

# Effect of Helium on Mechanical Properties of ODS Ferritic/Martensitic Steels for Fusion Applications

著者	Hasegawa A., Ejiri M., Nogami S., Satou M., Abe K., Kimura A., Jitsukawa S.
journal or publication title	CYRIC annual report
volume	2006
page range	19-24
year	2006
URL	<a href="http://hdl.handle.net/10097/50343">http://hdl.handle.net/10097/50343</a>

### III. 1. Effect of Helium on Mechanical Properties of ODS Ferritic/Martensitic Steels for Fusion Applications

*Hasegawa A.<sup>1</sup>, Ejiri M.<sup>1</sup>, Nogami S.<sup>1</sup>, Satou M.<sup>1</sup>, Abe K.<sup>1</sup>  
Kimura A.<sup>2</sup>, and Jitsukawa S.<sup>3</sup>*

<sup>1</sup>*Department of Quantum Science and Energy Engineering, Tohoku University*

<sup>2</sup>*Institute of Advanced Energy, Kyoto University*

<sup>3</sup>*Japan Atomic Energy Agency*

#### Introduction

The reduced activation ferritic/martensitic steels are one of the candidate structural materials for fusion reactor<sup>1)</sup>. In the fusion reactor environment, 14 MeV neutron irradiation might produce large amount of displacement damage and transmutant helium (He) atoms in structural materials. For instance, the displacement damage will be 100 dpa and He concentration will be 1000 appm in a ferritic/martensitic steel after 10 MW/m<sup>2</sup> neutron wall loading.

The displacement damage might cause an increase of strength (irradiation hardening) at temperature below 400°C and the irradiation hardening might reduce fracture toughness, which includes a ductile brittle transient temperature (DBTT) shift to higher temperatures<sup>1)</sup>. It is well known that He might stabilize a point defect cluster and cause the additional hardening at lower temperature region and the increase of swelling at higher temperature region. He atoms in material might diffuse to form He bubbles at the preexisting grain boundary during higher temperature irradiation and tend to change the fracture mode from the transgranular fracture to the intergranular fracture. The previous study<sup>2)</sup> in our group showed that the irradiation hardening, increment of the DBTT and the intergranular fracture of the 8Cr-2W ferritic/martensitic steel (F82H by JAEA) due to He implantation up to 1000 appm at 550°C using the Cyclotron accelerator of CYRIC.

The oxide dispersion strengthened (ODS) ferritic/martensitic steels were recently developed<sup>3)</sup>, which consists of fine grains and ultra fine dispersed oxides. The ODS ferritic/martensitic steels are expected to have higher strength under high temperature neutron irradiation than the conventional (non-ODS) ferritic/martensitic steels described

above because the grain boundaries and the fine dispersed oxides in this material might effectively behave as a trapping site and a sink for defects including He<sup>4-6</sup>).

The objective of this study is to investigate the effect of He at high temperature on mechanical properties of the ODS ferritic/martensitic steel using high energy  $\alpha$ -particle irradiation by the Cyclotron accelerator.

## Experimental

The material used in this study was the ODS 9Cr-2W ferritic/martensitic steel developed by Japan Atomic Energy Agency (JAEA), which was fabricated by a mechanical alloying (MA) process. The chemical composition of this material is shown in Table 1. This material includes high density ultra fine oxides, which were produced from original Y<sub>2</sub>O<sub>3</sub> powders during the MA process and the following heat treatment (1050°C x 1 h for tempering and 800°C x 1h for annealing). Miniaturized Charpy V notch (CVN) specimen for the Charpy impact test was machined with the dimension of 1.5 mm x 1.5 mm x 20 mm and the notch geometry of 0.3 mm in notch depth, 0.08 mm in notch root radius and 30° in notch angle. Figure 1 shows the CVN specimen shape and geometry.

