Priority Subjects — **Further Improvement of Facility Operations and Maintenance Technologies**

Structural Integrity Evaluation of Reactor Pressure Vessels and Core Internals

Background and Objective

In order to accomplish the safe and stable operation of LWR plants, we will enforce the technical basis for structural integrity of reactor pressure vessels (RPVs) and core internals through better understanding of various degradation mechanisms together with the development and the improvement of evaluation methods. In this project, we have conducted the following research.

Main results

1 Development of applied techniques for fracture toughness evaluation of actual plant components by the Master Curve method

A fracture toughness evaluation method by the Master Curve method using miniature specimens, which can be made from broken halves of Charpy impact test specimens, was developed. The international round robin test was conducted and the results are comparable among the organizations (Fig. 1). Distribution of the fracture toughness data conforms to Weibull distribution which is assumed in the Master Curve method and is equivalent to that of the standard 1-inch thick specimens [1][2] (Fig. 2). The results establish the efficiency of the Master Curve method using the miniature specimens.

2 Study on strength evaluation for penetrations of nuclear pressure vessels

It is likely that penetrations in the bottom of reactor vessels were damaged by the effect of core melting, causing the leak of melted fuel from the vessels in Units 1 to 3 of Fukushima Daiichi nuclear power plant. Evaluation of the damage process requires estimation of temperature history and stress/damage analysis for the penetrations to be made. We developed constitutive models to estimate stress-strain relationship of the three materials used for RPVs (Fig. 3) (Q14016).

3 Improvement in the method for integrity evaluation of irradiation embrittlement in RPV steels

Atomistic scale observations by atom probe tomography on thermally aged or neutron irradiated Fe-Cu-Ni-Mn quarternary alloy simulating RPV steels were conducted*. Solute atom clusters were formed in all the materials, however Ni and Mn composition in the clusters differed between the thermally aged and irradiated materials indicating differences in cluster formation mechanisms (Fig. 4).

* Collaboration with the University of Tokyo.

[1] M. Yamamoto et al., Procs. ASME 2013 Pressure Vessels & Piping Division conference, PVP2013-97936 (2013).
[2] M. Yamamoto et al., Procs. ASME 2014 Pressure Vessels & Piping Division conference, PVP2014-28898 (2014).

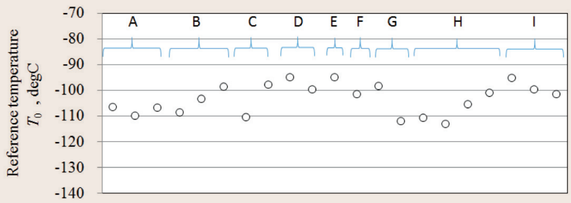

Fig. 1: Comparison of reference temperature obtained from the international round robin testing

This compares the reference temperature obtained from the same RPV steels among various organizations. All results are comparable independent of the organizations (A~I indicate the respective organization).

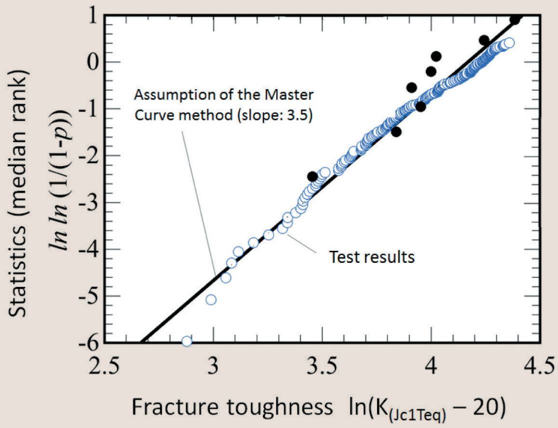

Fig. 2: Statistical plot (Weibull plot) of the fracture toughness data

The Master Curve method assumes that distribution of fracture toughness data conforms to Weibull distribution. All the data obtained in the international round robin test shows good agreement with the assumption.

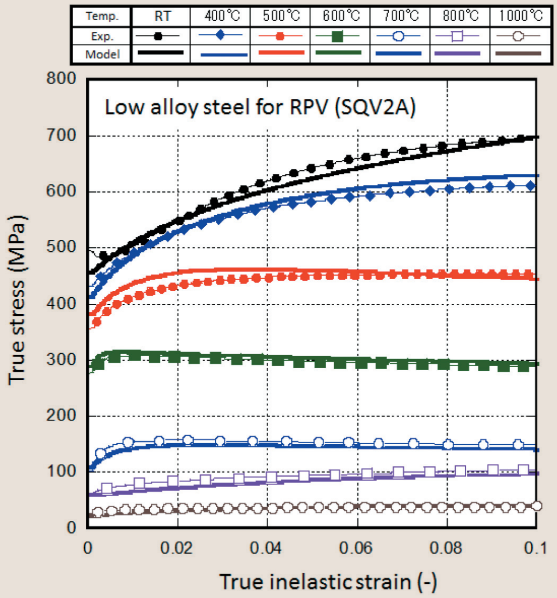

Fig. 3: Stress strain curves obtained by the experiments and the constitutive modeling developed in this study

This figure shows stress-strain curves obtained from the tensile tests at various temperatures and the simulations by the model developed. The model reproduced the experimental results with good accuracy.

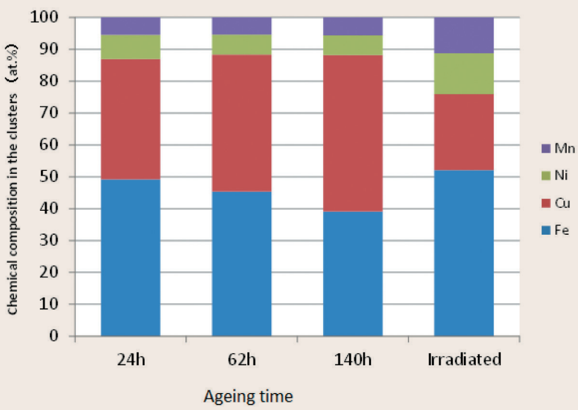

Fig. 4: Comparison of chemical compositions of the solute atom clusters formed in the Fe-Cu-Ni-Mn model alloys

Solute atom clusters were formed in the Fe-Cu-Ni-Mn model alloy after thermal ageing at 450℃ or neutron irradiation. However the amount of Ni and Mn in the clusters of the thermally aged alloys is smaller than that in the irradiated alloy and independent of ageing time. This indicates a difference in cluster formation mechanisms between the aged and irradiated alloys.