



Original Article

Parametric study on stress distribution of thin disk specimen of rupture disk corrosion test influencing SCC initiation using finite element analysis

Tae Young Kim^{a,b}, Sung Woo Kim^{a,*}, Dong Jim Kim^a, Sang Tae Kim^b^a Material Safety Technology Research Division, Korea Atomic Energy Research Institute, Daedeok-daero 989-111, Yuseong-gu, Daejeon, 34057, Republic of Korea^b Department of Nuclear Engineering, Hanyang University, Wangsimni-ro 222, Seoul, Seongdong-gu, 04763, Republic of Korea

ARTICLE INFO

Keywords:

Finite element analysis
Friction coefficient
Rupture disk corrosion test
Stress corrosion cracking
Thin disk specimen

ABSTRACT

Rupture disk corrosion test (RDCT) method has been recently developed for real-time measurement of initiation of stress corrosion cracking (SCC) in a high-temperature water. This work presents a parametric study on the stress distribution of a thin disk specimen of RDCT to consider the fixture shape and friction using finite element analysis (FEA). The FEA results showed a dome-shaped deformation of the specimen. From the stress analysis as a function of friction coefficient, it was suggested that the maximum stress was applied around the dome-edge, which was invariant with change to the friction coefficient. This indicates that friction between the fixture and the specimen has little effect on stress distribution. On the other hand, the stress analysis as a function of a rounded-corner radius (Rc) revealed the location at which the maximum stress was applied shifted from the dome edge to the dome center as Rc increased. From SCC initiation tests using the RDCT apparatus in a primary water environment, it was found that SCC initiates at the dome edge when Rc is 0.5 mm, while SCC initiates near the disk center when Rc is 2.0 mm. This experimental result is in good agreement with the results of FEA.

1. Introduction

The main components of pressurized water reactors (PWRs) in a pressure boundary are made of corrosion-resistant alloys such as nickel alloys and stainless steels. However, those alloys have been known to show many types of corrosion behaviors over a long period of operation time. Among corrosion behaviors, stress corrosion cracking (SCC) is an important corrosion mechanism because the failure of these components can cause the loss of cooling water that can lead to the LOCA (loss of coolant accident) and leakage of radioactive materials [1–4]. To secure the integrity of components from failure, it is important to predict the initiation time of SCC and repair the degradation proactively for the long-term operation of PWRs.

Recently, to evaluate the SCC initiation time of nickel alloys in high-temperature water, the rupture disk corrosion test (RDCT) was newly developed as a real-time measurement method [5]. Fig. 1 shows the schematic diagram of the test procedure of the RDCT method [5]. In Fig. 1(a)–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 as shown in Fig. 1(b). While immersed in high-temperature water for a long time, SCC occurs on the disk specimen due to the tensile stress (Fig. 1(c)), leading to a rupture of the disk specimen or a water leakage (Fig. 1(d)). Therefore, SCC initiation can be detected in real-time from the pressure change. In the previous work on the measurement of SCC initiation time of Alloy 600 by using the RDCT method [5], 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 [5].

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 [6], the proper finite element (FE) model has been established for the disk specimen by analyzing its sensitivity of design parameters with various mesh designs such as a hexahedron, hex-dominated, and tetrahedron

* Corresponding author.

E-mail address: kimsw@kaeri.re.kr (S.W. Kim).<https://doi.org/10.1016/j.net.2024.03.019>

Received 20 September 2023; Received in revised form 22 February 2024; Accepted 14 March 2024

Available online 15 March 2024

1738-5733/© 2024 Korean Nuclear Society. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

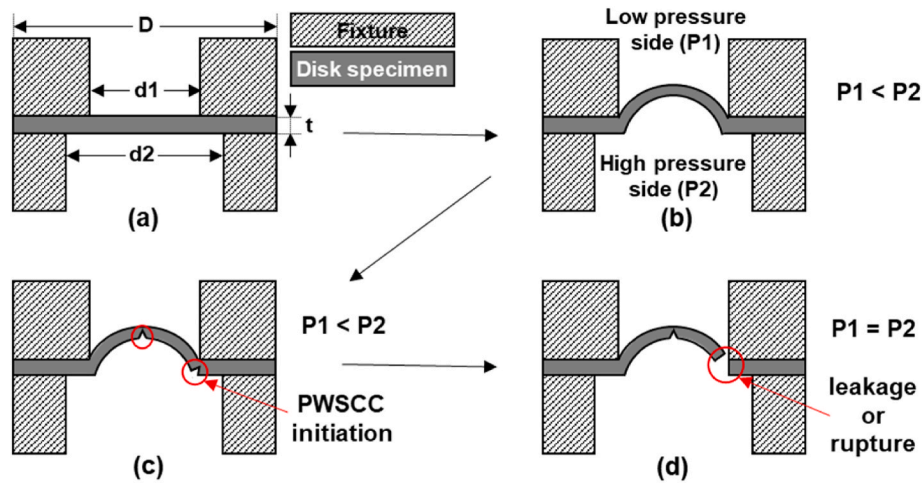


Fig. 1. Schematic diagram of the RDCT method: (a) a flat disk is placed in the specimen fixtures, (b) the disk specimen is deformed in a dome-shape by exposure to primary water in the high-pressure side, (c) SCC initiates on the deformed disk specimen, and (d) water leakage or disk rupture occurs leading to a pressure change in the low-pressure side [5].

