

Table 1: Chemical analysis of vanadium alloy (in wt.%, nominal composition in brackets)

	V	Ti	Cr	Si	Al	Y	C	O	N
V-5Ti-5Cr-1Si-Al-Y	Bal.	4.97	4.01	0.85	0.95	0.77	0.0126	0.014	0.0054
		(5.0)	(5.0)	(1.0)	(1.0)	(1.0)			

electron microscope.

3. Results

3.1. Stress–strain curves

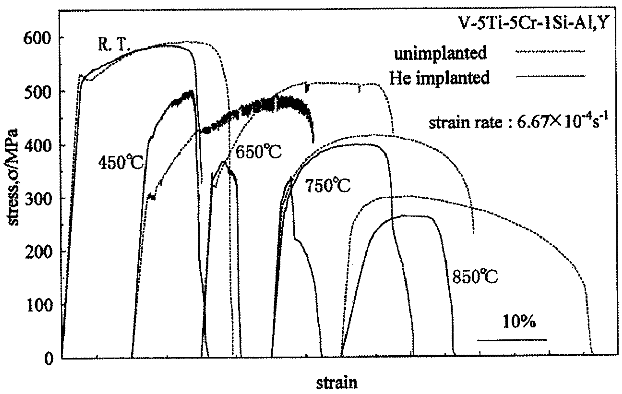

Fig.1 Typical stress-strain curves of the V-5Ti-5Cr-1Si-Al-Y alloy at various test temperatures. Helium was implanted about 50at.ppm.

Typical stress-strain curves of the V–5Ti–5Cr–1Si-Al-Y alloy are shown in Fig.1. In both of helium-implanted and un-implanted conditions, serrated portion are observed in the curves of the alloy tested at 450 and 650 ℃. In un-implanted pure-vanadium, serration was observed in those at 350 and 450 ℃. After implantation, the serration in pure-vanadium was disappeared at 450 ℃. The serration in the strain-stress curves is caused by dynamic strain aging due to impurity atoms such as oxygen and nitrogen. The impurities trapped in the defects introduced by helium implantation can influence the serration.

3.2. Tensile properties

3.3. Dependence on strain rate of tensile properties

Results of the tensile tests such as yield stress, tensile strength and elongation of unimplanted and helium-implanted specimens are shown in Fig.2. Increase of yield stress is not appreciable in helium-implanted al-