He-ion implantation was performed using 50 MeV  $\alpha$ -particles from the AVF cyclotron of CYRIC of Tohoku University. The projected range of 50 MeV He-ions in a Fe-9Cr steel was calculated to be about 400  $\mu$ m by TRIM code<sup>7</sup>). The tandem type energy degrader system consisting of 2 rotating wheels was used to obtain the uniform depth distribution of He atoms in specimens<sup>8</sup>). The calculated depth distribution of He concentration and displacement damage is shown in figure 2. The nominal He concentration was about 1000 appm. The displacement damage was about 0.37 dpa at the specimen surface and 0.28dpa in average. The implantation temperature was 550°C +/-10°C, which was measured using thermocouples during the implantation test.

The Vickers hardness measurement, the Charpy impact property evaluation, and the fracture surface analysis after the impact test was carried out after He implantation. The Vickers hardness was measured using a Vickers hardness tester at Radio Isotope Laboratory of Tohoku University. The indentation load and dwell time was 200 gf and 15 sec, respectively. The Charpy impact test was carried out using an instrumented Charpy impact testing equipment at the Hot Laboratory of International Research Center for Nuclear Materials Science of Tohoku University. The test temperature ranged from -120°C to room temperature. The fracture surface of the CVN specimens after the impact test was observed using a scanning electron microscope (SEM) at the Hot Laboratory of

## Results and Discussion

Figure 3 shows the Vickers hardness of the ODS 9Cr-2W steel and the conventional 8Cr-2W steel (F82H) in the previous work<sup>2)</sup>. The hardness of the as-received ODS 9Cr-2W steel before He implantation ( $H_v = 385$ ) was about 55% larger than that of the as-received conventional 8Cr-2W steel ( $H_v = 248$ ). Almost no change of the hardness in the ODS 9Cr-2W steel due to He implantation at 550°C was observed though the conventional 8Cr-2W steel showed the clear irradiation hardening ( $\Delta H_v = +27$ ).

The Charpy impact data for the ODS 9Cr-2W steel and the conventional 8Cr-2W steel in the previous work<sup>2)</sup> are shown in Figure 4. The DBTT of the as-received ODS 9Cr-2W steel before He implantation ( $DBTT = -51^\circ\text{C}$ ) was about 54°C higher than that of the as-received conventional 8Cr-2W steel ( $DBTT = -105^\circ\text{C}$ ). The upper shelf of the absorbed energy for the as-received ODS 9Cr-2W steel before He implantation ( $E_{\text{upper}} = 0.5$  J) was about 45% lower than that for the as-received conventional 8Cr-2W steel ( $E_{\text{upper}} = 0.9$  J), though the lower shelf energies of these two materials were almost the same. Almost no change of the DBTT in the ODS 9Cr-2W steel due to He implantation at 550°C was observed though the conventional 8Cr-2W steel showed the clear increment of the DBTT ( $\Delta DBTT = +70^\circ\text{C}$ ).

The typical fracture surfaces for the He-implanted Charpy impact specimen of the ODS 9Cr-2W steel tested at  $-120^\circ\text{C}$  and the conventional 8Cr-2W steel tested at  $-60^\circ\text{C}$  in the previous work<sup>2)</sup> are shown in Figure 5. Fracture mode for the He-implanted region and the He-unimplanted region of the ODS 9Cr-2W steel was cleavage fracture, though the He-implanted region of the conventional 8Cr-2W steel showed an intergranular fracture.

Almost no irradiation hardening, no increment of the DBTT and no intergranular fracture due to He implantation at 550°C were observed for the ODS 9Cr-2W steel though the conventional 8Cr-2W steel showed them. The ODS 9Cr-2W steel consists of fine grains and ultra fine dispersed oxides. Therefore, almost no embrittlement due to He implantation occurred since the grain boundaries and the fines dispersed oxides in this material are considered to effectively behave as a He-trapping site and sink of He atoms. Based on these results in this study, suppression of the irradiation hardening (increment of the yield strength) and the grain boundary degradation due to transmutant He during high temperature neutron irradiation can be expected for the ODS 9Cr-2W steel in comparison with the conventional 8Cr-2W steel.

