Effects of Helium-implantation on Fracture Behavior of Reduced Activation Martensitic Steel F82H

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III. 1. Effects of Helium-implantation on Fracture Behavior of Reduced Activation Martensitic Steel F82H

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Introduction

Reduced activation ferritic/martensitic steels are candidate structural materials for fusion reactor. In the fusion reactor environment, 14 MeV neutron irradiation will produce large amount of displacement damage and helium in structural materials. For instance, displacement damage will be 100 dpa and helium concentration will be 1000 appm in ferritic/martensitic steels after 10 MW/m^2 neutron wall loading. The irradiation caused an increase of strength (hardening) at temperature below 400˚C and the hardening reduces facture toughness, which includes a DBTT (Ductile Brittle Transition Temperature) shift to higher temperatures. It is one of important material issues for component design. Previous works showed that the ferritic/martensitic steels had enough resistance to microstructural changes by irradiation and DBTT shift caused by the irradiation mainly depended on the irradiation hardening below 400˚C[1,2)].

It is well known that helium stabilizes point defect cluster and causes additional hardening at lower temperature region or increases swelling at higher temperature region. To study the helium effects of ferritic/martensitic steels, helium doping experiment using neutron irradiation with B- or Ni-doped specimen have been used, and these results show that helium doping tends to be accompanied by additional hardening, and the increased effect of helium seems to be about one third or smaller than has been indicated previously with He levels less than 400 appm irradiated below 400˚C[2)]. On the other hand, helium atoms in the materials diffused to form bubbles at preexisting grain boundaries during irradiation at a high temperature. The bubble formation at grain boundary tends to change the fracture mode from transgranular to intergranular cracking. It was reported that the martensitic steels were highly resistant to helium bubble-induced grain boundary embrittlement at high temperatures by tensile test[3-5] but the effect on fracture behavior by impact test after higher helium concentration had not been performed yet.

Helium implantation technique is more effective to evaluate helium effects directly and many investigations have been performed for the martensitic steels. Since the range of the implantation is usually smaller than 0.2 mm, the experiments have been often limited to microstructural observation, hardness measurement and tensile test with thin specimens. We had already reported the He effect of DBTT of martensitic steels JLF-1 using 650 appm He implanted TEM disks by means of small punch test[6]. Increase of DBTT caused by irradiation hardening was observed, however, grainboundary embrittlement was not observed. It is well known that charpy impact test is more appropriate to estimate DBTT behavior, but relatively larger specimen volume is needed for charpy impact test.

In this work, to study the He effects on fracture behavior of reduced activation steels by impact test after higher temperature irradiation, He-ion implantation at around 550°C was performed and small size charpy impact test of the He implanted specimens was conducted.

Experimental

He-ion implantation was carried using an irradiation chamber of target course 4. Detail of the irradiation apparatus and post irradiation experiments were already shown in elsewhere[7]. Mini size charpy specimens (1.5 CVN) were prepared from a F82H IEA heat. Helium implantation was performed by a cyclotron of Tohoku University with a beam of 50MeV α-particles at temperature around 550°C. A tandem-type energy degrader system was used to implant helium into the specimen homogeneously from the surface to the implanted range of 50MeV α-particles, which was about 380 μm. Calculated implanted He concentration was about 1000 appm. Charpy impact test was performed using an instrumented impact test apparatus of Oarai branch of IMR, Tohoku University. Analyses of absorbed energy change and fracture surface were carried out. Vickers hardness test was also carried out on the He implanted area of the 1.5 CVN specimen to estimate irradiation hardening.

Results

Figure 1 shows result of DBTT curves of F82H before and after He-implantation. The DBTT of unimplanted specimen was about -110°C and that of helium implanted specimen was about -40°C. Analysis of absorbed energy showed that DBTT increase by the 1000 appm He implantation at around 550°C was about 70°C.