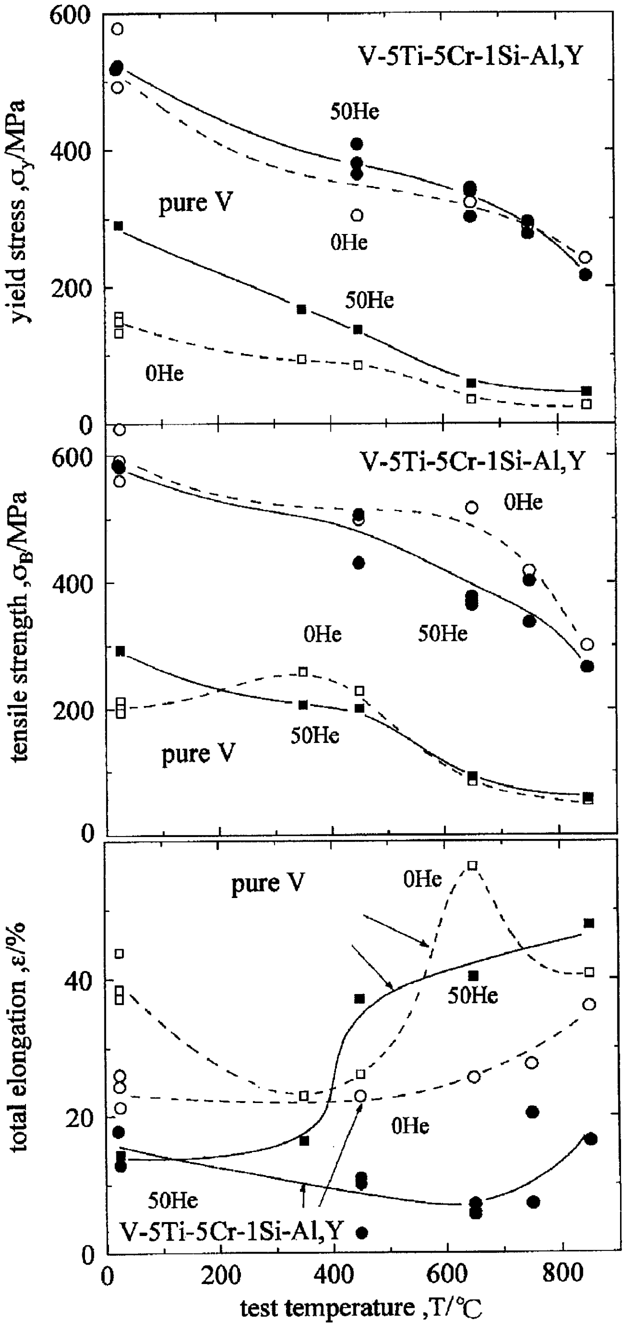

Fig.2 Tensile properties of helium-implanted V-5Ti-5Cr-1Si-Al-Y alloy and pure vanadium tested at temperatures from room temperature to 850 ℃.

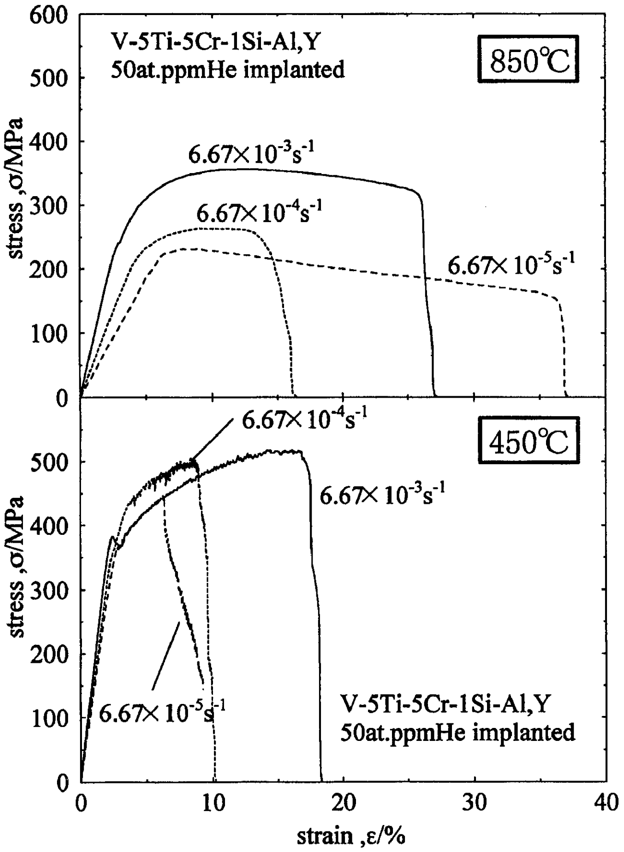

Fig.3 Typical stress-strain curves of helium-implanted V-5Ti-5Cr-1Si-Al-Y alloy tested at 450 or 850 °C with various strain rates.

loy except for 450 °C testing. Increase of yield stress is observed in pure-vanadium. The level of the hardening is decrease with testing temperatures.

Tensile strength of the implanted alloy shows almost the same trend of the unimplanted one except for 650 °C testing. The decrease of tensile strength at 650 °C is corresponding to decrease of elongation. The maximum tensile strength of unimplanted vanadium is observed at 350 °C, that is corresponding to dynamic strain aging. Helium implanted vanadium shows increase of strength at room temperature, decrease at 350 and 450 °C.

Total elongation of the helium implanted alloy decreases to the level of 15% at room temperature and to 6.2% at 650 °C. At 850 °C, elongation becomes to 16%. Total elongation of unimplanted vanadium is 40% at room temperature. At 350 or 450 °C, elongation decreases to about 25%. Helium implanted vanadium shows decrease of elongation at room temperature. At higher temperature above 450 °C, elongation is recovered.

Stress-strain curves of the alloys tested with various strain rates are shown in Fig.3. Tensile strength increases with strain rates at 850 °C testing. Yield stress does not varied with strain rate of the ranging from 6.7×10^{-5} to 6.7×10^{-3}/s at 450 °C. Tensile strength increases with the strain rate. The increase corresponds to the change of uniform elongation with the strain rate. Total elongation of the specimen tested at 450 °C decreased with the strain rate. It is possible that He atoms are swept to grain boundary by moving dislocations more effectively under low strain rate condition.

