Project Research — **Further Improvement of Facility Operations and Maintenance Technologies**

Irradiation Embrittlement and Structural Integrity of Reactor Pressure Vessels

Background and Objective

The metallic materials of nuclear reactor components are used under extreme conditions, such as neutron irradiation and high temperature, resulting in mechanical properties changes such as embrittlement. To ensure the structural integrity of components during operation, the effects of neutron irradiation on reactor pressure vessels (RPVs) and core internals steels, along with the thermal ageing of duplex stainless steel used in primary pipings and pumps, need to be characterized.

In this project, efforts have been devoted to: improve the accuracy of RPV embrittlement prediction at high fluences, develop a new method to monitor the amount of embrittlement, understand the detailed mechanism of the thermal ageing embrittlement of duplex stainless steels, and characterize the microstructural changes in neutron-irradiated stainless steels.

Main results

1 Effect of Irradiation Temperature on the Embrittlement of RPV Steels

The effect of irradiation temperature on the embrittlement of RPV steels was studied by comparing the amount of embrittlement and microstructural changes in high- and low-copper (Cu)-content materials irradiated at different temperatures. The number density and size of the solute atom clusters are higher and smaller, respectively, at a lower irradiation temperature, as shown in Fig. 1, and this trend is more evident in high-Cu material. However, the increase in yield stress, which is proportional to the amount of embrittlement, is proportional to the square root of the volume fraction of the solute atom clusters irrespective of the difference in cluster morphology (Fig. 2) (Q11019).

2 Effect of Solute Atoms on the Cu-enriched Cluster Formation and Hardening of RPV Steels

The effects of solute atoms such as nickel (Ni), manganese (Mn), and silicon (Si) on the solute atom cluster formation were investigated through comparisons between the hardness and microstructural changes in thermally aged RPV model alloys containing these elements and Cu. Ni addition results in a decrease in peak hardness, but the time necessary to reach peak hardness does not change. On the other hand, Mn addition shortens the time necessary to reach peak hardness (Fig. 3) (Q11026).

3 Round-robin Test of the Fracture Toughness Master Curve Method using Miniature CT Specimens

Toward the establishment of the fracture toughness Master Curve method utilizing miniature compact tension specimens that can be machined from a broken half of a Charpy specimen, a round-robin test was organized and conducted by CRIEPI with the participation of several domestic research organizations. It was found that valid reference temperatures, T_o*, were determined by all the participants for a given test condition.

4 Effect of Temperature on the Thermal Ageing Mechanism of Duplex Stainless Steel

Thermal ageing tests of duplex stainless steel were conducted at temperatures from 350 to 450°C with a maximum of 8,000 hours of ageing time, and the microstructural changes were studied in the materials. It was identified that the number density of G-phase precipitates is higher at lower temperatures, the size of G-phase precipitates as well as the representative distance between chromium-enriched phases becomes larger with ageing time, and the growth rates of G-phase precipitation and phase decomposition are faster at higher temperatures (Fig. 4).

*T_o: An index that corresponds to the temperature where the Master Curve mean fracture toughness, K_{Jc}, becomes 100 MPa$\sqrt{m}$.

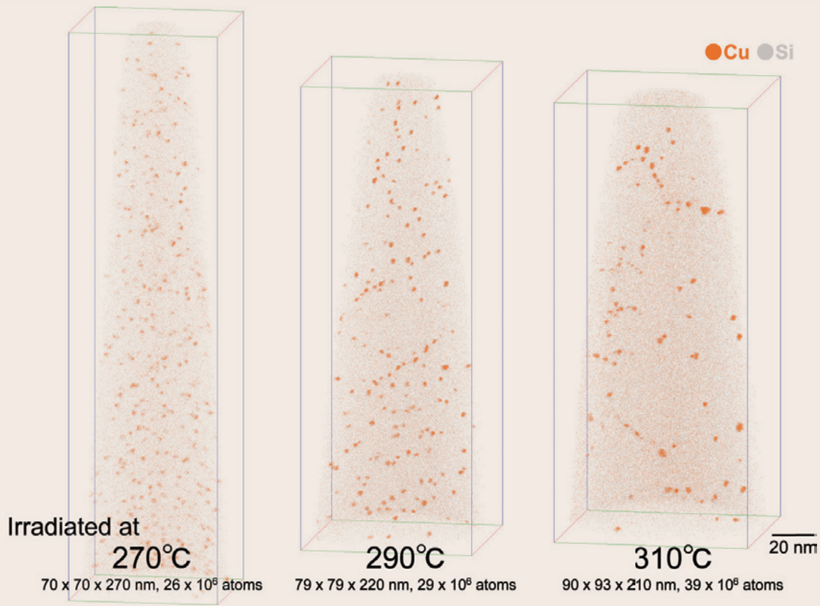


Fig. 1: Effect of irradiation temperature on the solute atom cluster formation in Cu-containing (0.2 wt% Cu) material