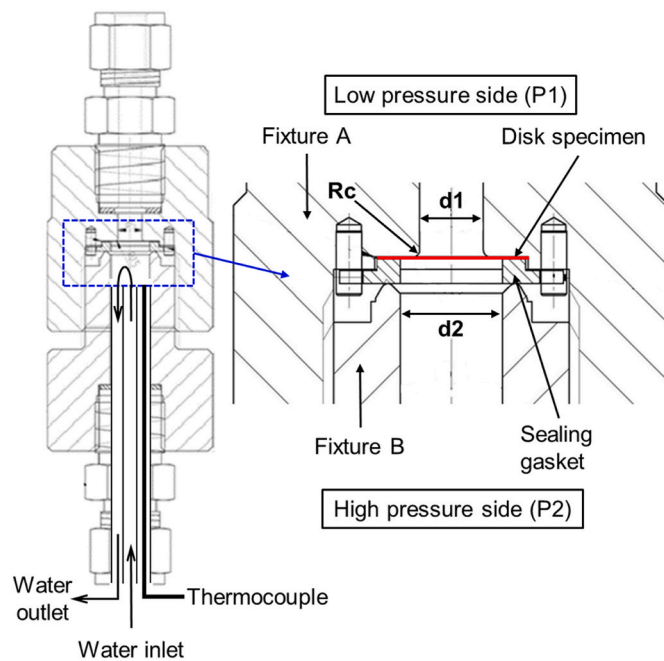


Fig. 2. Drawing of the RDCT apparatus with the cross-sectional view of the disk specimen placed in the fixtures and sealing gasket.

model. All FE models simulated similar deformation behavior in a dome shape, which coincided with the deformed disk specimen after the SCC initiation experiment using the RDCT method. However, there was a remarkable discrepancy in applied stress on the disk specimen; the maximum stress was applied at the center of the dome in the hex-dominated model, while the maximum stress was applied at the edge of the dome in the hexahedron and tetrahedron models. By comparing this with the experimental results of the SCC initiation test using the RDCT method, the optimal mesh design was determined to be the tetrahedron model for the disk specimen.

Table 1
Chemical compositions of Alloy 600 (wt %).

Cr	Fe	Si	Mn	C	Cu	P	S	Ni
16.11	8.83	0.34	0.26	0.062	0.02	0.005	0.001	Bal

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. Similar contact analyses have been performed for the small punch (SP) test using FEA [7–13]. The SP test is used to measure mechanical properties of materials such as tensile strength, fracture toughness, creep properties, etc. by utilizing a test specimen in the form of a thin disk. From a sensitivity analysis for the design parameters of the SP test apparatus, it was found that there are several key parameters such as disk thickness, ball diameter, die corner radius, and friction among disk, ball and die contacting with each other.

Like the SP test, the deformation and stress distribution of the disk specimen in the RDCT method may also be affected by the shape of the specimen fixture and friction between the specimen and the fixture. Therefore, 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 ABAQUS™. 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. Rupture disk corrosion test (RDCT) method

Fig. 2 shows a drawing of the RDCT apparatus and the cross-sectional view of the disk specimen placed in fixtures and a sealing gasket. In Fig. 2, d1 is the inner diameter of the fixture A (female connector) in the low-pressure side, d2 is the inner diameter of the gasket and fixture B (male connector) in the high-pressure side, and Rc is the radius of the rounded-corner of the fixture A. In experiments and simulations, d2 was fixed as 8.0 mm, d1 was varied from 2.0 mm to 5.0 mm and Rc was varied from 0.5 mm to 2.0 mm, satisfying the constrained condition of $d1 + 2Rc = 6.0$ mm which was lower than d2 to avoid any involvement of a compressive stress by fastening fixtures in SCC initiation on the specimen surface in the primary water side. The fixtures were made of Type 316 stainless steel and the gasket was made of Ni 200.

The diameter of the disk specimen was fixed as 12.0 mm, and the thickness was varied from 0.1 mm to 0.2 mm depending on a desired stress on the specimen. To prepare the disk specimen, flat disks with a 12.0 mm diameter and 0.5 mm thickness were first machined from the test material using electrical discharge machining (EDM). The machined disk was mounted on AccuStop™ holder with Crystalbond™ wax for surface grinding and polishing. The surface of the mounted specimen

Table 2
Mechanical properties of Alloy 600.

Temperature (°C)	Yield strength (MPa)	Ultimate tensile strength (MPa)	Total elongation (%)
25	254	671	50.9
350	222	613	44.6

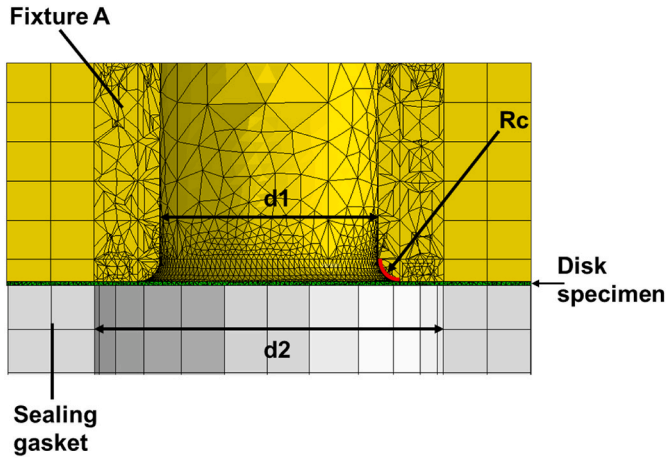


Fig. 3. Finite element model of the disk specimen, fixture A, and sealing gasket in the finite element analysis ($d1 = 5.0$ mm, $d2 = 8.0$ mm, $Rc = 0.5$ mm).

was ground to a target thickness with abrasive paper up to 2000 grit, and then polished with 1 μ m alumina and 0.3 μ m diamond suspension. The final thickness of disk specimen was measured using a micrometer at ten different points and confirmed to have a thickness variation less than 0.01 mm. In this work, the test material was Alloy 600 (solution annealed at 950 °C and water quenched). Tables 1 and 2 list the chemical composition and mechanical properties of the test material, respectively.

