Microstructure, Mechanical Properties and Fracture Behavior of α Particle Irradiated Type 316 Stainless Steel

著者	Miyahara Kazuya, Sakamoto Yasuhiro, Itoh Akira, Kayano Hideo, Hosoi Yuzo
journal or publication title	Science reports of the Research Institutes, Tohoku University. Ser. A, Physics, chemistry and metallurgy
volume	35
number	2
page range	359-366
year	1991-03-05
URL	http://hdl.handle.net/10097/28354

Microstructure, Mechanical Properties and Fracture Behavior of α Particle Irradiated Type 316 Stainless Steel*.

Kazuya Miyahara**, Yasuhiro Sakamoto**, Akira Itoh**, Hideo Kayano*** and Yuzo Hosoi**

(Received January 19,1991)

Synopsis

The present work is a research of the effect of helium on the microstructure, mechanical properties and fracture behaviors of a type 316 austenitic steel. Helium implantation was performed by 30-MeV α-particle injection on very small size specimens, using a cyclotron. Average helium content in a He-deposited region was up to 2000 appm He. In the case of 2000appm He implantation, intergranular fracture was sometimes observed on the helium deposited region after tensile test at room temperature. At elevated temperature test, however, this material showed the transition of fracture mode from transgranular-ductile fracture at 773K to intergranular fracture at 873. In the case of 500 appm He implantation, the transition of fracture mode was recognized at a temperature range of 873K to 973K.

---

* The 1865th report of Institute for Materials Research
** Department of Materials Science and Engineering, Nagoya University, Furoh-cho, Nagoya, 464

*** The Oarai Branch, Institute for Materials Research, Tohoku University, Oarai, Ibaraki, 311-13

I. Introduction

Ductility loss or brittle fracture of the first wall structural materials due to the helium generated by (n,α) reaction with fusion neutrons, is considered to be one of the important problems to be solved for the development of fusion materials. The research of this area is still very active[1-3]. Recently, Mansur and Grossbeck reviewed the various aspects of the mechanical property changes induced by helium, and discussed the effects of helium level (He/dpa) and strain rate in tensile and creep test on the ductility of irradiated structural materials[4].

The present work is performed to investigate the mechanical property change, especially, fracture mode of a type 316 stainless steel which contains high concentration of helium (500-2000 appm He) injected by a cyclotron, in tensile tests at room temperature and elevated temperature.

II. Experimental

The material used in this work is thin foils of a type 316 austenitic steel (27.5μm thick). The chemical compositions of the material as followings, C:0.05wt%, Ni:10.4%, Cr:16.9%, Mo:2.2%, N:0.066%. The foils enclosed in a silica tube in vacuum were solution treated at 1373K for 3.6ks and quenched into water. 3.0 mm diameter disks for transmission electron microscope (TEM) observation and very small specimens for tensile test (gauge length; 5mm, gauge width; 1.2mm, total length; 12.5mm) were die punched from the foils after heat treatment.

Helium was injected by 30-MeV α-particle bombardment, by using a SF cyclotron of Institute of Nuclear Study (INS), the University of Tokyo, and the bombardment was made on the deck of 4 foil specimens of the 316 steel, inserting 0 to 4 sheets of aluminum foils of 7μm thickness and a carbon foil of 250μm thickness into the beam pass as an energy absorber. Calculation of the projected range based on the E-DEP-1 code and the reported stopping powers shows that this irradiation condition generates a uniformly He-implanted region of 20μm width around the midst of the third specimen from the top of the deck of the 316 steel specimens and around the depth center of the other material specimen foils[5,6]. Average helium content and displacement damage in a He-deposited region are calculated to be about 500 to 2000 appm He and 0.1 to 0.4 dpa in the 316 steel specimen. The foil specimens were held down by the carbon foil(250μm thick) on the specimen holder of aluminium which was cooled by flowing water. As described in the paragraph of the experimental results, however, the temperature of the specimen during the bombardment is estimated to be about 673 to 773K, although the specimen temperature may vary depending on the contact between the specimens and the holder(7).

