Effect of Stress Distribution of Thin Disk Specimen of Rupture Disk Corrosion Test on SCC Initiation of Nickel Alloys

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1. Introduction

Recently, the rupture disk corrosion test (RDCT) was newly developed as a real-time measurement method to evaluate the SCC initiation time of nickel alloys in high-temperature water [1]. In the RDCT method (Fig. 1), a flat disk specimen is first placed and fastened in specimen fixtures. Then, one side of a thin disk specimen made of a test material is exposed to high-temperature water simulating the primary water of PWRs, while the other side is maintained at atmosphere conditions. This pressure difference induces the deformation of the disk specimen in a dome-shape and tensile stress on a specific region of the disk specimen. While immersed in high-temperature water for a long time, SCC occurs on the disk specimen due to the tensile stress, leading to a rupture of the disk specimen or a water leakage. Therefore, SCC initiation can be detected in real-time from the pressure change.

In the previous work [1] on the measurement of SCC initiation time of Alloy 600 by using the RDCT method, it was reported that the crack initiation time decreased with the decrease of specimen thickness owing to the increase of applied stress on the disk surface exposed to the primary water. The result of SCC initiation time vs. applied stress was similar to data reported in other works on Alloy 600 materials having similar grain size and heat treatment history.

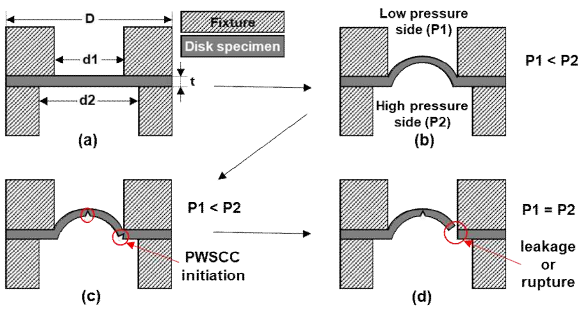

Fig. 1. Schematic diagram of RDCT method

Even though the RDCT method has a great capability for accurately measuring SCC initiation time, it is hard to directly measure stress on the disk specimen in high-temperature water. To overcome this, a finite element analysis (FEA) has been developed to calculate the applied stress and deformation of a disk specimen. In the previous work, the proper finite element (FE) model has been established with the tetrahedron model for the disk specimen.

In addition to the disk model, it is also crucial to establish a FE model of the other parts of the RDCT apparatus that contact and influence the deformation of the disk specimen for more accurate calculation of the applied stress. In this study, we consider these parameters in the calculation of stress distribution of the disk specimen using FEA. For considering the specimen fixture that makes contact with the disk specimen, 3D modeling was carried out using ABAQUSTM. The effects of the friction and shape of the specimen fixture were investigated using a contact analysis. The stress distribution calculated by FEA was compared with the experimental findings from RDCT in terms of the maximum stress location and SCC initiation site.

2. Finite Element Analysis

Fig. 2 shows one of FE models established for the RDCT apparatus including the disk specimen with a thickness of 0.1 mm and seed size of 0.1 mm, the fixture A with a dimension of d1 = 5.0 mm and Rc = 0.5 mm, and the gasket with a dimension of d2 = 8.0 mm. For the simplified contact analysis in FEA, the mesh design of the rounded-corner of the fixture A was set as a tetrahedron model (C3D10) with a seed size of 0.2 mm which was much finer than non-sliding boundaries.

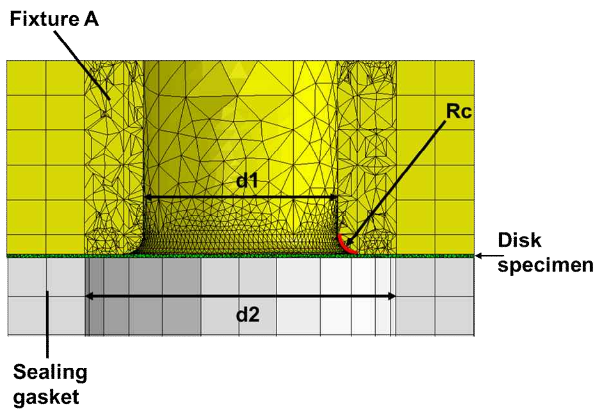

Fig. 2. Finite element model of the disk specimen, fixture A, and sealing gasket in the finite element analysis (d1 = 5.0 mm, d2 = 8.0 mm, Rc = 0.5 mm).

3. Results and Discussion

Fig. 3 presents the Von Mises stress profile on the disk specimen in the high-pressure side along the distance from the disk center in the radial direction, calculated from the FEA with various rounded corner radius Rc. As Rc increased from 0.5 mm to 2.0 mm, the location where the maximum stress was applied shifted from the dome edge to the dome center, and the maximum value decreased. On the other hand, from the FEA with various friction coefficients, it was found that the friction between the fixture A and disk specimen has little effect on the stress distribution.

