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

Development of Life Assessment Technology for High Temperature Structural Components of High Chromium Steels

Background and Objective

Ultra-supercritical (USC) pressure thermal power plants supply power with high efficiency and large capacity. However, trouble caused by creep damage has occurred in various types of welded joints in the large-diameter high chromium steel pipes used in such plants. Such trouble adversely affects the stable operation of USC thermal power plants. The establishment of highly reliable diagnostic technologies for high-temperature equipment made of high-Cr steels is required as a preventive measure.

In this project, we aim to develop diagnostic techniques for assessing creep damage in girth welded and nozzle stub welded portions of the high-Cr steel pipes, which are vulnerable to creep damage, and to apply the technologies to the on-site maintenance and operation of facilities.

Main results

1 Formulating equations for evaluating the creep rupture life of welded joints

A number of data obtained by creep tests on small welded joint specimens made of typical high-Cr steels were analyzed by The Assessment Committee on Creep Data of High Chromium Steels, whose members are from all electric utilities that operate thermal power plants, plant and steel manufacturers, and research institutions. The equation for evaluating the creep rupture life formulated in FY2005 was also reviewed (Fig. 1).[1] The equation revised using the latest data and knowledge enables the long-term creep rupture life for welded joint materials to be evaluated with higher reliability than was previously possible. The validity of the revised equation has been accepted by the committee on Review on Reliability of High Temperature Strength Enhanced Ferritic Steels for Fitness-for-Service of Thermal Power Components, established by the Ministry of Economy, Trade and Industry, and is currently used in the management of operating USC plants.

2 Assessment of applicability of equations for evaluating the creep rupture life of girth welded portions

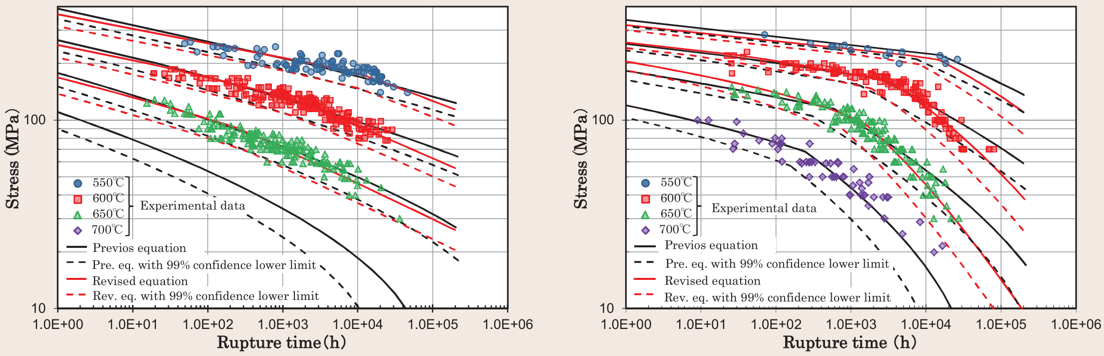
Girth welding is essential for connecting pipes in power stations. In assessing the creep rupture life of girth weld zones, axial stress should be appropriately considered. To achieve this, creep tests were carried out under conditions where a mechanical load for generating axial stress and an internal pressure were superimposed. Specimens were small cylinders equivalent to boiler tubes and large-diameter pipes with the dimensions of real piping (outer diameter, ≈700 mm). All specimens were made of 12Cr steel and had girth weld zones. Test results indicated that the revised equation estimates creep rupture lives shorter compared with experimental ones in the region where the contribution of axial stress is large (Fig. 2).

3 Assessment of the effect of welding conditions on creep strength

A uniaxial creep test was performed using a 9Cr steel joint specimen with a diagonal groove, which is frequently adopted in on-site welding. The creep rupture life of this specimen was approximately 60% that of a 9Cr steel joint specimen with a narrow groove, which is frequently adopted in shop welding (Fig. 3). Another uniaxial creep test was carried out using a specimen prepared by following the temperature history in the heat-affected zones of a material subjected to multilayer welding to clarify the mechanism underlying type IV cracking*1 and to assess the weld zone subjected to multiple welding passes. From the test results, the relationship between the temperature history and creep deformation characteristics was examined. The creep deformation characteristics strongly depended on the temperature history; a creep deformation rate of up to approximately 1000 times higher than that of the base metal was observed when the specimen was heated to around the transformation temperature range*2 of the microstructure. Thus, the quantitative information necessary to analyze the effect of the thermal history during welding on the strength of a material was obtained (Fig. 4).

*1 Pattern of an internal crack propagating in the fine-grain region of a welded heat-affected zone.
*2 Temperature range in which a crystal structure transforms from a body-centered cubic lattice to a face-centered cubic lattice. For high-Cr steels, the transformation temperature range is approximately 810-930°C.