After the helium implantation, tensile tests (strain rate; 1×10^{-3}/s) at room temperature and at elevated temperatures of 773 to 973K in the atmosphere of argon gas, scanning electron microscope (SEM) observation of fracture surface of the specimens and transmission electron microscope (TEM) observation of helium-bubble distribution in the He-deposited area were made. In the high temperature tensile test at 773 to 973K, specimens were heated up to the test temperatures within 900s, held for 900s and then tested.

III. Experimental Results and Discussions

1. Helium bubble formation and distribution

Fig.1 shows the helium bubbles formed in the grain interior and at the grain boundary of the 316 stainless steel. A general tendency that a higher number density and larger size of helium bubbles are formed at the grain boundaries than in the grain interior is recognized. This tendency is also suggested quantitatively in Fig.2 which shows the summarized size distributions of helium bubbles. In the measurement of number density of bubbles at grain boundary, the volume of grain boundary area is roughly assumed to be the product of the area of grain boundary image on the negative plate and specimen thickness.

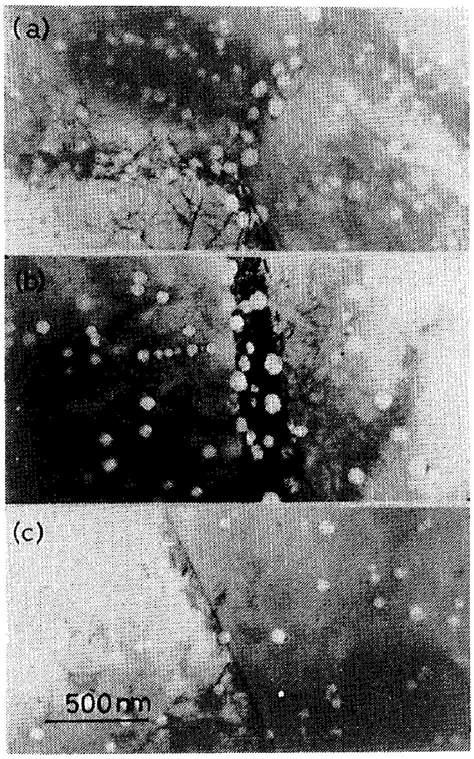

Fig.1 Helium bubble formation and distribution in the specimen containing 2000 appm He.

The mechanism of helium bubble growth in the present experiment of the 316 steel was explained by "pressure driven model", because the number of helium atoms measured by a beam current

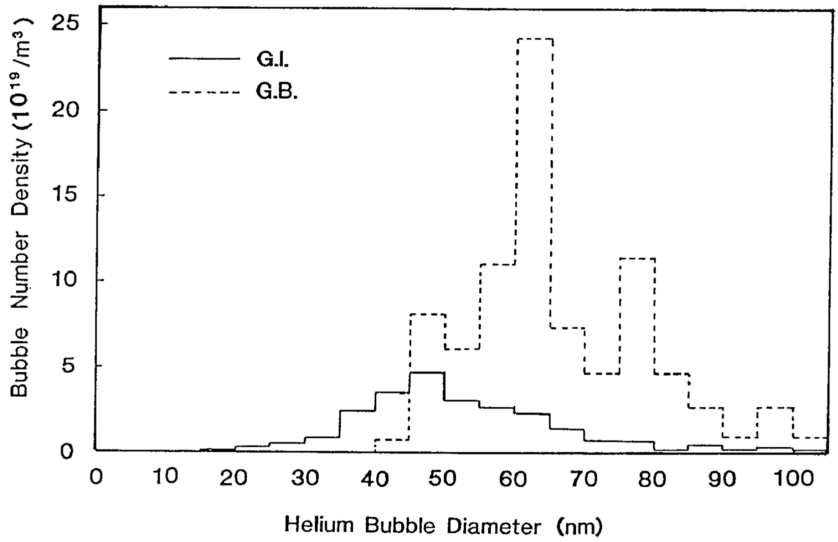

Fig.2 Size distribution of helium bubble in the grain interior and the grain boundaries of 2000 appm He implanted specimen.

integrator coincided with the number of helium atoms which was obtained by the number density and size distribution of gas bubbles with the assumption that helium gas is an ideal gas and that the internal pressure of helium gas bubbles is balancing with the ratio of surface tension/bubble radius(6).

