Project Subjects

Irradiation Embrittlement and Structural Integrity of Reactor Pressure Vessel

Background and Objective

Mechanical properties of metallic materials used in nuclear reactors change due to circumstances such as radiation and heat, which are called irradiation embrittlement and thermal aging. To maintain the integrity of components, it is necessary to study the effect of neutron irradiation embrittlement on reactor pressure vessels and core internals, and the effect of thermal aging on pipes and pumps in primary cooling systems using duplex stainless steels with ferrite and austenite phases.

In this project, we aim to improve the accuracy of the irradiation embrittlement prediction of highly irradiated reactor pressure vessel steels with the development of new technologies to monitor embrittlement, and understand the mechanism of microstructural changes in neutron-irradiated stainless steels and thermal aging in duplex stainless steels.

Main results

1. Assessment of effects of accelerated irradiation on irradiation embrittlement of pressure vessel steels

Accelerated irradiation tests using test reactors are needed to investigate irradiation embrittlement of reactor pressure vessel steels at the high fluence region prior to commercial reactor irradiation. We compared changes of mechanical properties and microstructures between archive materials irradiated in in a test reactor and surveillance test materials irradiated in commercial reactors to understand effects of the accelerated irradiation. It was found that the effect of the accelerated irradiation on embrittlement in the low copper (0.04wt.%) steel is negligible although the embrittlement in the high copper (0.16wt.%) steel exposed to the accelerated irradiation tended to be larger than that of the surveillance test materials (Fig. 1). Solute atom clusters, which cause embrittlement, in the accelerated irradiation materials are also smaller in size and higher in number density than those of surveillance irradiation materials.

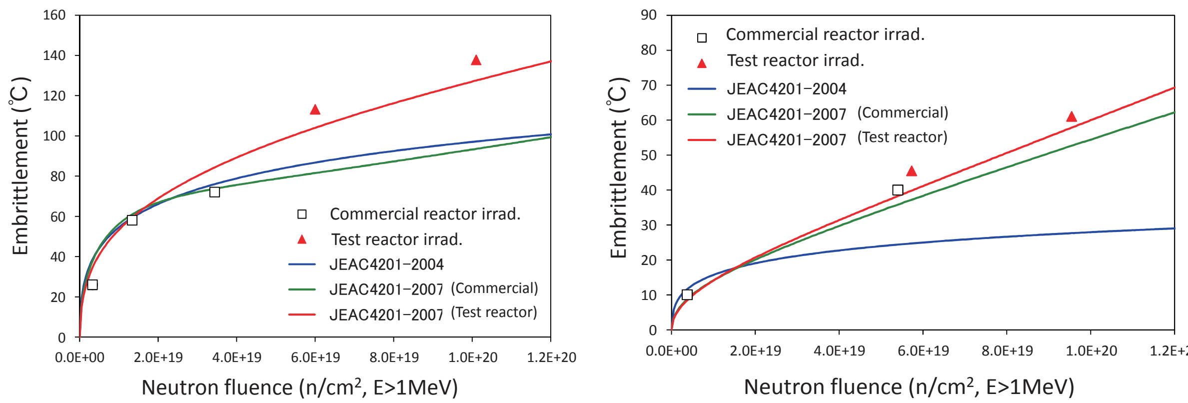
2. Evaluation of microstructural changes in irradiated stainless steels

It is important to investigate microstructural changes in neutron-irradiated stainless steels in order to understand the toughness degradation and the mechanism of radiation assisted stress corrosion cracking. In collaboration with EPRI, the microstructural characterization of stainless steels used and disposed as core internals of commercial reactors was carried out. The results showed that nickel- and silicon-enriched solute atom clusters are formed due to neutron irradiation (Fig. 2), and the ratio of the chemical composition of nickel and silicon becomes close to be 3:1 on increasing the neutron fluence (Fig. 3). It was also found that impurity elements like aluminum produce the clusters, and boron included in a small amount in the materials is transmuted to lithium due to irradiation and segregated at the grain boundary.

3. Investigation of thermal aging mechanism of duplex stainless steels

The phase separation in the ferrite phase of thermally aged duplex stainless steels, which means the formation of high and low regions of chromium concentration, and the correlation between the formation of precipitates (G-phase) and the change in hardness were studied (Fig. 4, 5). It was found that the variation of phase separation (the difference in chromium concentration) in thermal aging materials aged at 400℃ and 450℃ is proportional to the change in hardness but the slope depends on the aging temperature, and the hardness increases drastically once G-phase is precipitated .

