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Experimental Evaluation on the Applicability of Friction Stir Welding for Sealing Spent Nuclear Fuel Disposal Canister

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1. Introduction

Disposal canister for spent nuclear fuel (SNF) should be completely isolated from human life by preventing nuclide leakage in underground disposal conditions for a long period of time. To achieve this, the outer barrier of the disposal canister is designed by oxygen-free copper (OFC), which shows highly resistant to oxidation in underground disposal environments. Regardless of the applicable welding method after loading the SNFs, welds must be formed in the outer OFC disposal canister. Generally, the corrosion resistance of welds is reduced compared to the base material, which indicates that a welding process should be selected for ensuring that have similar or comparable corrosion resistances to the base materials of disposal canister. Among previous researches on various welding methods for disposal canister, friction stir welding (FSW) is considered as one of the strong candidates of canister welding methods [1,2]. This is because FSW is a solid-phase welding method that does not involve melting and solidification [3] when compared with other fusion welding methods such as arc, laser and electron beam welding. Therefore, a comprehensive review of welding methods suitable for the domestic disposal environment is essential to ensure the reliability of the disposal canister. In this study, an experimental study was performed to evaluate the applicability of FSW welding method, which is known to have the best corrosion properties to up to date. To achieve this goal, FSW weld specimen of OFC was manufactured using a specially designed FSW facility and microstructures and corrosion characteristics of FSW welds were experimentally evaluated.

2. Methods and Results

2.1 Sample preparation and FSW tester

In this study, FSW welded specimens were fabricated by butt welding method using an oxygen-free copper plate with a thickness of 5 mm as shown in Fig. 1. Among the various FSW test parameters, the rotational speed of the FSW tool was 900 rpm and the welding speed was 5 mm/min. Cross-sections of the fabricated FSW welding specimens were cut to analyze the formation behaviors of stir zone (SZ), heat-affected zone (HAZ), and thermo-mechanically affected zone (TMAZ) in the FSW welds.

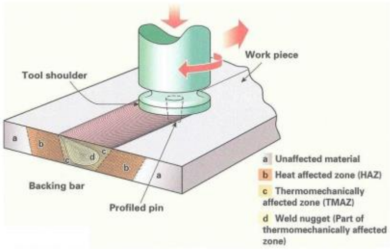

Fig. 1. Schematic view of friction stir welding for simulating the sealing of disposal canister used in this study

2.2 Microstructural analysis

Microstructure analysis was performed by cutting the cross section of the FSW specimen in the welding direction of the welds. The OM results show that the cross section of the FSW welds can be divided into SZ, HAZ, and BM regions, but the formation of TMAZ region was difficult to identify as shown in Fig. 2. In addition, nugget formation in SZ was not observed, which was due to the effect of relatively thin thickness of copper plate. As expected from the microstructure results, fine grain formation was observed in the SZ region, and it can be seen that grain refinement occurred due to dynamic recrystallization phenomenon [4-6], consistent with previous experimental results. In the HAZ region, relatively elongated grains were observed, which indicates that grain coarsening occurred by frictional heat during the FSW process. However, some dynamic recrystallization phenomena were also observed in HAZ region as fine grains were observed locally.

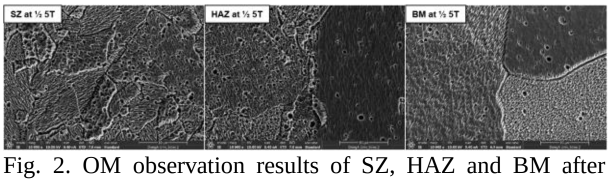

Fig. 2. OM observation results of SZ, HAZ and BM after FSW tests

In the high magnification SEM observation, tiny precipitates were randomly observed, which were identified as Al oxide in the EDS analysis, suggesting that the Al_2O_3 used as abrasive in the sample preparation process remained on the cross section of copper sample. The EBSD (Electron Backscatter Diffraction) analysis was performed to determine the grain size and orientation of each welding region and typical results are shown in Fig. 3. The grains in the SZ and BM region showed an equiaxed structure with different size with the FCC structure. But misoriented grain structures inside the elongated grains of HAZ region was detected, indicating that some extent of residual stress was expected to exist in the HAZ.

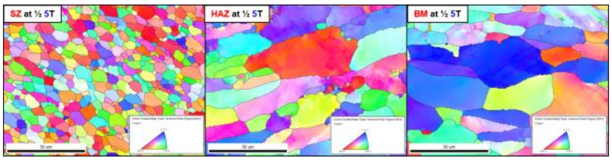

Fig. 3. EBSD results of SZ, HAZ and BM in the center region of FSW welds.

2.3 Corrosion test results

Corrosion samples were fabricated with a disk type with 15 mm in diameter and 1 mm in thickness from each FSW weld region and potentiostatic polarization tests were performed in 0.1M NaCl solution. Corrosion test results indicated that the corrosion rate was relatively faster in the HAZ region when compared to SZ and BM region as summarized in Table 1. This result means that inhomogeneous microstructure and remained residual stresses after the FSW process are sensitive to corrosive environment. In particular, high corrosion current density of the HAZ specimen suggested that the lifetime of the disposal canister can be determined by the presence of the HAZ region if FSW process are selected as the strong candidate among various sealing methods. Although solid-state welding by the FSW process formed the good corrosion-resistant welds compared with other fusion welding methods, the HAZ region still exhibits a relatively faster corrosion rate than the BM.

Table 1 Summary of corrosion test results in FSW welds

ID	I_{corr}[A/cm^2]	E_{corr} [mV]	E_{pit} [mV]
SZ	3.21×10^{-9}	312.88	603
HAZ	3.81×10^{-8}	275.07	425
BM	1.53×10^{-10}	329.27	670

3. Summary

In this study, FSW specimens of oxygen-free copper was fabricated to evaluate the microstructure and corrosion properties for simulating the sealing of a disposal canister. It was found that although a solid-phase weld with good oxidation resistance was formed, a relatively fast corrosion rate was observed in HAZ region. In the further study, improved FSW process should be developed for securing the corrosion resistance of HAZ region similar or comparable to BM region of oxygen-free copper.

Acknowledgment

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REFERENCES

[1] L. Cederqvist, T. Öberg., Reliability study of friction stir welded copper canisters containing Sweden's nuclear waste. Reliability Engineering & System Safety, Vol.93, p.1491, 2008.
[2] Forsström, A., et al., Strain localization in copper canister FSW welds for spent nuclear fuel disposal., Journal of Nuclear Materials, Vol.523, p.347, 2019.
[3] R.S. Mishra, Z. Y. Ma., Friction stir welding and processing. Materials science and engineering: R: reports 50.1-2, p.1, 2005.
[4] G.M. Xie, Z.Y. Ma, L. Geng, Development of a fine-grained microstructure and the properties of a nugget zone in friction stir welded pure copper, Scripta Materialia, Vol.57, p.73, 2007.
[5] Y.F. Sun, H. Fujii, Investigation of the welding parameter dependent microstructure and mechanical properties of friction stir welded pure copper, Materials Science and Engineering: A, Vol.527, p.6879, 2010.
[6] Y. Wang, R. Fu, L. Jing, Y. Li, D. Sang, Grain refinement and nanostructure formation in pure copper during cryogenic friction stir processing, Materials Science and Engineering: A, Vol. 703, p.470, 2017.