The SCC initiation experiments were performed using an RDCT facility with a primary water loop system. To simulate typical primary water chemistry in PWRs, the test solution was made by dissolving 1200 ppm B (as H_3BO_3) and 2.2 ppm Li (as $LiOH$) in distilled water to have a pH of 6.4, conductivity of 23 μ S/cm, dissolved oxygen less than 5 ppb, and dissolved hydrogen of 22 cc/kg- H_2O . The pressure applied to the specimen on the primary water side was steadily increased to 20 MPa

over an hour, followed by heating to the test temperature of 360 °C for acceleration of SCC initiation. In the RDCT apparatus, the primary water is injected to the vicinity of the specimen surface through a 1/16 inch tube and flows out through a 1/4 inch tube in a double-wall tube configuration as shown in Fig. 2, to maintain the local water chemistry as constant. More detailed experimental procedures are described in previous work [5]. When a pressure change or water leakage was detected, the specimen was observed with an optical microscope (OM) and scanning electron microscope (SEM).

3. Finite element analysis (FEA) method

In the previous study [6], the best mesh design for thin disk specimen was established by comparing three different models, i.e. hexahedron, hex-dominated, and tetrahedron in terms of mesh type, seed size and the disk thickness, without considering the friction and shape of fixtures. All models showed a similar dome-shaped deformation behavior of the disk specimen. However, there was a considerable difference in the stress distribution and expected location of SCC initiation on the disk specimen. From comparison of FEA results with the deformation behavior and PWSCC location on the disk specimen after the SCC experiments using the RDCT method, the best estimate FE model with efficient simulation time for disk specimen having a thickness ranging from 0.1 mm to 0.2 mm was found to be the tetrahedron C3D10 (10 nodes and 4 integration points) model with a seed size of 0.1 mm.

In addition to the disk model, FE models of the other parts of the RDCT apparatus that contact and influence the deformation of the disk specimen were established in this work. Fig. 3 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. When the disk specimen is deformed by the pressure difference, a contact occurs between the specimen surface and the rounded-corner of the fixture A in the low-pressure side. For the simplified contact analysis in FEA, therefore, 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. 4 illustrates the contact surface of the specimen fixture and the disk specimen. The contact surface of the fixture A (indicated by the red area in Fig. 4(a)) is set as the master surface (higher stiffness and lower mesh density), and the contact surface of the disk specimen in the low-pressure side (indicated by the violet area in Fig. 4(b)) is set as the slave

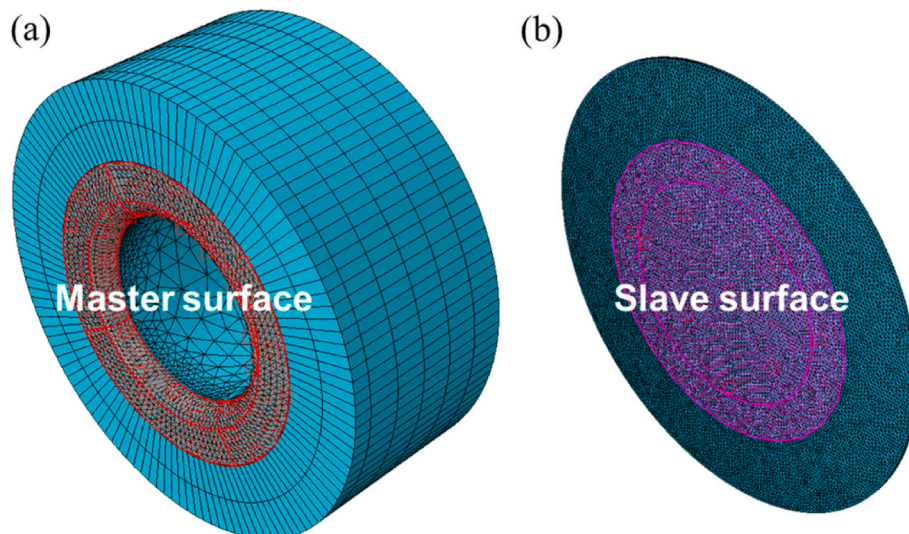


Fig. 4. Contact surface of (a) the fixture A set as a master surface and (b) the disk specimen set as a slave surface.

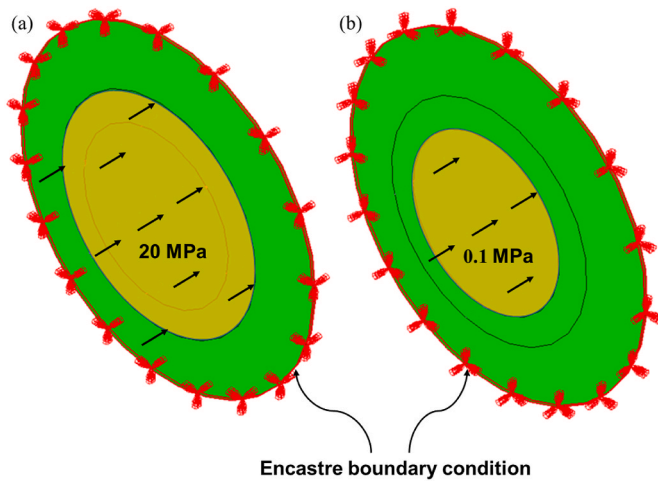


Fig. 5. Schematic diagrams of the load and boundary conditions of the disk specimen in the (a) high-pressure side and (b) low-pressure side.

surface (lower stiffness and higher mesh density) [14]. In the FE modeling, a finite sliding formulation and a discretization in surface to surface are used as the contact condition with various friction coefficients (μ) of 0.1, 0.3 and 0.5.