Figures 2 to 4 show typical fracture surface observation result of unimplanted and helium implanted specimen using a scanning electron microscope. Figure 2 and 3 show the results of unimplanted specimen tested at -80°C and -140°C, respectively. Figure 2 shows typical results of ductile ruptured specimens. It shows a reduction of area at the cross section of ruptured area, and dimple pattern which correspond to plastic deformation.

Figure 3 shows result of brittle ruptured unimplanted specimen tested at -140°C. Ruptured surface is covered by cleavage surface and the reduction of area at a ruptured surface was not observed. This is typical ruptured surface of transgranular fracture mode.

Figure 4 shows result of He implanted specimen ruptured in brittle manner. Tested temperature of this specimen was -60°C. Grain boundary surface was observed from the specimen surface to about 400 μm depth region. It corresponds to helium implanted region. The grain boundary ruptured surface was not observed in helium implanted specimens ruptured in a ductile manner. Microstructural observation of the helium implanted specimen had not been carried out yet, but previous works showed that helium bubble formed in ferritic/martensitic steels around 500 to 600°C[5,6)]. Therefore, it may be considered that the grainboundary fracture probably caused by crack initiation from helium bubble at grain boundary during deformation and decreased the absorbed energy. Microstructural observation will be performed near future and the helium effect on the fracture behavior will be discussed based on these experimental results.

Summary

Helium implantation up to about 1000 appm at 550°C was performed to reduced activation ferritic/martensitic steel F82H. Small size charpy impact test was conducted to the He implanted specimens. The following results were obtained.

(1) Increase of DBTT by the He implantation was about 70°C.

(2) Grain boundary ruptured surface was only observed He implanted region of specimens ruptured in brittle manner.

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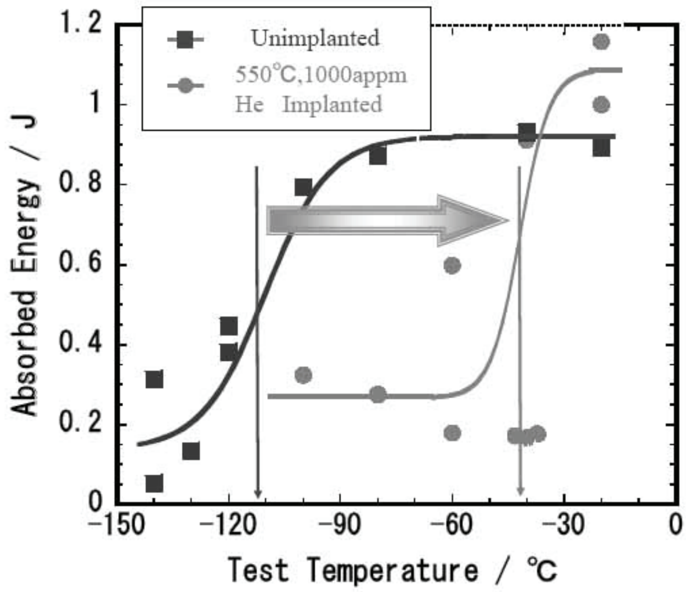

Figure 1. Absorbed energy vs. test temperature curves of helium implanted/unimplanted samples.

