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Microstructural Characterization of Hydrogen Irradiated Austenitic Stainless Steel

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Irradiation assisted stress corrosion cracking by neutron irradiation has been recognized as a significant concern for extended operation of commercial nuclear reactors [1, 2]. Recently, the retention of helium and hydrogen has been raised for a promising factor affecting the IASCC susceptibility of nuclear internals [3, 4]. In this work, we are attempting microstructural characterization of hydrogen irradiated austenitic stainless steels to get more information on effect of hydrogen on microstructural changes in austenitic stainless steel. A commercial austenitic stainless steel (SS316 type) was used for this work. An ion irradiation experiment was carried out with a multi-purpose ion implanter in the Korea Institute of Geoscience & Mineral Resources (KIGAM). In the ion irradiation, hydrogen ions (H_2^+) were used with various energy ranges from 50keV to 490keV for the development of uniform radiation damage and implanted ion concentration in the experimental sample. Since the ion-irradiated layer was calculated to be about 1 μm in depth by "Stopping Range of Ions and Matter (SRIM)" [5]. TEM lamellae were prepared by FIB milling and low energy argon ion milling. A transmission electron microscope (TEM) equipped with an energy dispersive spectrometer (EDS) system was used for the analyzing of radiation induced defects and radiation induced segregation (RIS) behavior at grain boundaries.

According to a low magnification TEM image in Figure 1, radiation damage layer was formed up to a depth of around 1 μm. In the ion irradiated austenitic stainless steel, dislocation loops were observed in the matrix as shown in Figure 1(b). Most dislocation loops were identified to be Flank faulted loops with a burgers vector of 1/3<111>. Cavities by implanted hydrogen were also observed in the matrix as shown in Figure 1(c). The formation of unknown phase at the grain boundary was observed in the hydrogen irradiated sample. Figure 2(a) is a montage of TEM images taken near grain boundary region in the hydrogen irradiated region. HRTEM analysis in Figure 2(b) clearly indicates that the unknown phase has a body centered crystal (BCC) structure. The unknown phase is identified to be ferrite (α) or martensite (α′) with the BCC structure. Since implanted hydrogen was expected to be built up to 100000 appm (~ 0.1-0.2 wt%) in the hydrogen irradiation sample, the high density of hydrogen seems to play a role in the formation of ferrite or martensite at grain boundary. The EDS result in Figure 2(c) shows that the BCC phase has low Cr and high Ni concentration compared with the matrix. It was found that strong RIS was developed at the interfaces between the transformed ferrite or martensite and austenitic (γ) matrix as well as grain boundaries through the hydrogen irradiation. The strong RIS seems to lead to high Ni and low Cr concentration in the transformed ferrite or martensite. In conclusion, the implanted hydrogen during the irradiation is expected to enhance $\gamma \rightarrow \alpha$ or α' transformation and to develop strong RIS near grain boundary.

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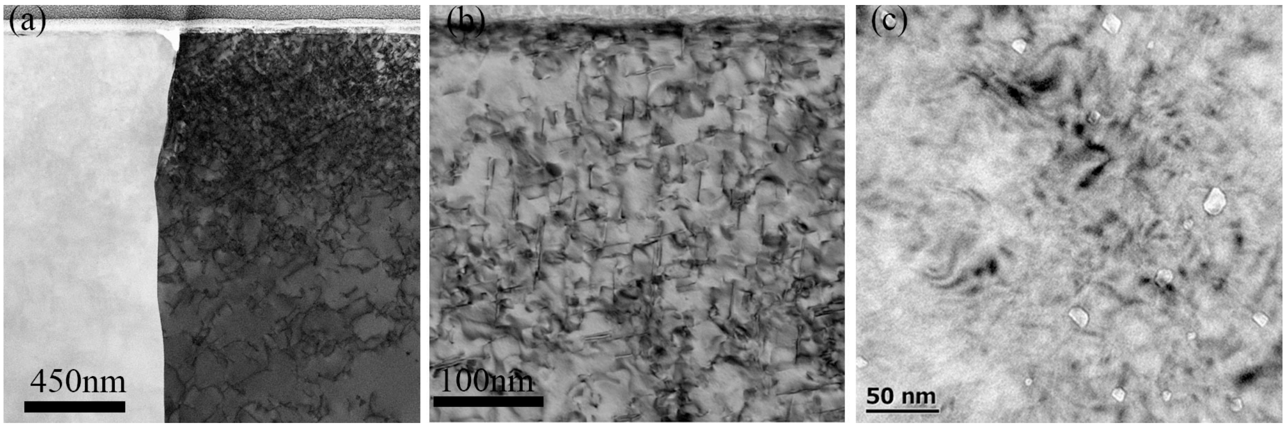

Figure 1. A Low magnified TEM image (a), TEM images showing Frank faulted loops (b) and cavities (c) after hydrogen ion irradiation.

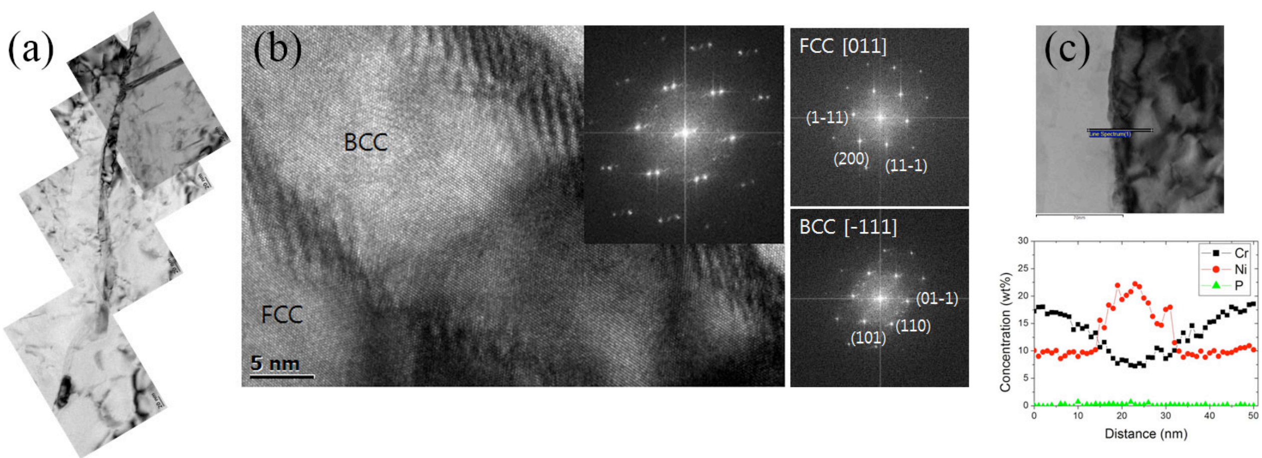

Figure 2. A Low magnified TEM image near grain boundary (a), HRTEM image and corresponding FFT images indicating the formation of BCC (α or α′) in vicinity of grain boundary (b) and EDS result showing Ni enrichment of Cr depletion in the transformed BCC (α or α′) phase.