## Summary

Effect of transmutant He on mechanical properties of the ODS 9Cr-2W ferritic/martensitic steel was evaluated using high energy  $\alpha$ -particle irradiation by the Cyclotron accelerator of CYRIC and was compared with that of the conventional 8Cr-2W ferritic/martensitic steel. The following results were obtained.

- 1) Almost no irradiation hardening of the ODS 9Cr-2W steel due to He implantation at 550°C was clearly observed.
- 2) Almost no change of the DBTT in the ODS 9Cr-2W steel due to He implantation at 550°C was observed though the conventional 8Cr-2W steel showed the clear increment of the DBTT ( $\Delta$ DBTT = +70°C).
- 3) The He-implanted region of the ODS 9Cr-2W steel showed a cleavage fracture, though that of the conventional 8Cr-2W steel showed an intergranular fracture.

## Acknowledgement

The authors are grateful to the staffs of CYRIC of Tohoku University relating to the accelerator operation and the irradiation experiments. This work was partly supported by the JUPITER-II (Japan-USA Program of Irradiation Testing for Fusion Research II) program.

## References

- 1) Baluc N., Gelles D.S., Jitsukawa S., Kimura A., Klueh R.L., Odette G.R., van der Schaaf B., Jinnan Yu., *J. Nucl. Mater.* **367-370** (2007) 33.
- 2) Hasegawa A., Suzuki A., Tanaka K., Satou M., Abe K., Jitsukawa S., CYRIC Annual Report 2004, 27.
- 3) Ukai S., Fujiwara M., *J. Nucl. Mater.* **307-311** (2002) 749.
- 4) Klueh R.L., Maziasz P.J., Kim I.S., Heatherly L., Hoelzer D.T., Hashimoto N., Kenik E.A., Miyahara K., *J. Nucl. Mater.* **307-311** (2002) 773.
- 5) Schaeublin R., Leguey T., Spätig P., Baluc N., Victoria M., *J. Nucl. Mater.* **307-311** (2002) 778.
- 6) Goshchitskii B.N., Sagaradze V.V., Shalaev V.I., Arbuzov V.L., Tian Y., Qun W., Jiguang S., *J. Nucl. Mater.* **307-311** (2002) 783.
- 7) Biersack J.P., Ziegler J.F., TRIM85 Program, IBM Corp., Yorktown, NY, 1985.
- 8) Hasegawa A., Wakabayashi E., Tanaka K., Abe K., Jitsukawa S., CYRIC Annual Report 2002, 34.

Table 1. The chemical composition of the ODS ferritic steel (unit: wt.%).

C	Si	Mn	Cr	W	N	Ti	Y	Y <sub>2</sub> O <sub>3</sub>	Fe
0.14	0.048	0.05	8.67	1.96	0.017	0.23	0.27	0.34	Bal.

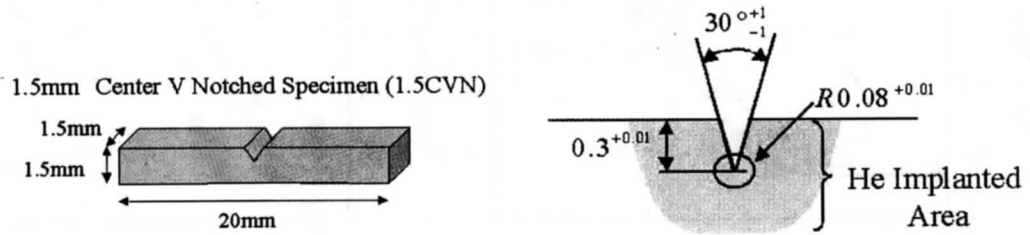


Figure 1. The shape and geometry of the miniaturized Charpy V notch (CVN) specimen.