Fig. 5 shows the load and boundary condition of the disk specimen. The load condition is set as the pressure applied on the disk specimen; 20 MPa on the high-pressure side (yellow region in Fig. 4(a)) and 0.1 MPa on the low-pressure side (blue region in Fig. 4(b)). The ENCASTRE

boundary condition, $U1=U2=U3=UR1=UR2=UR3 = 0$ (neither displacement nor rotation), given in ABAQUS™ [14] was applied at the disk rim.

4. Results and discussion

Fig. 6 presents the cross-sectional snapshot of the deformation of the disk specimen (thickness = 0.1 mm, seed size = 0.1 mm) and von-Mises stress of the deformed disk specimen calculated by FEA considering the fixture A and sealing gasket as a function of friction coefficient ($\mu = 0.1, 0.3, 0.5$) with constant dimensions of $d1 = 5.0$ mm, $d2 = 8.0$ mm and $Rc = 0.5$ mm. All models showed dome-shaped deformation of the disk specimen toward the low-pressure side in the apparatus. This is similar to the deformation behavior simulated by FEA of the disk specimen itself [5,6], because the disk is much thinner than other parts of the apparatus acting as rigid body in FEA. The von-Mises stress distribution revealed that tensile stress was applied on both center and edge of the dome. Since SCC can initiate on the disk surface exposed to the primary water, the stress profile on the high-pressure side was extracted from the FEA results in Fig. 6 and plotted along the distance from the disk center in the radial direction as shown in Fig. 7. In Fig. 7, the applied stress is the engineering stress that is converted from the von-Mises stress using the equivalent strain distribution on the disk surface in the high-pressure side. The maximum stress is applied around the edge of dome, and the maximum value is nearly the same regardless of the friction coefficient. This means that the friction between the fixture A and disk specimen has little effect on the stress distribution.

Fig. 8 shows the cross-sectional snapshot of the deformation of the disk specimen (thickness = 0.1 mm, seed size = 0.1 mm) and the von-

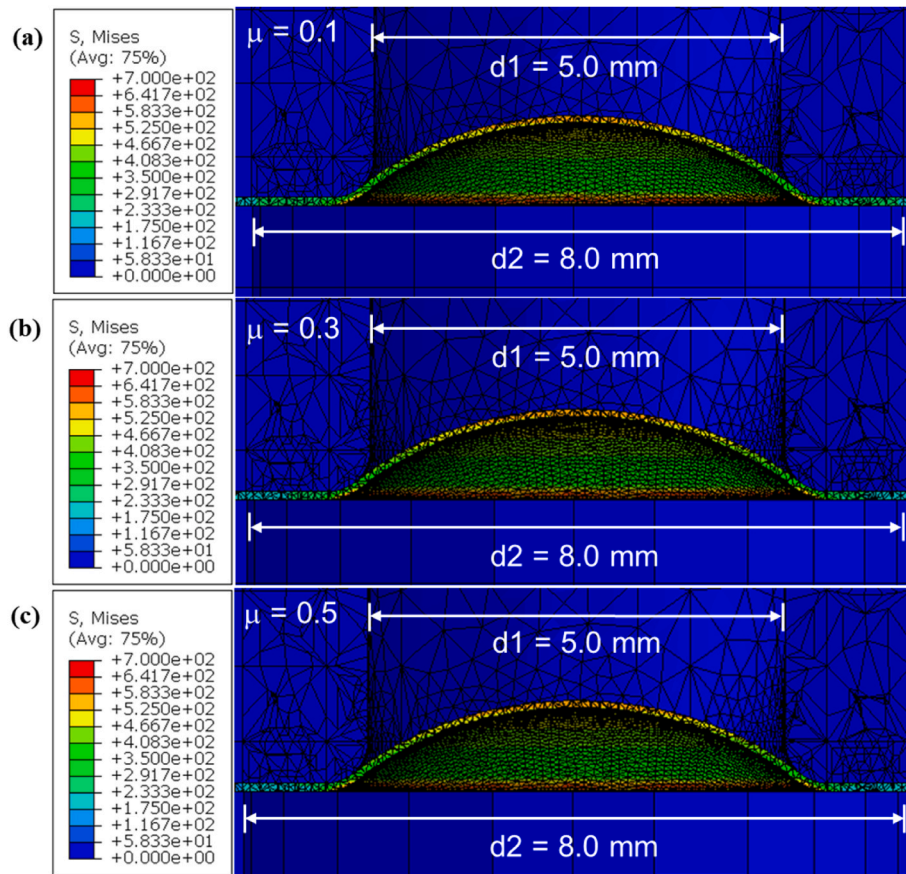


Fig. 6. Cross-sectional snapshot of the deformation of the disk specimen and von-mises stress distribution of the deformed disk specimen calculated in consideration of the fixture A and sealing gasket as a function of friction coefficient ($\mu = 0.1, 0.3, 0.5$) with constant dimensions of $d1 = 5.0$ mm, $d2 = 8.0$ mm and $Rc = 0.5$ mm by FEA.

