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

Wall Thinning and the Seismic Evaluation of Piping

Background and Objective

Flow-accelerated corrosion (FAC) and liquid droplet impingement erosion (LDI) are pipe wall-thinning phenomena that require consideration regarding management of the safety and maintenance of nuclear power plants with long-term operation. Pipe wall thinning management is based on residual lifetime evaluated by pipe wall thickness measurement conducted at about a 100 to 1,000 locations per outage.

In this project, to improve management by focusing on measurement location with priority, detailed local thinning profile predictions and a simplified evaluation method for a maximum thinning rate by FAC/LDI is developed. For the seismic evaluation for piping with wall thinning, while currently, conservative evaluation is required by assuming complete thinning, appropriate seismic strength for local thinning piping is investigated, which may lead to the rationalization of seismic criterion for piping with wall thinning.

Main results

1 Dissolved Oxygen Concentration for FAC Suppression

The FAC rate in the simulated BWR primary water at 140℃ dramatically decreases when the dissolved oxygen concentration is higher than 40 to 60 ppb. The dissolved oxygen concentration is lowered to 10 ppb in the alkaline condition such as in the simulated PWR secondary water. These results indicate that the wall thinning in the PWR secondary system will be mitigated by a small amount of oxygen injection (Fig. 1) (Q11025).

2 Development of an Evaluation Method for Flashing Erosion

LDI in a hot-water piping system due to flashing phenomena (flashing erosion) is sometimes observed. The flashing flow is defined as the flow with a sudden phase change, and it is usually difficult to simulate the flow structure of the flashing flow. Therefore, based on a steam flow CFD (Computational Fluid Dynamics) code previously developed, a pre-conditioning method was adopted to achieve the stable calculation of the water region, and a new CFD code for water-steam flow was developed. Several benchmark tests were conducted, and those results show that this new code can reproduce the flashing phenomena and is applicable to the evaluation of the flashing erosion (Fig. 2) (L11016).

3 Verification of the FAC/LDI Model and the Development of FALSET Prediction Software

Utilizing the maximum local thinning rate measurement data of FAC/LDI in actual power plants, the calculated values with the developed prediction method were compared. From the comparison, the present method for FAC/LDI showed prediction accuracy with about a factor of 2 for high thinning rate data, which needs to be managed with high priority (Fig. 3). In addition, toward easily adapting the models to actual plant piping management, the "FALSET" prediction software was developed, equipped with an essential function for pipe wall thinning management in power plants (Fig. 4) (L11007). With the further verification and improvement of each function, there are prospects for this software to be utilized as a management tool in power plants.

4 Seismic Evaluation of a Local Wall-thinning Elbow Detected by LDI

The earthquake-proof safety of local wall-thinning elbows with a back side detected by LDI was investigated by the hybrid testing*. No damage was observed in the in-plane and out-of-plane bending of elbows, defected by a 75% condition under the five-times-large amplitude seismic motion of the design-basis earthquake, which expanded the allowable stress level. In addition, torsion buckling occurred, and a wall-through crack was penetrated by cyclic loading under eight times large amplitude due to the abovementioned seismic motion (Fig. 5). The torsion buckling of the out-of-plane bending of the elbow could be demonstrated by finite element analyses and a buckling formula.

*Hybrid testing is a new seismic experiment that incorporates a numerical analysis of the entire structure system with the loading test of a damage-concentrating model.