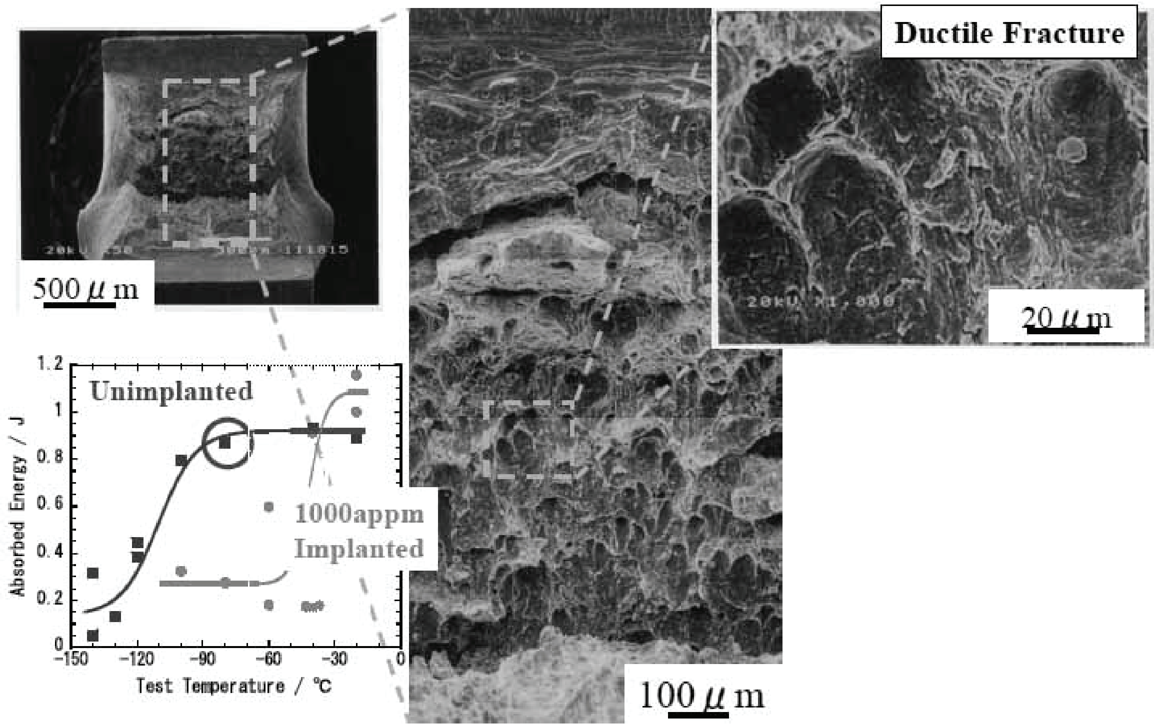

Figure 2. Fracture surface observation results of unimplanted specimen. Test temperature: -80°C.