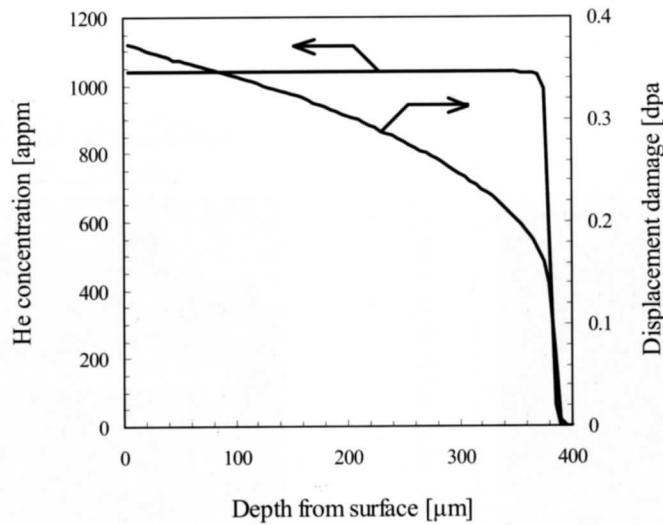


Figure 2. The calculated depth distribution of He concentration and displacement damage in the ODS 9Cr-2W ferritic/martensitic steel.

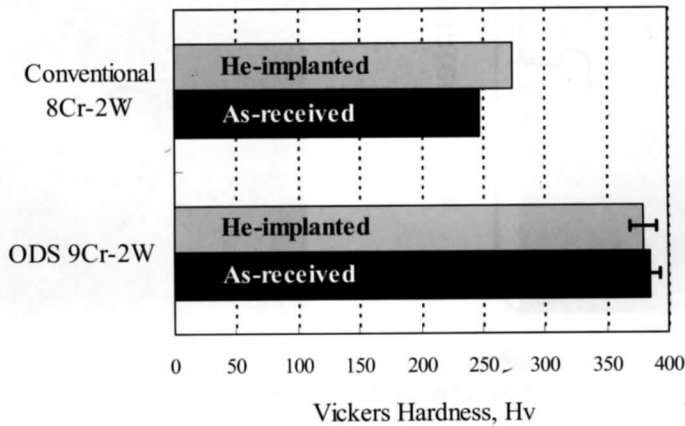


Figure 3. The Vickers hardness of the ODS 9Cr-2W steel and the conventional 8Cr-2W steel (F82H) in the previous work<sup>2)</sup>.

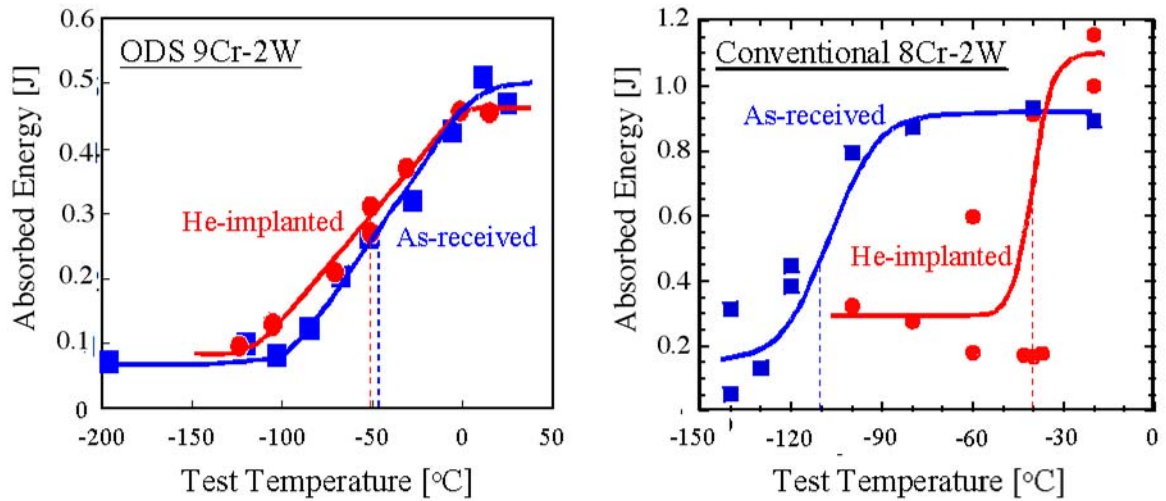


Figure 4. The Charpy impact data for the ODS 9Cr-2W steel and the conventional 8Cr-2W steel in the previous work<sup>2)</sup>.

