Stress Corrosion Cracking Field Test in KAERI Underground Research Tunnel Using 3D Printed Cells

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1. Introduction

Testing and demonstrating the potential for stress corrosion cracking (SCC) in copper canisters for deep geological repositories is essential for licensing[1−2]. In Korea, research simulating SCC in copper under deep geological conditions has been limited due to the 400 m depths required for accurate simulation. Recently, the Korea Atomic Energy Research Institute (KAERI) Underground Research Tunnel (KURT) has offered new opportunities to conduct these tests. This paper suggests using KURT for SCC tests employing 3D-printed cells to explore the feasibility and simplification of this approach.

2. Methods and results

2.1 Experimental setup

This study utilized 3D-printed corrosion cells to contain U-bend copper specimens in KURT's underground water. The cells were made from PLA plastic and designed using Blender software. Each contained two thicknesses of copper U-bend specimens (1 mm and 2.5 mm), with copper purity exceeding 99.9%. Only the corrosion cells were 3D printed; the U-bend specimens were purchased from a local vendor. Four corrosion cells were submerged in a corrosion chamber for durations of 6, 12, 18, and 24 months. A water feed-through supplied the underground water from a depth of 200 m within KURT. The corrosion chamber was maintained at 30°C.

2.2 Analytical methods

Samples were extracted after 6 months to characterize corrosion features. Methods employed included inductively coupled plasma optical emission spectroscopy (ICP-OES), ion chromatography, colorimetric methods, and multimeter measurements to determine element concentrations, ion concentrations, pH, redox potential, dissolved oxygen concentrations, and water conductivity. Surface analysis of U-bend specimens was performed using microscopy and X-ray diffraction (XRD).

2.3 Maximum stress estimation

Stress analysis of the U-bend specimens was conducted using the COMSOL Solid Mechanics module.

3. Results and discussion

Table 1 displays the concentrations of major elements in KURT's groundwater at a depth of 200 m. Calcium, sodium, silicon, and sulfur are predominant, with sulfur potentially existing as sulfide (HS^-), an SCC agent. However, no measurable amounts of sulfide were detected using colorimetric analysis, and oxygen concentrations ranged between 0.2 and 0.5 ppm.

Table 1. Concentration of major elements in KURT’s 200 m groundwater

Elements	Concentration ($mg \cdot kg^{-1}$)
Al	0.026
Ba	0.020
Ca	15.758
Cu	0.001
Fe	-
K	0.460
Li	0.033
Mg	0.767
Mn	0.001
Mo	0.067
Na	15.612
S	2.726
Si	7.869

Figures 1 and 2 illustrate the surface characterization of U-bend specimens. Copper corrosion was evident through the formation of Cu-carbonate, Cu hydroxide, cuprite, and tenorite, as indicated by surface coloration, although XRD results identified only cuprite. These findings underscore the need to employ additional characterization methods, such as electrochemical techniques and X-ray photoelectron spectroscopy (XPS), to more accurately identify corrosion products.

Notably, no evidence of SCC was observed in the U-bend specimens, consistent with the absence of detectable SCC agents, such as sulfide and ammonia, in the 200 m deep underground water of KURT. Copper's high ductility also limits cracking, as seen in dry-stored reference specimens.

Figure 1 . U-bend Cu specimens after 6 months immersed in KURT underground water. Left: 1 mm thickness; Right: 2.5 mm thickness.

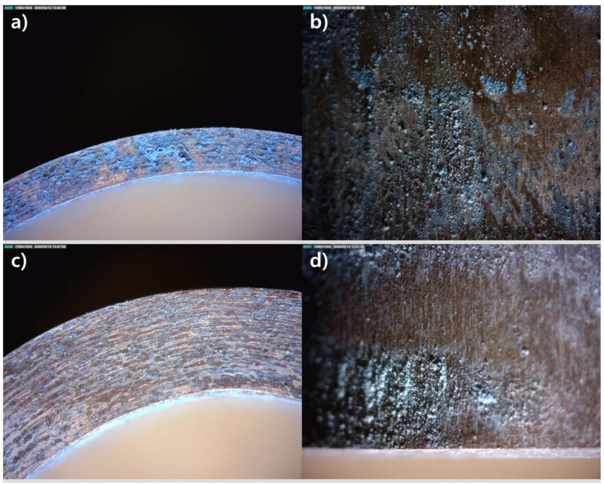

Figure 2. Microscopy images of U-bend specimens after 6 months in KURT underground water. (a, b) 1 mm thickness side and top views; (c, d) 2.5 mm thickness side and top views.

4. Conclusion

After 6 months, no cracks were detected in U-bend specimens of either thickness, aligning with the lack of traceable amounts of SCC agents. While corrosion products could be inferred, limitations in the analytical methods necessitate further evaluation using XPS and electrochemical techniques for precise identification. The study will continue for another 18 months to monitor the SCC potential of copper under South Korean environmental conditions.

REFERENCES

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