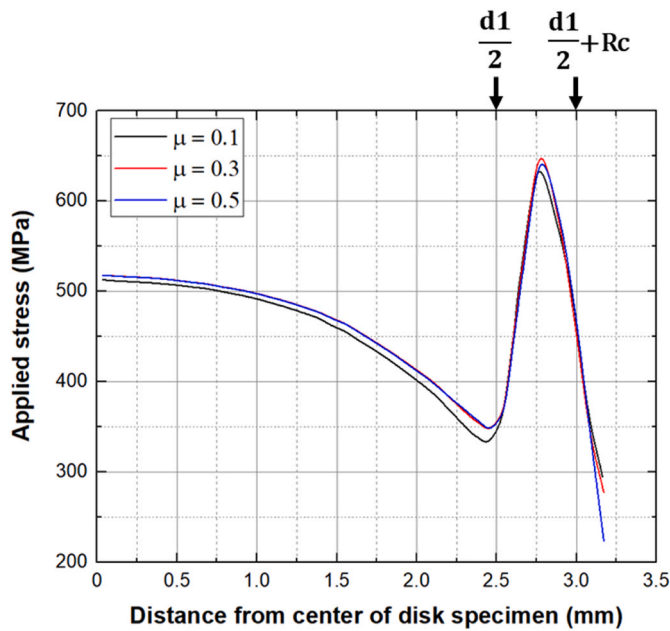


Fig. 7. Applied stress calculated on the deformed disk specimen in the primary water side along the distance from the disk center in consideration of the fixture A and sealing gasket as a function of friction coefficient ($\mu = 0.1, 0.3, 0.5$) with constant dimensions of $d_1 = 5.0$ mm, $d_2 = 8.0$ mm and $R_c = 0.5$ mm by FEA.

Mises stress of the deformed disk specimen calculated by FEA

considering the fixture A and sealing gasket as a function of the rounded corner radius of the fixture A, $R_c = 0.5$ mm ($d_1 = 5.0$ mm), $R_c = 1.0$ mm ($d_1 = 4.0$ mm), and $R_c = 2.0$ mm ($d_1 = 2.0$ mm) with constant friction coefficient, $\mu = 0.3$. All models revealed a similar dome-shaped deformation of the disk specimen toward the low-pressure side of the apparatus. However, the curvature of the dome-edge and height of the dome tended to decrease with increase of R_c and decrease of d_1 . This leads to considerable change in the stress distribution on the disk specimen. For more detailed analysis, the stress profile on the high-pressure side was extracted from the FEA results in Fig. 8 and plotted along the distance from the disk center in the radial direction as shown in Fig. 9. As R_c increased from 0.5 mm to 2.0 mm (as d_1 decreased from 5.0 mm to 2.0 mm accordingly), the location where the maximum stress was applied shifted from the dome edge to the dome center, and the maximum value decreased.

SCC initiation tests were carried out by using the RDCT apparatus with the fixture A having a different R_c of 0.5 mm and 2.0 mm. Fig. 10 shows the SEM images of the disk specimen surface in the primary water side after the SCC initiation test with disk thickness = 0.132 mm, $d_1 = 5.0$ mm, $d_2 = 8.0$ mm, and $R_c = 0.5$ mm (the applied stress calculated from FEA = 433 MPa). As shown in Fig. 10(a), cracks were found near the dome edge of the disk specimen in the primary water side after exposure time of 899 h. The magnified SEM images shown in Fig. 10(b) and (c) reveal that all cracks initiated and extended along the grain boundaries, a fracture morphology which is known as a typical SCC feature of Alloy 600 in the primary water environment. Fig. 11(a) presents the SEM images of the disk specimen surface in the primary water side after the SCC initiation test with disk thickness = 0.099 mm, $d_1 = 2.0$ mm, $d_2 = 8.0$ mm, and $R_c = 2.0$ mm (the applied stress calculated

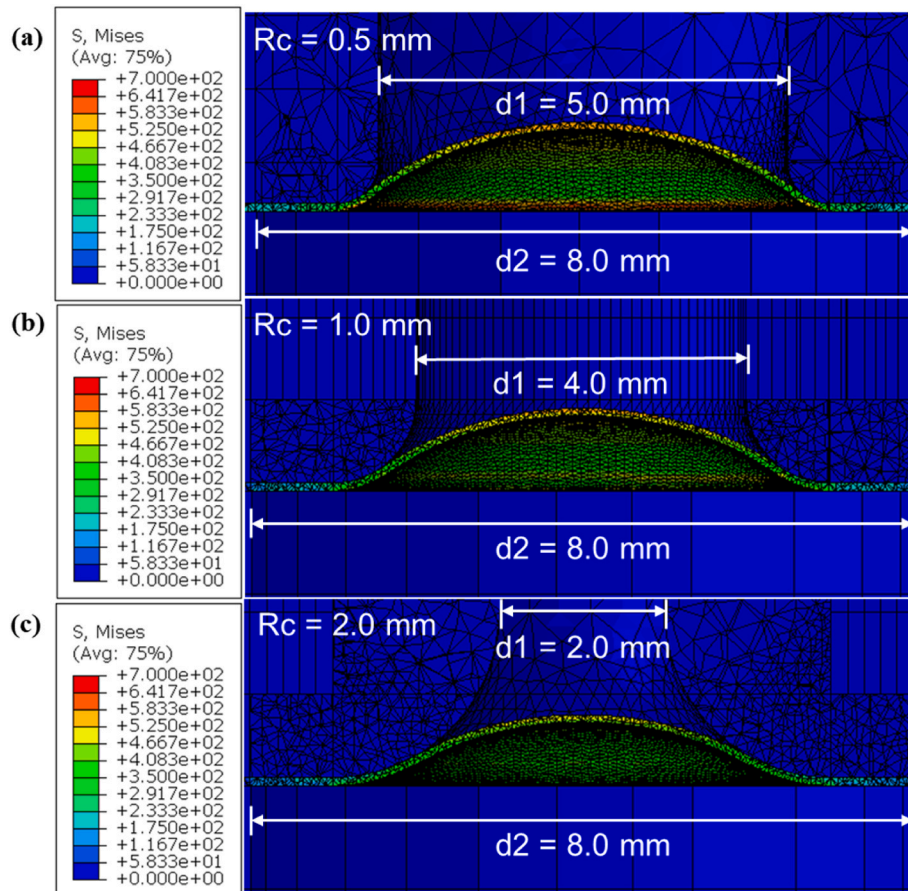


Fig. 8. Cross-sectional snapshot of the deformation of the disk specimen and von-mises stress distribution of the deformed disk specimen calculated in consideration of the fixture A and sealing gasket as a function of rounded-corner radius (a) $R_c = 0.5$ mm ($d_1 = 5.0$ mm), (b) $R_c = 1.0$ mm ($d_1 = 4.0$ mm), and (c) $R_c = 2.0$ mm ($d_1 = 2.0$ mm) with constant friction coefficient, $\mu = 0.3$ by FEA.

