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Corrosion Resistance Assessment of Nickel in Molten Salt Environments

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1. Introduction

MSR(Molten salt reactor), which is being developed by more than 15 research institutes around the world, such as ORNL in the US, is known to be more advantageous than conventional large-scale PWR reactors in terms of miniaturization, safety, and economy. Unlike fluorine salt, structural material corrosion studies on chloride-based molten salt reactors are very few worldwide.

ASME section III Division 5 Code Rules says that only five types of materials can be used: 2.25Cr-1Mo steel, 9Cr-1Mo steel, Type 304, Type 316 stainless steel, and Alloy 800H. [1] Although these materials also satisfy high-temperature mechanical properties, verification data for corrosion resistance in harsh molten salt corrosion environments are still very lacking. As a way to overcome this, a plan is being considered to design it by cladding it with a highly corrosion-resistant material such as Ni.

The current ASME Section III Division 5 Code Rules [1] for cladded structural components in elevated temperature service are quite limited. The Division 5 allows non-Code qualified materials to be used for cladding if the clad thickness is 10% or less of the thickness of the base material. Division 5 specifies that no structural strength shall be attributed to the cladding in satisfying the primary load stress limits. It also requires that the cladding shall be considered in design evaluation related to limits on deformation-controlled quantities. [2]

Code and standards activities for high-temperature nuclear reactor design are being actively carried out by the standards committee hosted by the American Society of Mechanical Engineers (ASME), led by experts from U.S. national laboratories and private companies. In Korea, the ASME-affiliated KIWG (Korea Int'l Working Group) is actively carrying out roles to revise high-temperature reactor design codes. The design technology standards of parts that need to be cladded are also a task that materials experts must participate in and understand. In order to dominate the increasingly competitive MSR-related technology development market, active code and standards activities by domestic experts in material corrosion are necessary.

In this study, we tried to organize the corrosion characteristic data of Ni materials in a molten salt environment by analyzing the literature and introduce a research and development plan to measure the corrosion rate using electrochemical methods.

2. Literature survey on corrosion rate of Ni

We investigated and analyzed the corrosion rate data of Ni materials in molten salt environments conducted until recently at home and abroad. The data conducted for the purpose of constructing a nuclear reactor for power generation was centered on experimental data from the U.S. National Laboratories. Many other research materials were analyzed and organized in research papers for thermal storage in concentrated solar power (CSP) systems.

3. Experimental

Methods for measuring the corrosion rate of Ni metal in a molten salt environment include measuring weight loss after an immersion test and measuring corrosion current using an electrochemical method and converting this to annual thickness loss (mm/year). In this study, a polarization experiment was performed by configuring a three-electrode system as shown below, and the experimental conditions were as follows.

Material
-Working electrode: Pure Ni rod(99.9 %)
-Counter electrode: Carbon rod
-Reference electrode: Pt
-Salts: 57 mol% NaCl + 43 mol % $MgCl_2$
O_2 : ~ 300 ppm(to be confirmed)
H_2O < 0.1 ppm

Figure 1 shows the glove box containing the molten salt used in the experiment.

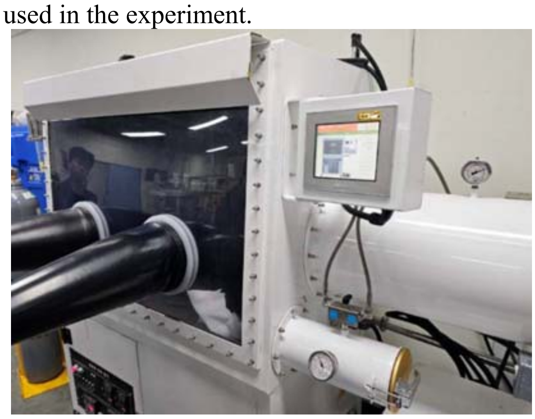

Fig. 1. Glove box set up for corrosion test

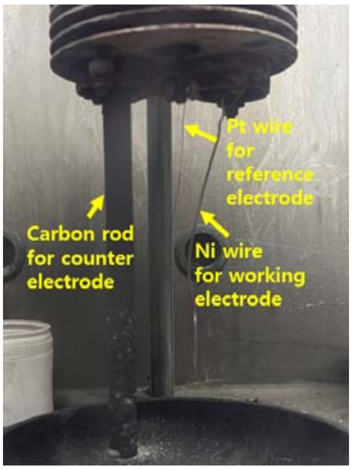

Fig. 2. Three-electrode set up for polarization test

Figure 2 shows the three-electrode system mentioned above.

4. Result and discussion

As a result of literature analysis, it is generally known that corrosion and deterioration of structural alloys in chloride salts are greater than in fluoride salts. The use of stainless steel in molten salt reactors is limited to an operating temperature of around 650°C, and its service life is determined by the composition of the steel and the molten salt. The composition of the fuel salt is very important to reduce corrosion of structural materials, and in the case of metal-fluoride salts, the upper limit of the UF_4/UF_3 ratio appears to be around 60. Additionally, the corrosion rate can be minimized by lowering this ratio by introducing a reducing agent such as metallic beryllium. Mg metal is being considered as a metal reducing agent in chloride salts. [3]

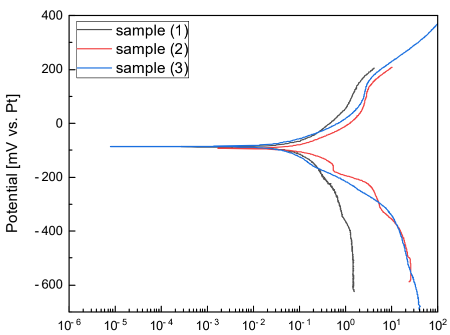

Fig. 3. Polarization curves of pure Ni in molten chloride at 650 °C

Figure 3 shows the polarization curves tested three times for pure Ni metal, showing very good reproducibility in molten salt at 650°C. Based on this, the process of calculating the corrosion rate (mm/year) is being performed.

5. Summary

- It is generally known that corrosion and deterioration of structural alloys in chloride salts are greater than in fluoride salts.
- The use of stainless steel in molten salt reactors is limited to an operating temperature of around 650°C.
- Mg metal is being considered as a metal reducing agent in molten chloride salts.
- The results of three polarization experiments showed very good reproducibility, and the corrosion rate is being calculated based on this.

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