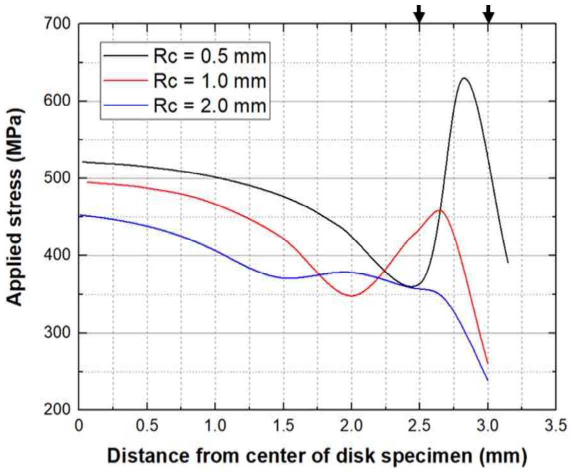

Fig. 3. Von Mises stress calculated to be applied on the deformed disk specimen in the primary water side as a function of rounded-corner radius Rc = 0.5, 1.0, 2.0 mm with a friction coefficient μ = 0.3 by FEA.

SCC initiation tests were carried out by using the RDCT apparatus with the fixture A having a different Rc of 0.5 mm and 2.0 mm. Fig. 4 shows the SEM images of the disk specimen surface in the primary water side after the SCC initiation test with disk thickness = 0.099 mm, d1 = 2.0 mm, d2 = 8.0 mm, and Rc = 2.0 mm (the applied stress calculated from FEA = 440 MPa). Intergranular (IG) SCC was found near the disk center (0.5 mm distance from the center) in the primary water side after exposure time of 868 h.

Fig. 5 gives the distribution of the SCC initiation site counted from the disk specimens tested in the RDCT apparatus with the fixture A having a different Rc of 0.5 mm and 2.0 mm. SCC initiated at the dome edge when Rc was 0.5 mm, while SCC initiated near the disk center when Rc was 2.0 mm. This result matches with the stress distribution calculated from the FEA. To compare the results of this work with the previous results obtained by using the typical uni-axial loading method, the difference in loading direction should be considered further.

4. Conclusion

In this study, a parametric study was carried out on the stress distribution of the thin disk specimen of RDCT in terms of the friction coefficient and the rounded-corner radius of the specimen fixture using FEA. From the SCC initiation tests, it was found that the SCC initiated at the dome edge when Rc was 0.5 mm, while the SCC initiated near the disk center when Rc was 2.0 mm, which is in good agreement with the stress analysis results by FEA.

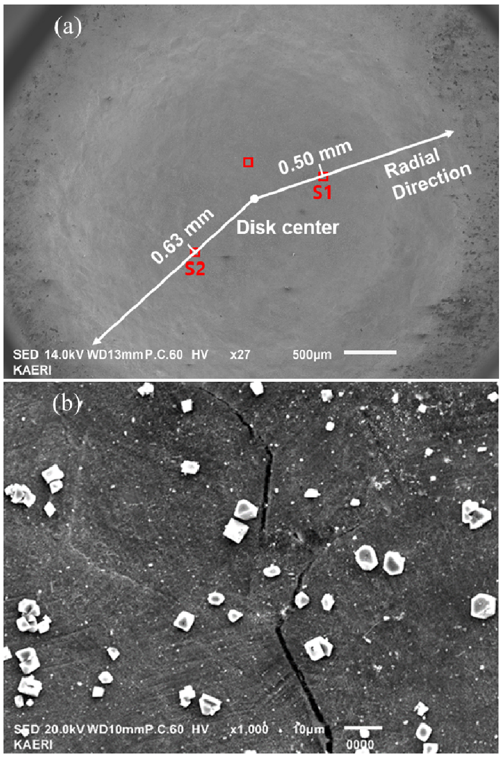

Fig. 4. (a) SEM image of the disk surface on the primary side after SCC initiation test (a rounded-corner radius, Rc = 2.0 mm), and (b) magnified images of crack S1

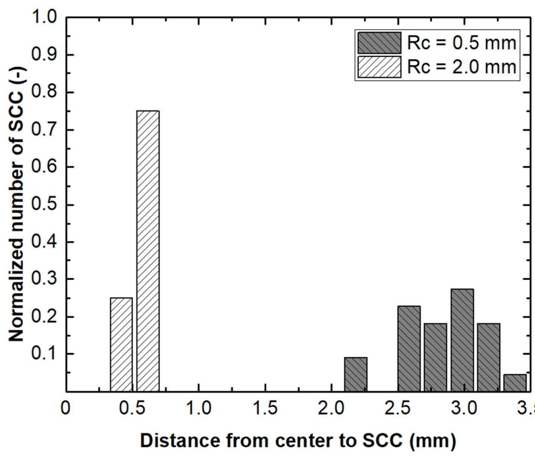

Fig. 5. Number of SCC initiated on disk specimens after the RDCT test with the fixture A with Rc of 0.5 mm and 2.0 mm.

REFERENCES

[1] G.W. Jeon, S.W. Kim, D.J. Kim et al., New Test Method for Real-Time Measurement of SCC Initiation of Thin Disk Specimen in High-Temperature Primary Water Environment, Nuclear Engineering and Technology, 54 (2022) 4481-4490.