3.4. SEM observation

Fracture mode of all the unimplanted alloy was ductile at the testing temperature range. Helium implanted alloy tested at room temperature showed ductile mode. Mixed fracture mode was observed at higher than 450 °C. Intergranular fracture surface was observed in small part. Segregation of helium atoms could decrease the grain boundary strength, so that intergranular surface was observed. In case of pure vanadium, higher reduction in area, almost 100%, was observed even after helium implantation.

Figure 4 shows intergranular fracture surface of the alloy tested at 850 °C. Relatively smooth surfaces of grain boundary are observed in the specimen tested with the strain rate of 6.7×10^{-3}/s. The surface of the fractured specimen tested with the strain rate of 6.7×10^{-5}/s is similar to that of 6.7×10^{-4}/s. These morphology of the surfaces might indicate helium-related segregation at the grain boundary caused the intergranular fracture.

Figure 5 shows reduction in area and fraction of intergranular fracture surface of the helium-implanted alloy. At 450 °C, reduction in area decreases with strain rate. At 850 °C, reduction in area does not vary with strain rate. Fraction of intergranular fracture surface increases with strain rate both at 450 and 850 °C. The fraction at 850 °C is about three times as large as that at 450 °C.

4. Discussion

Some of microstructures of the helium implanted alloy were reported in elsewhere.[4] In as-implanted specimen, fine black-dots were observed. After post-implantation annealing at 650 °C, the size of the defects became larger. Defects free zone was observed along grain boundaries, but no bubbles was observed. Disloca-

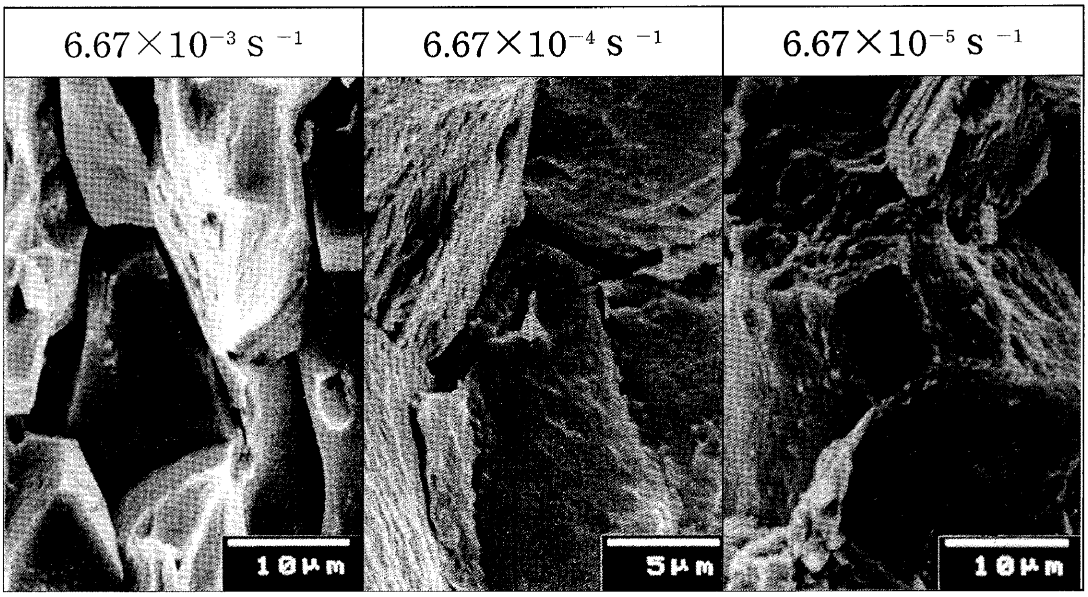

Fig.4 Scanning electron microscopy of the fracture surface of V-5Ti-5Cr-1Si-Al-Y alloy tested at 850 °C with various strain rates.