2. Tensile test

Fig.3 shows the stress-strain curves (S-S curves) of the 316 steel specimens (2000appm He-implanted or He-non implanted specimens) tested at room temperature and elevated temperatures of 773K to 973K. "He-implanted specimen" means the third specimen from the top of the deck of 4 foil specimens described in the paragraph of experimental method, and "He-non implanted" specimen indicates the fourth specimen. The He-implanted specimen showed the increase of strength (0.2% proof strength and ultimate tensile strength) and the decrease of ductility comparing with the non-implanted specimen at any temperature test. Fig.4 also shows S-S curves of the 316 steel specimens (500appm He-implanted or non He-implanted specimens) tested at elevated temperatures of 873K to 973K. The He-implanted specimens also show the increase of strength and the decrease of ductility comparing with the non-implanted specimen at any temperature test.

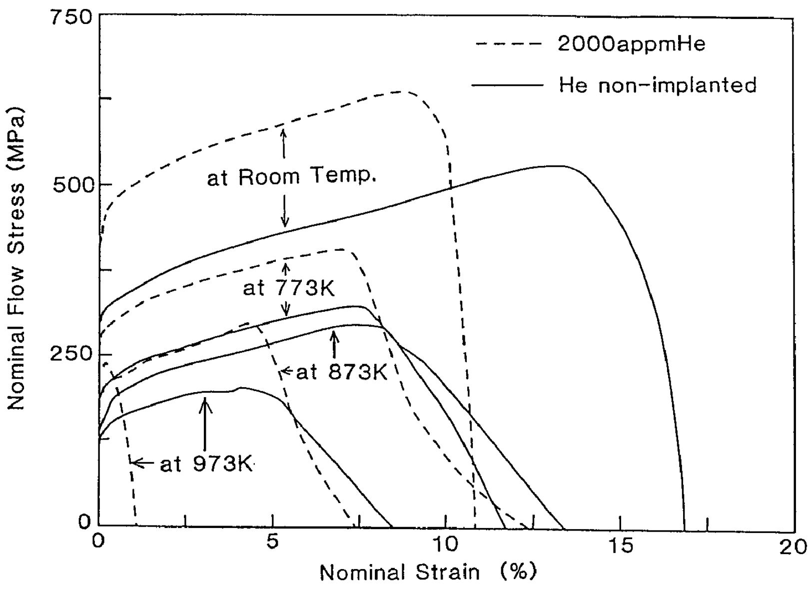

Fig.3 Stress-strain curves of 2000 appm He implanted or non implanted specimens tested at room temperature to 973K.

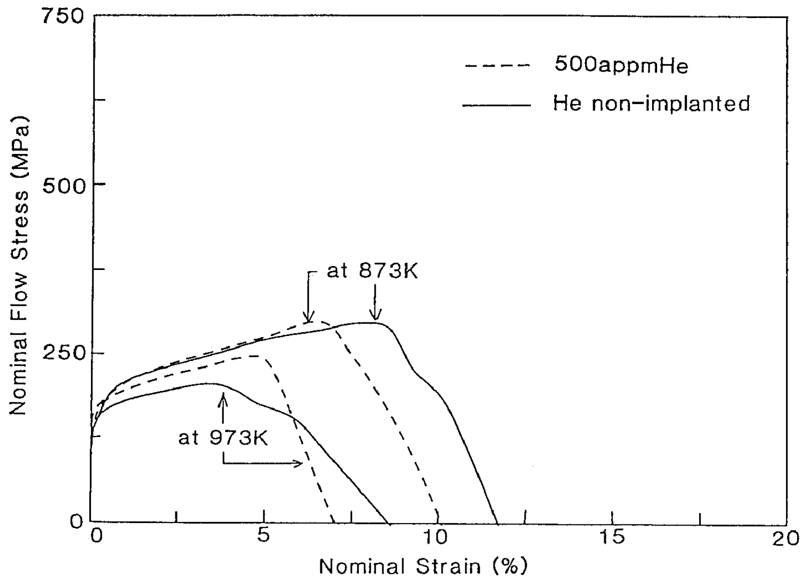

Fig.4 Stress-strain curves of 500 appm He implanted or non implanted specimens tested at 873K to 973K.

