7-4 New Approach for Testing Aging of Reactor Structural Materials
–Study of Stress Corrosion Cracking (SCC) Mechanisms Using Electron Backscatter Diffraction (EBSD) in Mesoscale Analysis–

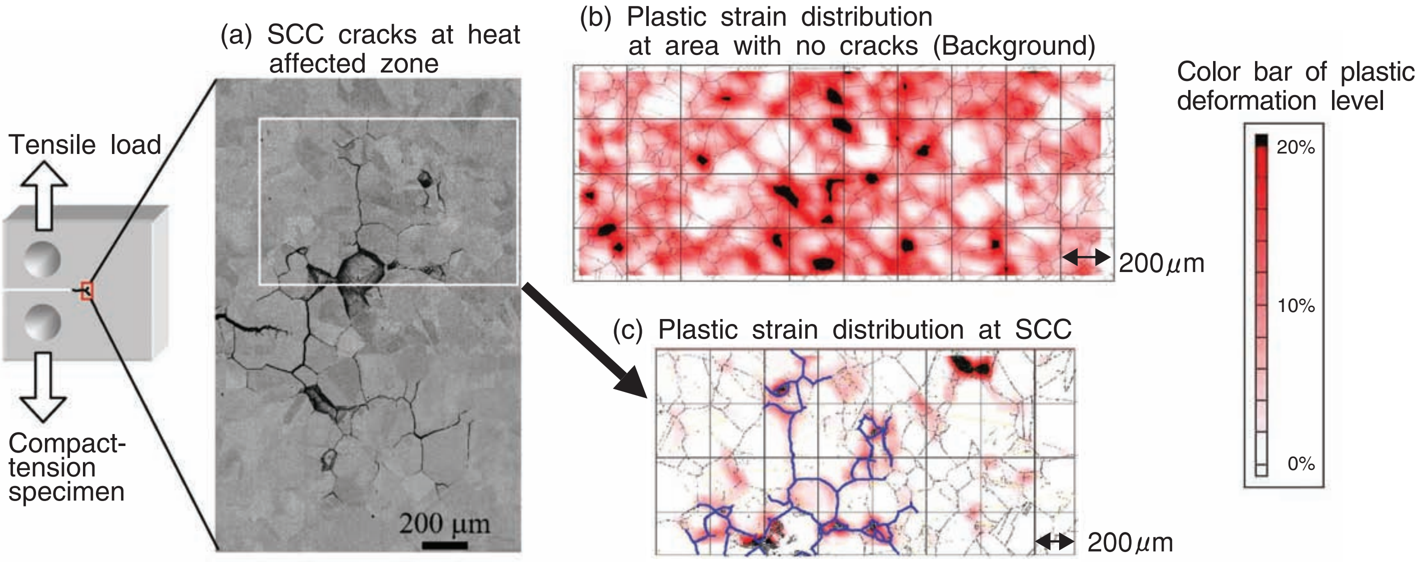

Fig.7-9 (a) Intergranular type SCC in compact-tension specimen, (b) plastic strain distribution at no crack area, and (c) at SCC area
In area (c), background strain was subtracted; blue lines indicate SCC cracks.

Austenitic stainless steels and nickel base alloys are used as structural materials of primary loop recirculation (PLR) pipes and shrouds/core barrels in light water reactors (LWRs). These steels and alloys are susceptible to SCC which is one of the quasi-brittle fracture modes. SCC was observed in the structural materials of LWRs after long term operation. Estimation of SCC initiation and growth behavior is important for preventive maintenance of LWRs.

The mechanisms of SCC are not clear yet. Recently, the following results on macro- and microscopic scale SCC have been obtained, but the mechanism relating the microscopic phenomena to macroscopic phenomena is still unknown. On the macroscopic scale, crack growth rate of SCC increases with increase in the materials' hardness and the stress intensity factor at the crack tip. The effect on hardness induced by irradiation damage was equivalent to that induced by cold work and welding processes. On the microscopic scale, segregation and precipitation are induced by heating during the welding process, and the effects of neutron irradiation are observed at grain boundaries (GBs). The segregation and precipitation are affected by the grain boundary character. SCC occurred also in low-carbon stainless steel which had no Cr depletion at GBs. Change of deformation mode from uniform to localized occurs in the grain matrix of irradiated materials.

We developed a new experimental technique using an EBSD in order to determine the properties of grain boundaries with and without crack propagation and plastic strain distribution near cracks. Fig.7-9 shows plastic strain near SCC cracks measured by this new technique in a compact-tension heat-hardened zone of a real size mock-up PLR pipe joint which is made of low carbon stainless steel. It was revealed in the heat affected zone that the plastic strain near grain boundaries reached about 15% and was much higher than that in the grain matrix (Fig.7-9(b)). When SCC occurred in such hardened stainless steel, additional plastic strain (about 10%) was observed along the SCC cracks (Fig.7-9(c)). The plastic strain gradient became very steep at the crack tip. It is likely that this steep strain gradient is one of the causes of SCC in low carbon stainless steel.

This pioneering work enables us to study the mechanism of SCC on a mesoscale and to model the SCC initiation and propagation behavior. We will improve prediction of aging degradation of reactor structural materials by means of multi-scale modeling.

Reference
Kaji, Y., Miwa, Y. et al., Multi-scale Analysis of Deformation Behavior at SCC Crack Tip (II) (Contract Research), JAEA-Research 2007-008, 2007, 69p. (in Japanese).