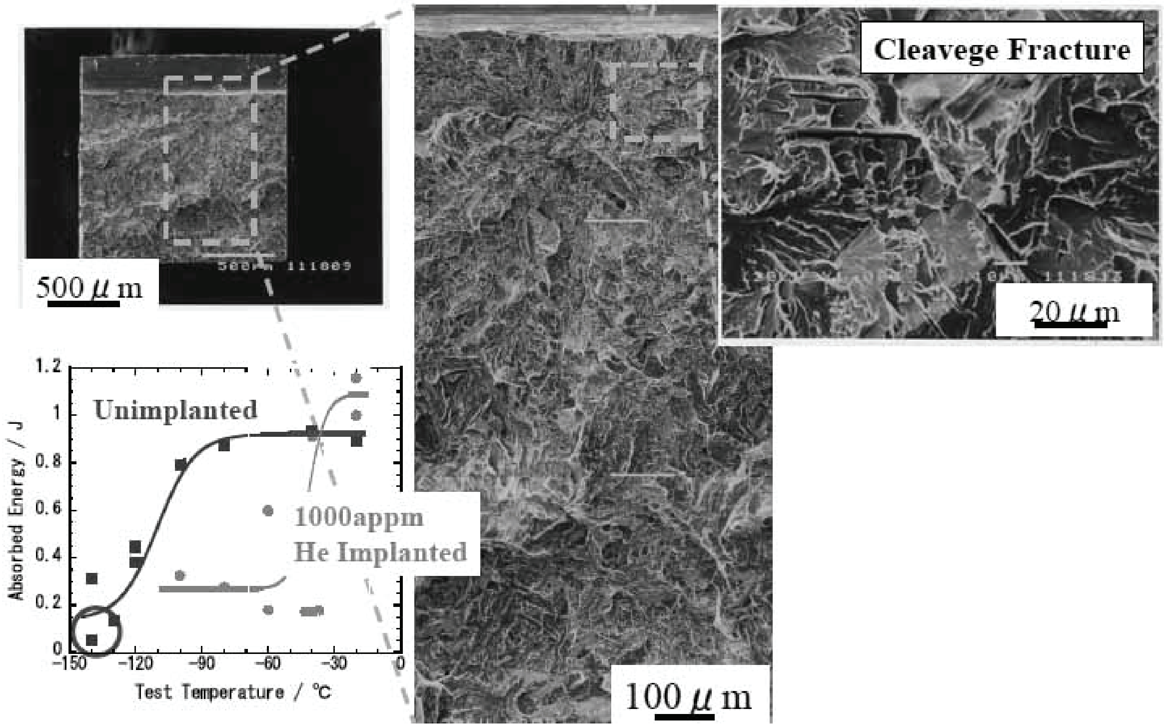

Figure 3. Fracture surface observation results of unimplanted specimen. Test temperature: -140°C.

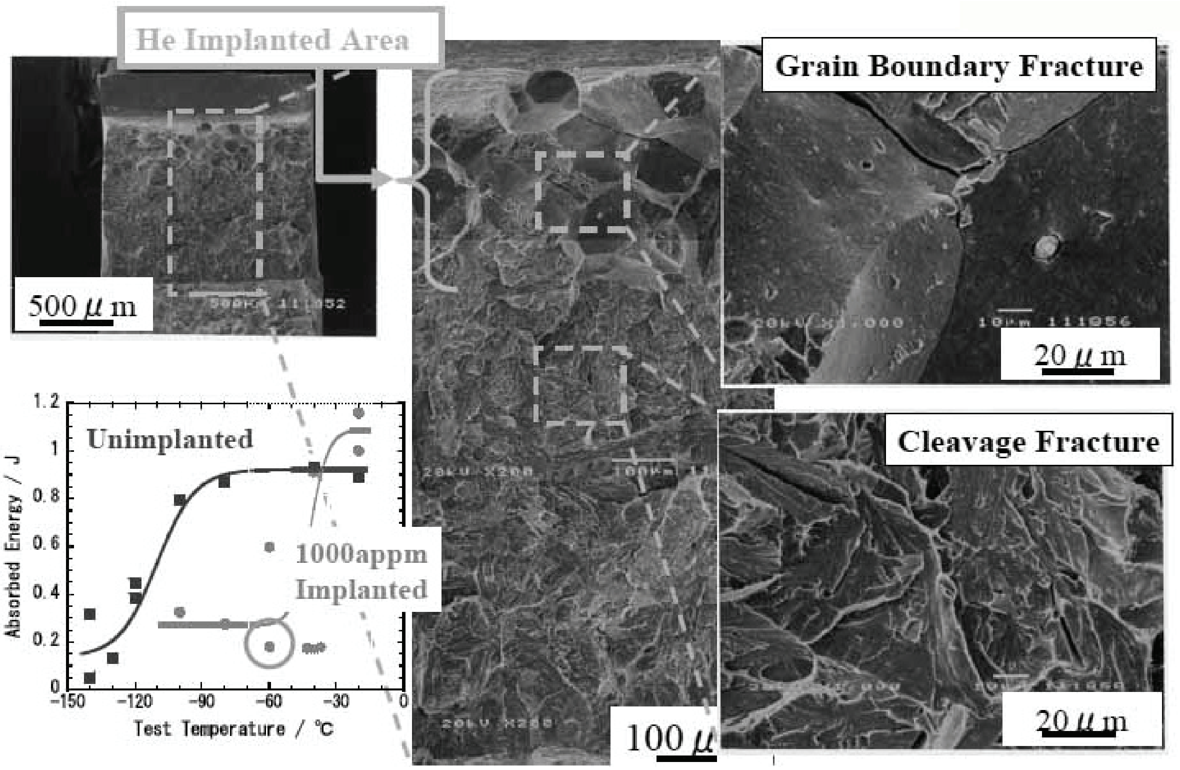

Figure 4.　Fracture surface observation results of helium implanted specimen.　Test temperature: -60˚C.