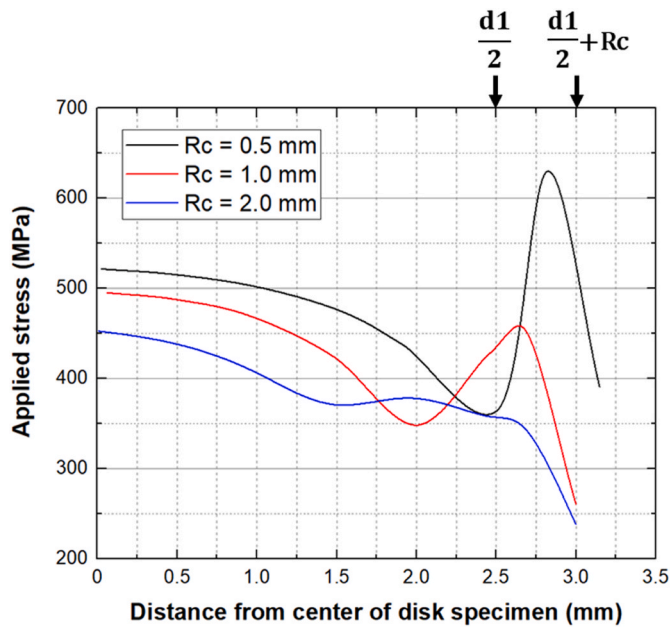


Fig. 9. Applied stress calculated on the deformed disk specimen in the primary water side along the distance from the disk center in consideration of the fixture A and sealing gasket as a function of rounded-corner radius (a) $R_c = 0.5$ mm ($d_1 = 5.0$ mm), (b) $R_c = 1.0$ mm ($d_1 = 4.0$ mm), and (c) $R_c = 2.0$ mm ($d_1 = 2.0$ mm) with constant friction coefficient, $\mu = 0.3$ by FEA.

from FEA = 440 MPa). IGSCC was found near the disk center (0.5 mm distance from the center) in the primary water side after exposure time of 868 h, as shown in Fig. 11(b) and (c). It is noteworthy that the SCC initiation occurred nearly at the same time period when the similar stress was applied even though dimensions of the disk and fixture were different. In addition, the SCC initiation time measured in this work fell within the range of those data reported for similar test conditions in recent works [5,15,16].

Fig. 12 shows the distribution of the SCC initiation site counted from the disk specimens tested in the RDCT apparatus with the fixture A having a different R_c of 0.5 mm and 2.0 mm (three disk specimens tested with $R_c = 0.5$ mm, two disk specimens tested with $R_c = 2.0$ mm). SCC initiated at the dome edge when R_c was 0.5 mm, while SCC initiated near the disk center when R_c was 2.0 mm. This result matches with the stress distribution calculated from the FEA shown in Fig. 9, that is, the applied stress is the maximum at the dome edge when R_c is 0.5 mm, while the stress is the maximum at the disk center when R_c is 2.0 mm. Based on the parametric analysis, it was concluded that the FE model of the RDCT apparatus including the disk specimen, fixture A and sealing gasket was well established, thereby providing a more accurate calculation of the applied stress on the disk specimen as compared to the previous model [5,6].

5. 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. The following conclusions were drawn from the FEA and experimental results.

The FE model of the disk specimen with fixture A and a sealing gasket in the RDCT apparatus showed a dome-shaped deformation of the disk specimen. From the stress analysis using FE models with various friction coefficients, the maximum stress was expected to be applied around the dome edge, and the maximum value to be nearly the same regardless of the friction coefficient. This means that the friction between the fixture A and disk specimen has little effect on the stress distribution. On the