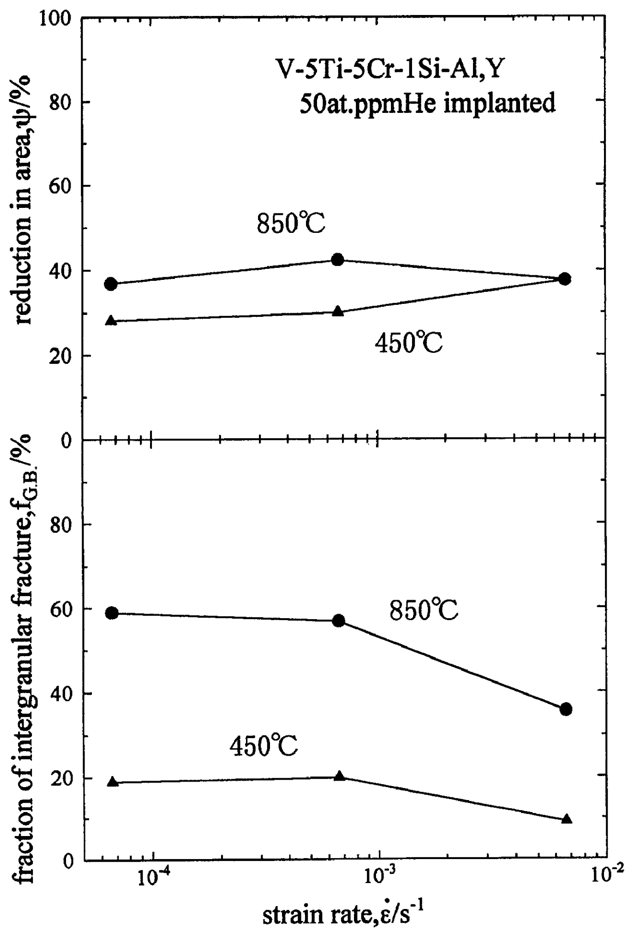

Fig.5 Strain rate dependence of reduction in area and fraction of intergranular fracture of helium-implanted V-5Ti-5Cr-1Si-Al-Y alloy tested at 450 or 850 °C.

tion loops of about 200nm diameter were observed in the specimen annealed at 850 °C. Helium bubbles were observed both on grain boundary and in the matrix. The size of bubble on the grain boundary was larger than that in the matrix. Intergranular fracture was observed in the specimens tested at 450 °C and higher ones. After testing at 850 °C, helium bubbles were observed both in the grain boundary and in the matrix. These results suggested that segregation of implanted helium caused the degradation of grain boundary strength.

The fraction of intergranular fracture surface depended on strain rate. It might be caused by the difference in the concentration of helium atoms on the grain boundary, which were swept by moving dislocations.

After post-implantation annealing at 850 °C or deformation at 850 °C, helium bubbles were observed on grain boundary, but no bubbles were observed in the specimen annealed at 650 °C. These observations indicated that invisible helium atoms might affect grain boundary strength below 650 °C testing. Segregation of helium atoms on grain boundary was larger at 850 °C than at 650 or 450 °C. Decrease of elongation was smaller at 850 °C than at 650 or 450 °C. Therefore, lower concentration of helium on grain boundary caused intergranular fracture at lower testing temperature. When intergranular fracture occurs, fracture stress of grain boundary must be smaller than that of matrix and at the same time deformation stress must be larger than the grain boundary strength. In the case of 850 ℃ testing, grain boundary strength decreased by helium atom segragated at grain boundary, which could defused from matrix and swept by moving dislocation, however, deformation stress was too small for fracture to occur at grain boundary. On the other hand, helium concentration on grain boundary tested at 450 ℃, was small but deformation strength was larger than grain boundary strength, so that intergranular fracture occured. The level of tensile strength of the alloy was almost constant at temperatures from 200 to 650 ℃. With increase of testing temperature, helium segregation on grain boundary became higher. Therefore, the specimen tested at 650 ℃ showed the lowest elongation compared to others.

Summary

Effects of helium on tensile properties of V-5Ti-5Cr-Si-Al-Y alloy were studied after implantation to 50at.ppmHe. Intergranular fracture surface was observed at 450, 650 and 850 ℃ testing after helium implantation. Elongation decreased with the strain rates lower at ranging from 6.7×10^{-3} to 6.7×10^{-5}/s at 450 ℃. The relationship between tensile strength and decrease of elongation was discussed, in connection with earlier observation that helium bubbles were observed in grain boundary and matrix of the specimen tested at 850 ℃.

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