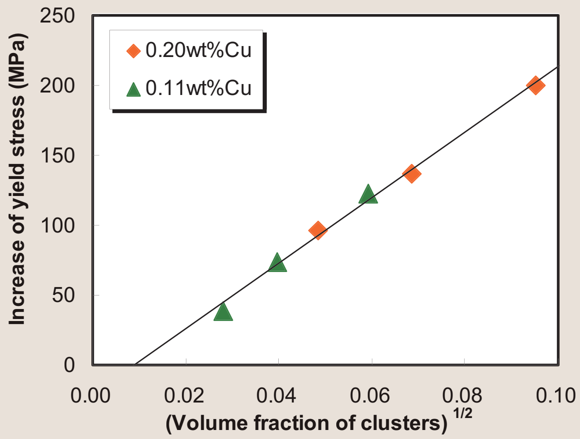


Fig. 2: Relationship between the microstructure (volume fraction) and the mechanical property (yield stress)

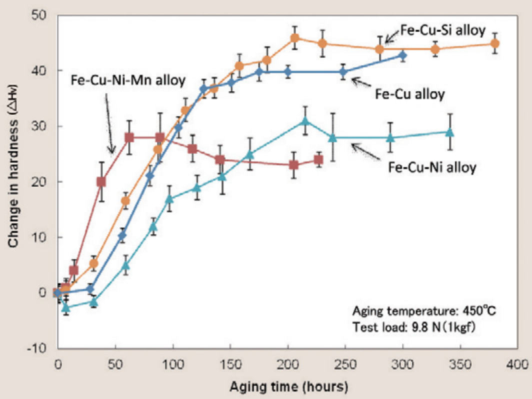
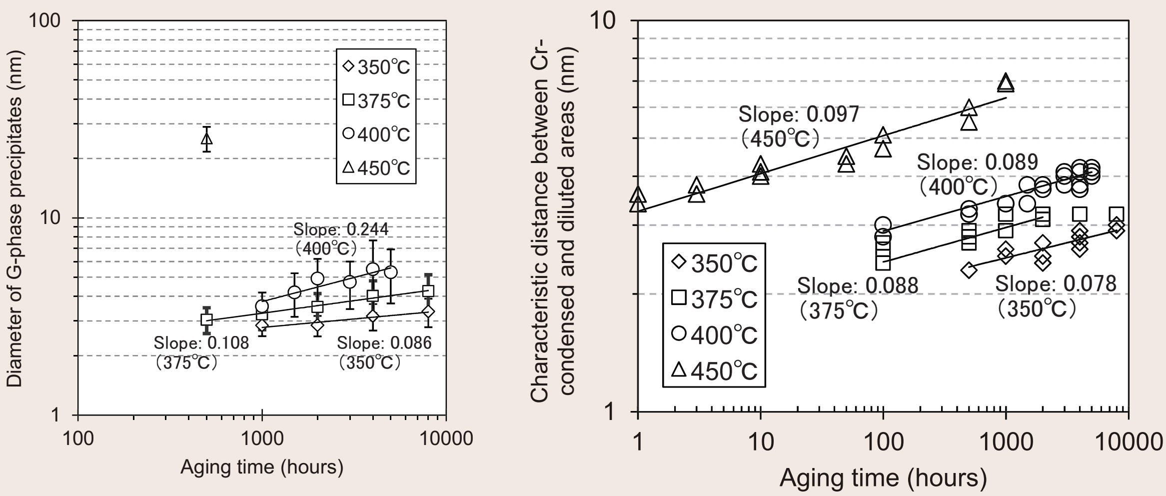


Fig. 3: Effect of solute elements on the hardening of thermally aged RPV model alloys



(a) Size of G-phase precipitates

(b) Representative length of Cr-rich phase decomposition

Fig. 4: Effect of ageing temperature on the microstructural changes in duplex stainless steel