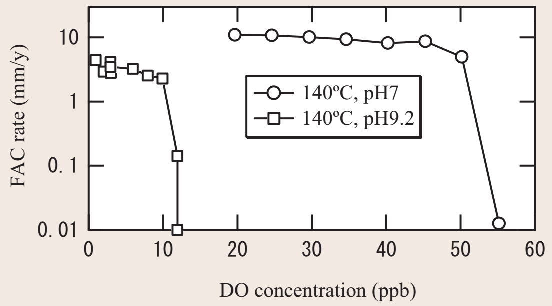
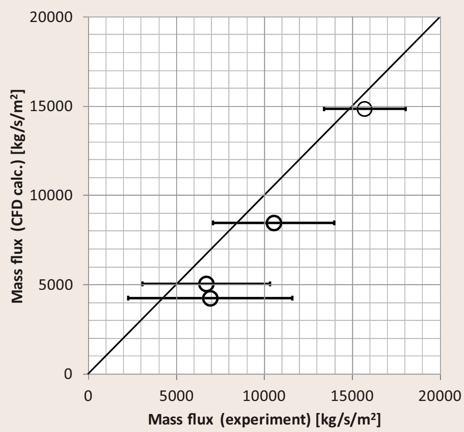
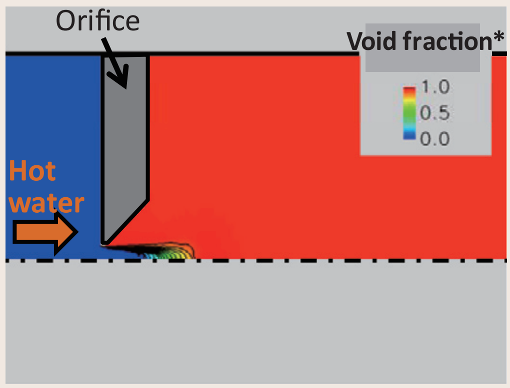


Fig. 1: Effect of dissolved oxygen concentration on the FAC rate of carbon steel

The FAC rate at 140°C in the solution with a pH of 7 is decreased by the dissolved oxygen of 40–60 ppb. More than 10 ppb of oxygen is effective for FAC suppression in a solution with a pH of 9.2, which simulates PWR secondary water.



(a) Mass flux comparison with the experiment



(b) Distribution of the void fraction around the orifice

Fig. 2: Calculation example of water-steam CFD code (flashing flow around orifice)

The sudden change of void fraction due to flashing around the orifice is calculated robustly, and the mass flux of flashing flow is validated. Utilizing this code, it becomes possible to evaluate flashing erosion in a plant piping system.

*Void fraction: the Fraction of the gas phase volume

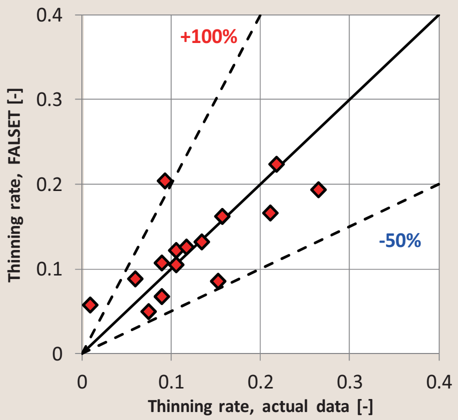


Fig. 3: Comparison of the measured and calculated results of thinning rates for an actual power plant (in the case of LDI)

By evaluating the unknown wetness condition using the partial data of thinning rate, the entire thinning rate data can be predicted with an accuracy of factor 2, approximately.

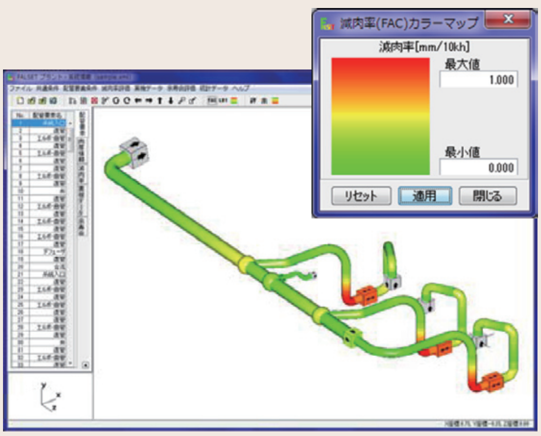


Fig. 4: Display example of the maximum thinning rate profile for a piping system by FALSET

FALSET is equipped with practical functions for management, and residual lifetime can be evaluated with CRIEPI's FAC/LDI prediction model.

Fig. 5: Failure mode of a wall- thinning elbow under an out-of-plane bending condition by hybrid testing (Pipe size; outer diameter is 216.3 mm; wall thickness is 5.8 mm)

In the case of a 75% defect and input seismic motion beyond the eight-times-larger amplitude of the design basis earthquake, which expanded allowable stress level, the torsion buckling deformation with an angle of 45 degrees can be observed.