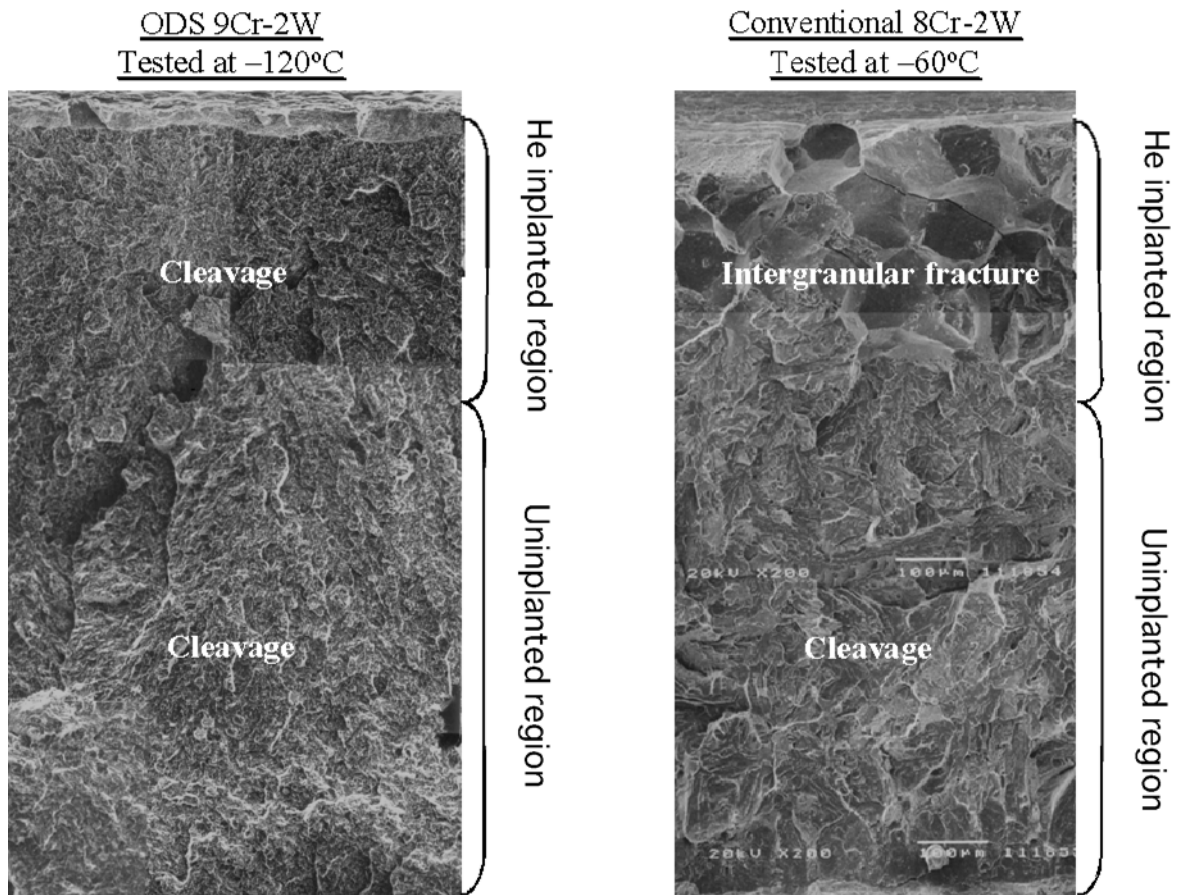


Figure 5. The typical fracture surfaces for the He-implanted Charpy impact specimen of the ODS 9Cr-2W steel tested at  $-120^{\circ}\text{C}$  and the conventional 8Cr-2W steel tested at  $-60^{\circ}\text{C}$  in the previous work<sup>2)</sup>.