3. Fracture behavior

Figs.5, 6 and 7 are the scanning electron micrographs of fracture surface after the tensile test. As shown in Fig.5, intergranular fracture was sometimes observed on the He-deposited region of 2000appm He-implanted specimens after the room temperature test. This observation is in agreement with the result which Igata and the present authors reported previously(8). After the test at 773K, however, the He-deposited region showed transgranular-ductile fracture. The non-implanted specimens also showed only the transgranular-ductile fracture after the test at room temperature and 773K. The SEM photographs of fracture surface of the He-non implanted or 2000appm He-implanted specimens after the tensile test at 873K or 973K are shown in Fig.6. This figure indicates that intergranular fracture dominates the fracture mode of 2000appm He-implanted specimens at 873K and 973K tensile tests. On the other hand, the non-implanted specimens show only the transgranular-ductile fracture after the tests at 873K and 973K. We can see from Figs.5 and 6 that the temperature of transition in fracture mode from transgranular type to intergranular type is in a temperature range from 773K to 873K in the

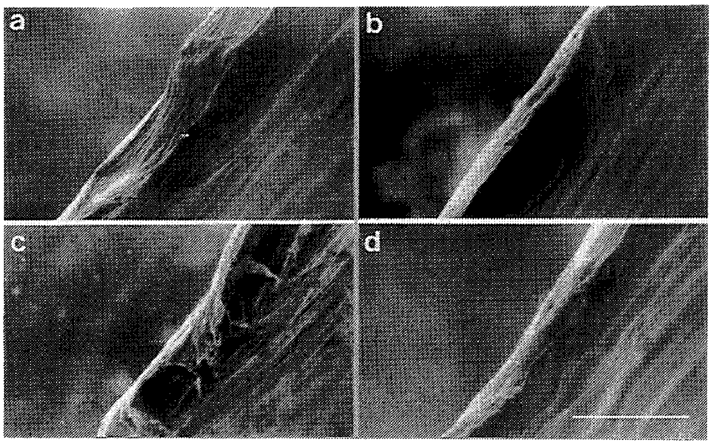

Fig.5 SEM photographs of fracture surface of 2000 appm He implanted or non implanted specimens tested at 773K or room temperature.
(a); He implanted, 773K test,
(b); non implanted, 773K test,
(c); He implanted, room temp. test,
(d); non implanted, room temp. test.
A white line indicates 30μm length.

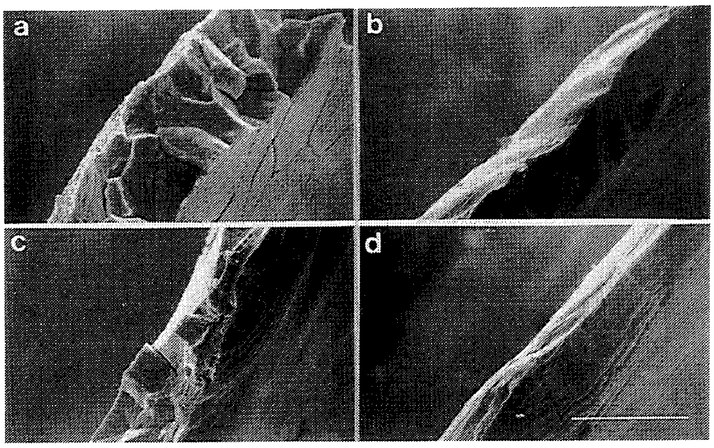

Fig.6 SEM photographs of fracture surface of 2000 appm He implanted or non implanted specimens tested at 873K or 973K.
(a); He implanted, 973K test,
(b); non implanted, 973K test,
(c); He implanted, 873K test,
(d); non implanted, 873K test.
A white line indicates 30μm length.