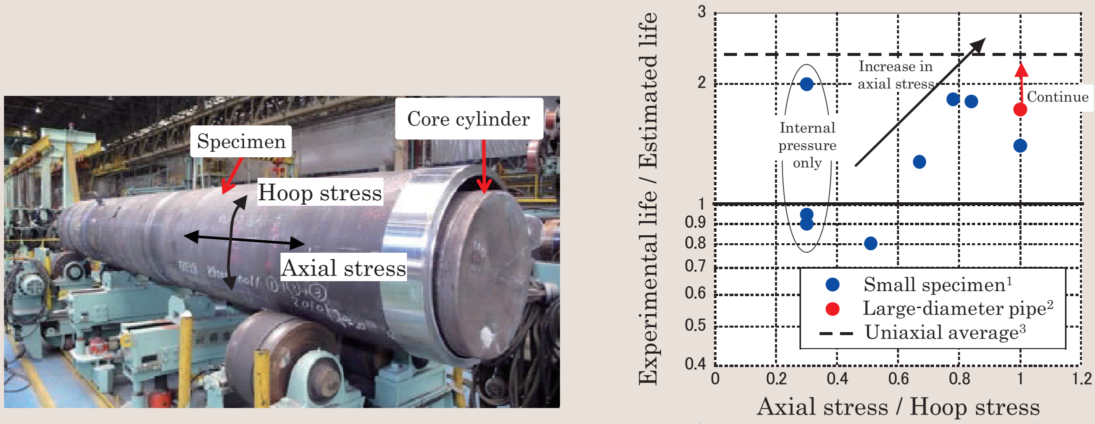
References: [1] M.Yaguchi, T. Matsumura and K. Hoshino, Proc. of ASME PVP2012 Conf., PVP2012-78393, 2012.



(1) 9Cr steel welded joint (2) 12Cr steel welded joint

Fig. 1: Creep data and creep curves obtained using equations for evaluating creep rupture life

Compared with previous equations, the equations revised using the latest data and knowledge estimate a shorter life for welded joints of the high chromium steels at 600°C, which is close to the temperatures of actual plants. Hence, the new equation has made it possible to estimate the critical rupture life of large-diameter high-Cr steel pipes with higher reliability than previously possible.



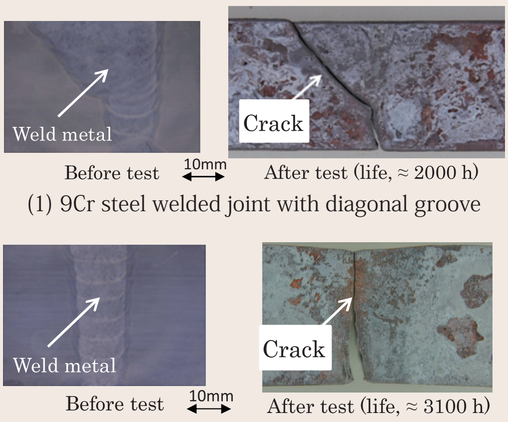
(1 Load condition: internal pressure + axial stress)
(2 Load condition: internal pressure + bending load)
(3 Mean values estimated under uniaxial tensile stress)

(1) Large-diameter pipe with dimensions of actual equipment (before test)

(2) Estimated creep rupture life of 12Cr steel girth joints

Fig. 2: Assessment of creep rupture life of girth welded portions

The demonstration test facility on structural integrity, BIPress, developed in our institute was used in a creep test on large-diameter pipes with the dimensions of an actual piping system. In the region of high axial stress, which may cause creep damage to girth welds, the revised equation tended to provide conservative estimation of creep life.



(1) 9Cr steel welded joint with diagonal groove

(2) 9Cr steel welded joint with narrow groove

Fig. 3: Effect of groove shape on creep rupture life (temperature, 650℃; stress, 60MPa)

Results indicate that welding conditions (particularly the groove angle) significantly affect the creep rupture life.

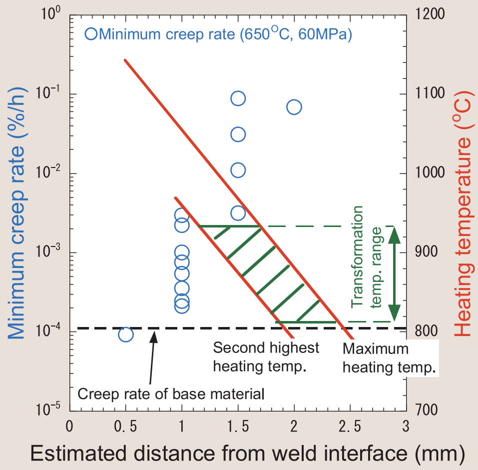


Fig. 4: Relationship between temperature history and creep rate

The creep deformation rate sharply increased when the peak heating temperatures during welding were in the transformation temperature range.