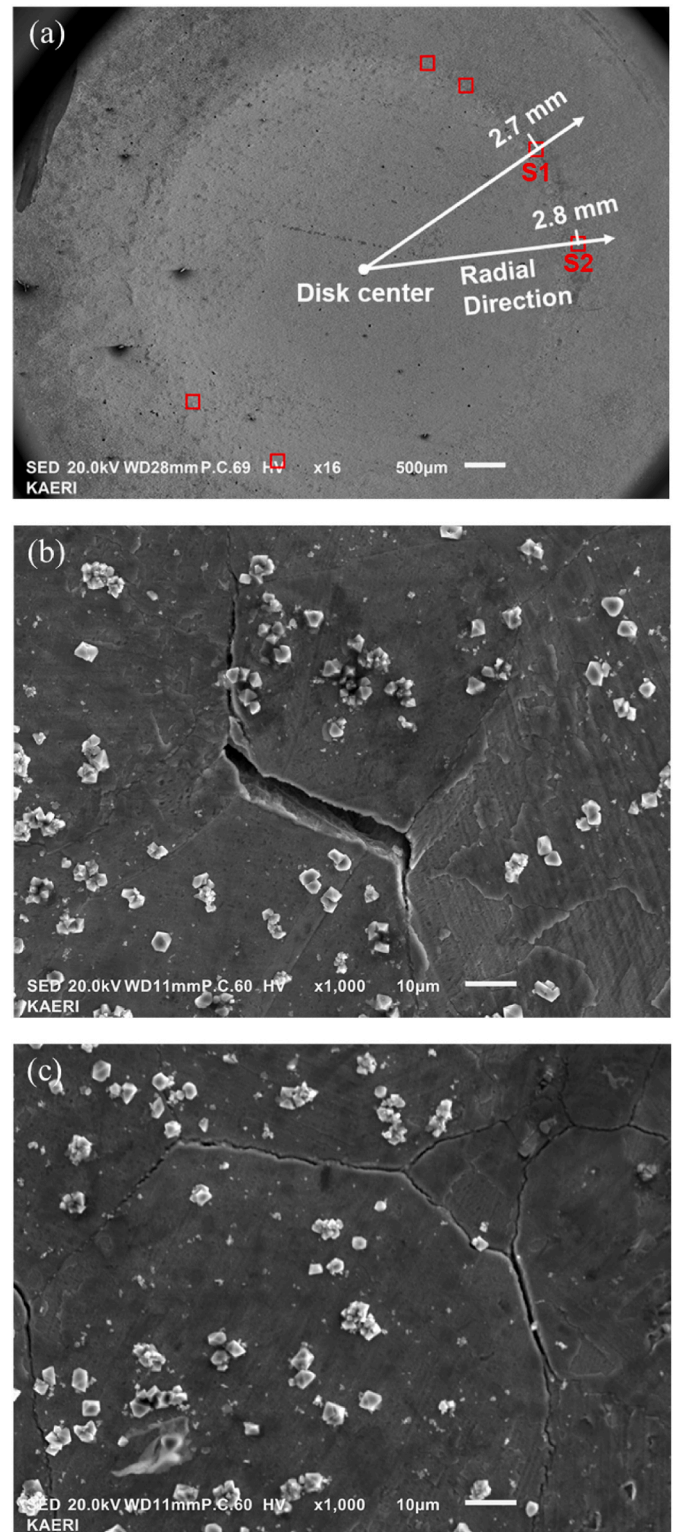


Fig. 10. (a) SEM image of the disk surface on the primary side after SCC initiation test (a rounded-corner radius, $R_c = 0.5$ mm), and magnified images of (b) crack S1 and (c) crack S2.

other hand, the stress analysis using FE models with various rounded-corner radii showed that the location at which the maximum stress was applied shifted from the dome edge to the dome center when R_c increased from 0.5 mm to 2.0 mm. From the SCC initiation tests using the RDCT apparatus with the fixture A having different R_c , it was found that the SCC initiated at the dome edge when R_c was 0.5 mm, while the

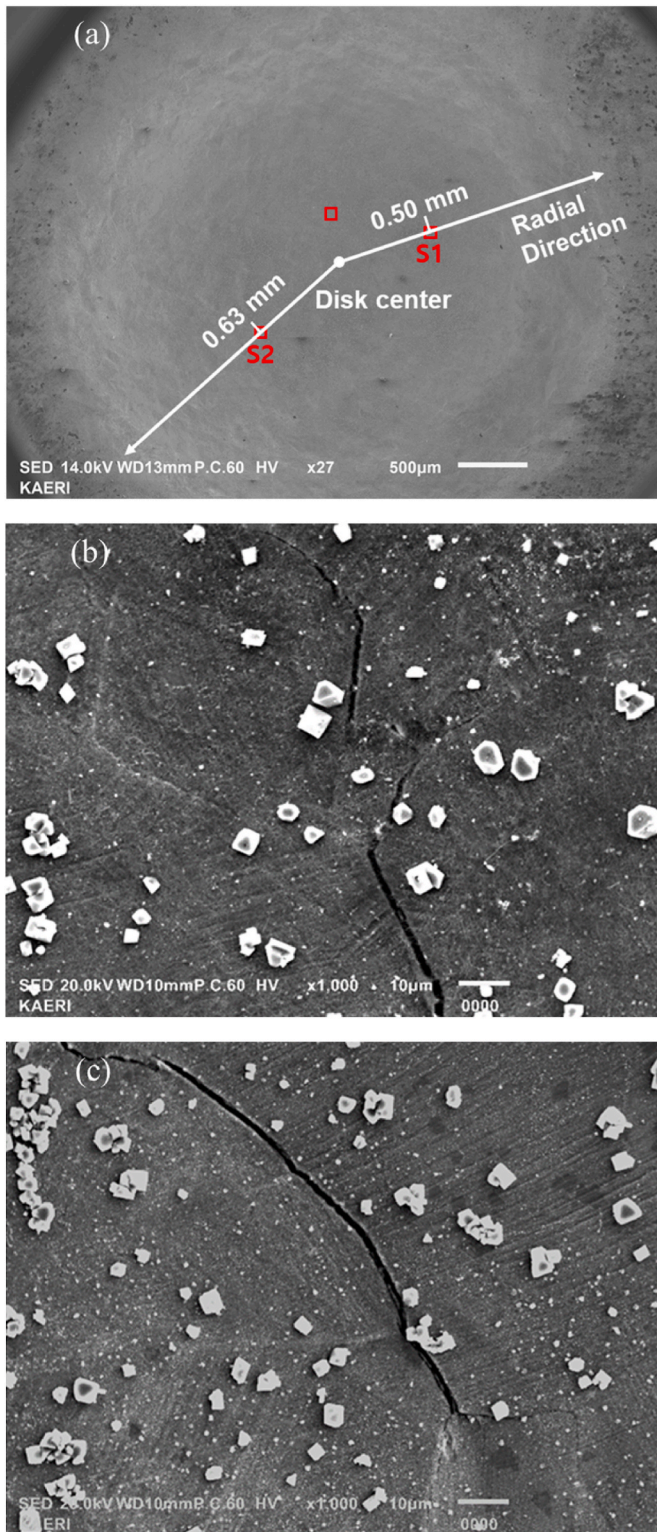


Fig. 11. (a) SEM image of the disk surface on the primary side after SCC initiation test (a rounded-corner radius, $R_c = 2.0$ mm), and magnified images of (b) crack S1 and (c) crack S2.