case of 2000 appm He injection. Fig.7 shows the SEM photographs of the He-non implanted or 500appm He-implanted specimens after the tensile test at 873K or 973K. This figure indicates that intergranular fracture occurs at 973K and the non-implanted specimens still show only the transgranular-ductile fracture after the tests at 873K and 973K. Accordingly, it is understood from the results of SEM observation shown in Figs.5, 6 and 7 that the fracture mode of He implanted specimen changes from transgranular type to intergranular type with increasing of test temperature and it is interesting to note that such transition temperature increases with decreasing of He content. In the present work we have not obtained the result of the case of low content of He implantation, but Shinno et al[9] report that a 10 appm He implanted 316 steel shows intergranular fracture in a tensile test at 1023K (strain rate; 5x10-4/s). Accordingly, we can understand that the above described behavior of transition temperature to increase with decreasing of He content may be applicable to very low content of He.

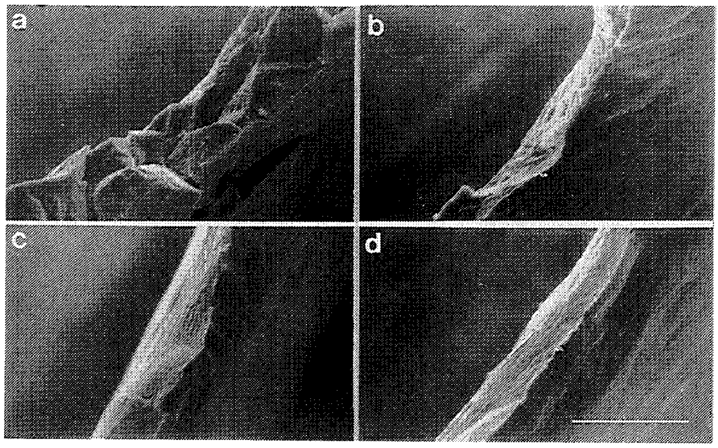

Fig.7 SEM photographs of fracture surface of 500 appm He implanted or non implanted specimens tested at 873K or 973K.
(a); He implanted, 973K test,
(b); non implanted, 973K test,
(c); He implanted, 873K test,
(d); non implanted, 873K test.
A white line indicates 30μm length.

IV. Conclusions

The summaries are as followings;

(1) It was generally observed that larger size of helium bubbles were more formed at grain boundaries than in grain interiors in a type 316 steel.

(2) He-implantation increased the strength of 316 steel at room temperature and elevated temperature tensile tests.

(3) Fracture mode of He implanted specimen changed from transgranular type to intergranular type with increasing of test temperature and such transition temperature increased with decreasing of He content in the 500-2000 appm He-implanted specimens of 316 steel.

References

(1) H.Ullmaier, J. Nucl. Mater., 133&134(1985),100.
(2) H.Trinkaus, ibid., p.105.
(3) H.Ullmaier and H.Trinkaus, J. Nucl. Mater.,155-157(1988),148.
(4) L.K.Mansur and M.L.Grossbeck, ibid, p.130.
(5) K.Miyahara, Y.Okazaki, M.Mochizuki, Y.Hosoi and H.Kayano, J. Nucl. Mater., 155-157 (1988), 1054.
(6) K.Miyahara, Y.Sakamoto, H.Kayano and Y.Hosoi, Tetsu to Hagane, 76(1990),964.
(7) K.Miyahara, Y.Sakamoto, S.Hamada, H.Kayano and Y.Hosoi, to be published in the Proc. of 4th Intern. Conf. on Fusion Reactor Mater.
(8) N.Igata, K.Miyahara, C.Tada, D.Blasl, S.Hamada, T.Sawai, H.Kayano and Y.Hosoi, J. Nucl. Mater., 141-143 (1986), 543.
(9) H.Shinno, H.Shiraishi, R.Watanabe, H.Kamitsubo, I.Kohno and T.Shikata, J. Nucl. Mater., 97(1981), 291.