Other reports [Q10035], [Q10016]



(a) High copper (0.16wt.%) steel **(b) Low copper (0.04wt.%) steel**

Fig. 1 Comparison between test reactor irradiation materials and commercial reactor irradiation materials

Test reactor irradiation is 50 times faster than commercial reactor irradiation. JEAC4201-2007, which was standardized on the basis of CRIEPI's outcome, succeeds in the prediction for any cases because of considering irradiation time although JEAC4201-2004 used in the past shows not to have sufficient accuracy of the prediction.

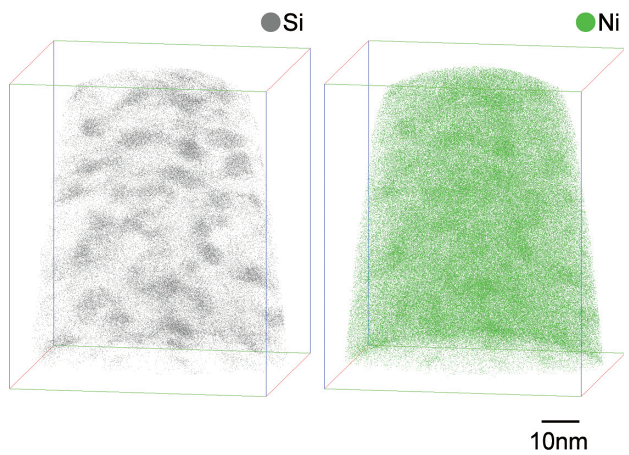


Fig. 2 Distribution of silicon (Si) and nickel (Ni) atoms in irradiated stainless steel

Some regions that solute atoms concentrated with the size of a few nanometers are formed.

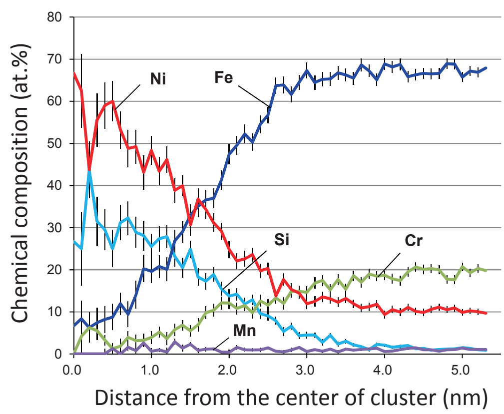


Fig. 3 Chemical composition of region where solute atoms concentrate in irradiated stainless steel

At the center region, iron (Fe) decreases and the ratio of nickel (Ni) and silicon (Si) becomes close to 3:1.

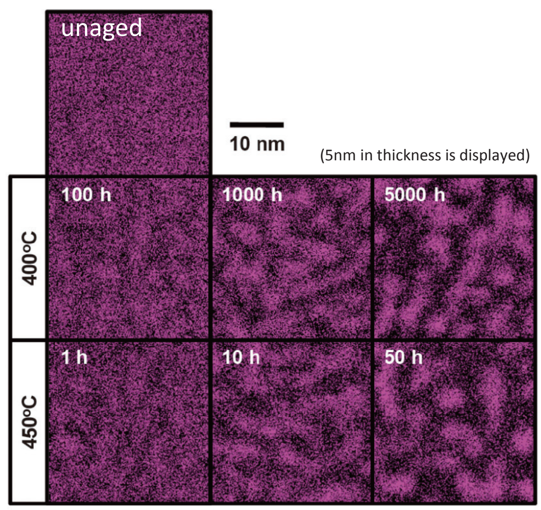


Fig. 4 Phase separation in ferrite phase of duplex stainless steels

Pink points in the figure stand for chromium atoms.

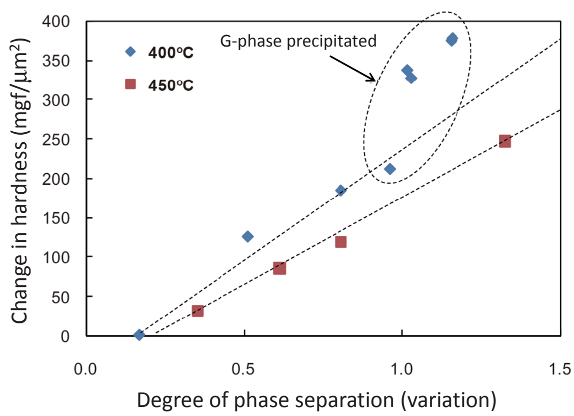


Fig. 5 Correlation between change in hardness and phase separation

Variation of phase separation means the difference in chromium concentration. The variation free from G-phase precipitation has linear correlation with the change in hardness, but the slope depends on the aging temperature.