SCC initiated near the disk center when R_c was 2.0 mm. This experimental result is in good agreement with the stress analysis results by FEA.

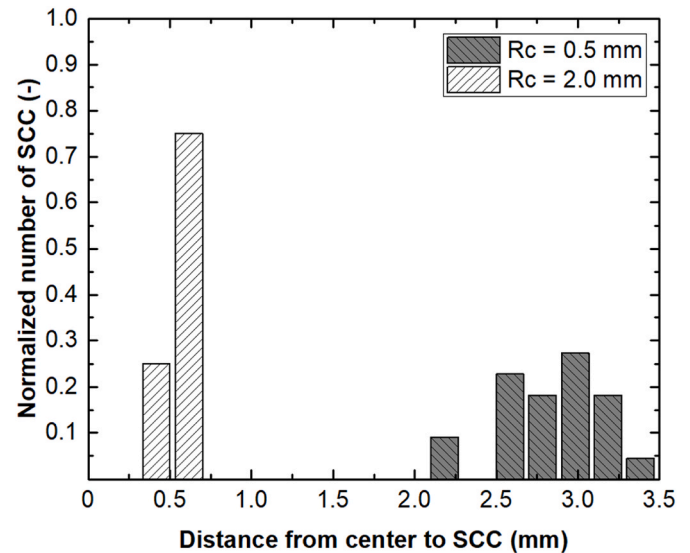


Fig. 12. Normalized number of SCC initiated on disk specimens in the primary water side after the RDCT test with the fixture A having a rounded-corner radius (R_c) of 0.5 mm and 2.0 mm.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This research was supported by the Korean Nuclear R&D Program (2021M2E4A1037979) through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, and partially funded by the Korean R&D program (RS-2022-00143718).

References

- [1] D. Feron, J.M. Olive (Eds.), *Corrosion Issues in Light Water Reactors – Stress Corrosion Cracking*, Woodhead Publishing Ltd, New York, 2007.
- [2] M. Le Calvar, I. De Curières, Corrosion issues in pressurized water reactor (PWR) systems, *Nucl. Corros. Sci. Eng.* (2012) 473–547.
- [3] S.S. Hwang, M.J. Choi, S.W. Kim, D.J. Kim, Review of factors affecting IASCC initiation of stainless steels in PWRs, *Corrosion Science and Technology* 20 (2021) 210–229.
- [4] François Cattant, Didier Crusset, Damien Féron, Corrosion issues in nuclear industry today, *Mater. Today* 11 (2008) 32–37, [https://doi.org/10.1016/S1369-7021\(08\)70205-0](https://doi.org/10.1016/S1369-7021(08)70205-0).
- [5] 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*, 2022, <https://doi.org/10.1016/j.net>.
- [6] T.Y. Kim, S.W. Kim, D.J. Kim, S.T. Kim, Finite Element Analysis of Stress and Strain Distribution on Thin Disk Specimen for Initiation Test in High Temperature and Pressure Environment, *Corrosion Science and Technology*, 2023, <https://doi.org/10.14773/CST.2023.22.1.44>.
- [7] I. Simonovski, S. Holmström, M. Bruchhausen, Small punch tensile testing of curved specimens: finite element analysis and experiment, *Int. J. Mech. Sci.* 120 (2017) 204–213.
- [8] K.F. Nilsson, D. Baraldi, S. Holmström, I. Simonovski, A Numerical and Experimental Assessment of the Small Punch Creep Test for 316L(N) Stainless Steels, *Metals*, 2021.
- [9] V. Brown, *Finite Element Modelling of the Small Punch Test for Structure Critical Design*, PhD Thesis, University of Sheffield, 2020.
- [10] J. Petruska, J. Hülka, K. Hülka, *Computational Simulation of Small Punch Test: in Applied Mechanics and Materials*, Trans Tech Publications, 2012.
- [11] K.K. Pathak, K.K. Dwivedi, Manali Shukla, Ramadasan Erakkath, Influence of key test parameters on SPT results, *Indian J. Eng. Mater. Sci.* 16 (2009) 385–389.
- [12] F. Cortellino, W. Sun, T. Hyde, On the effects of friction modelling on small punch creep test responses: a numerical investigation, *J. Strain Anal. Eng. Des.* 51 (2016) 493–506, <https://doi.org/10.1177/0309324716655661>.

- [13] Sisheng Yang, Jianxin Zhou, Ling Xiang, Yang Zheng, Effect of Geometric Factors and Processing Parameters on Plastic Damage of SUS304 Stainless Steel by Small Punch Test, *Materials & Design*, vol. 41, 2012, pp. 447–452, <https://doi.org/10.1016/j.matdes.2012.05.029>.
- [14] M. Smith, ABAQUS/Standard User's Manual, Version 6.9, Dassault Systèmes Simulia Corp, Providence, RI, 2009.
- [15] Z. Zhai, M.B. Toloczko, M.J. Olszta, S.M. Brummer, Stress corrosion crack initiation of alloy 600 in PWR primary water, *Corrosion Sci.* 123 (2017) 76–87.
- [16] P.J. Meadows, P.L. Andresen, M.B. Toloczko, W.-J. Kuang, S. Ritter, M. Bjurman, L. Zhang, M. Ernestova, A. Toivonen, F. Perosanz-Lopez, J.W. Stairmand, K. J. Mottershead, International round-robin on stress corrosion crack initiation of Alloy 600 material in pressurized water reactor primary water, *Corrosion* 76 (2020) 719–733.