

Development of Corrosion Resistant Cladding for Molten Salt Reactor Vessel Using Ni Forming Technique

Seong Sik Hwang^{a,*}, Gyeong Hoi Koo^a, Sang Ji Kim^a,

^a Korea Atomic Energy Research Institute, 989-111 Daedeok-daero, Yuseong-gu, Daejeon 34057, Korea

*Corresponding author: sshwang@kaeri.re.kr

***Keywords :** MSR, Ni forming, Cladded components, Bonding strength, Dilution zone

1. Introduction

Molten salt reactors (MSRs) are currently being developed by national laboratories (including Oak Ridge National Laboratory, ORNL) and private companies (such as TerraPower) in the U.S., as they are known to be superior to conventional large-scale pressurized water reactors (PWRs) in terms of miniaturization, safety, and economic efficiency. In Korea, research is also actively underway to apply MSRs as a power source for cargo ships, offshore structures and other applications.

According to the ASME (American Society of Mechanical Engineers) Section III, Division 5 Code Rules, which are the de facto international standard for reactor design, only a limited number of alloys (e.g., 2.25Cr-1Mo steel, 9Cr-1Mo steel, Type 304, Type 316 stainless steel, Alloy 800H, and Alloy 617) are permitted as structural materials for high-temperature reactors. While these materials satisfy high-temperature mechanical properties, verification data for corrosion resistance in the harsh molten salt environment remains insufficient. To overcome this limitation, a design approach involving the cladding of corrosion-resistant materials like Nickel (Ni) or Alloy 625 onto a high-temperature base material is being explored.

The current ASME Section III, Division 5 Code Rules [1] for cladded structural components are still under development, with technical standards being established based on ongoing experimental data. The rules currently permit the use of non-code-qualified materials for cladding if the clad thickness is 10% or less of the base material thickness.

Based on these technical standards, the Korea Atomic Energy Research Institute (KAERI) is developing a technique to create a corrosion-resistant cladding on the surface of Type 316H stainless steel using various methods.

This paper aims to describe the results of a fundamental study conducted with the goal of fabricating a cladded reactor vessel using a Ni-forming technique.

2. Experimental

2.1 Ni cladding formation by Ni forming

A specialized Ni forming technique is employed to produce robust, corrosion-resistant cladding on Type 316H stainless steel substrates, critical for molten salt reactor (MSR) components. While conceptually similar to conventional Ni electroplating, this advanced method enables the deposition of significantly thicker layers, exceeding 0.5 mm. This substantial thickness provides enhanced protection against the aggressive molten salt environment. The specimens utilized in this study were prepared using techniques commonly employed in industrial settings, ensuring practical relevance.

Figure 1 illustrates the general process flow diagram for Ni electroforming, and a similar procedure was followed in this study.

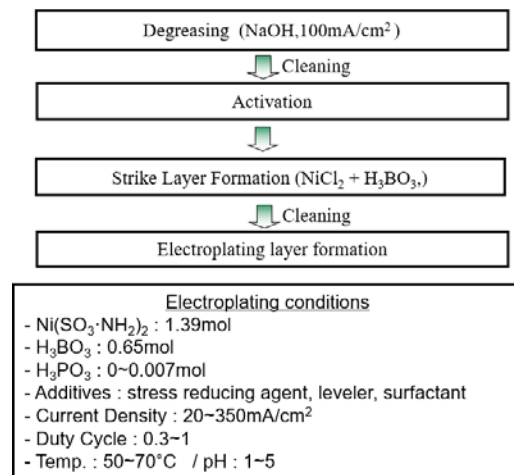


Fig. 1. General process flow diagram for Ni electroforming[2]

Figure 2 presents the typical equipment configuration used in the general Ni electroforming process.

2.2 Characterization on Ni clad layer

Characterization of the deposited Ni layer involved compositional analysis, interfacial analysis between the substrate and cladding, and adhesion strength evaluation. The elemental composition of the cladding layer was determined by accredited institutions using methods such as Atomic Absorption (AA) spectrometry and Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES), in accordance with KS standards. Adhesion strength was assessed by

performing root bend, face bend, and side bend tests as per ASME Section IX, QW 160 criteria.

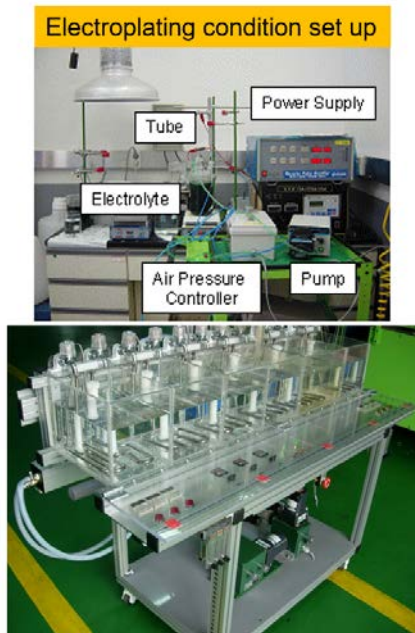


Fig. 2. Typical equipment configuration used in the general Ni electroforming process.

3. Results and Discussion

3.1 Analysis of the Ni cladding and Substrate Interfaces

Analysis of the Ni cladding itself revealed a composition of approximately 99.96 wt% (weight percent) Ni. This indicates the successful formation of a relatively pure Ni layer, with only trace amounts of impurities such as C, Fe, Mn, Si, and Cu typically found in conventional Ni electrodeposits. More importantly, detailed analysis of the elemental distribution at the interface between the cladding and the Type 316H stainless steel substrate is currently underway, along with a separate investigation into the grain structure of the cladding.

3.2 Adhesion and Durability Evaluation

To ensure the cladding's durability in a molten salt operating environment, robust adhesion to the substrate is essential. The evaluation method for this was a bend test, as shown in Figure 3. The side bend test showed no evidence of disbonding, suggesting that a successful cladding was produced. However, the long-term corrosion resistance of this cladding during extended operation will be assessed in a follow-up study.

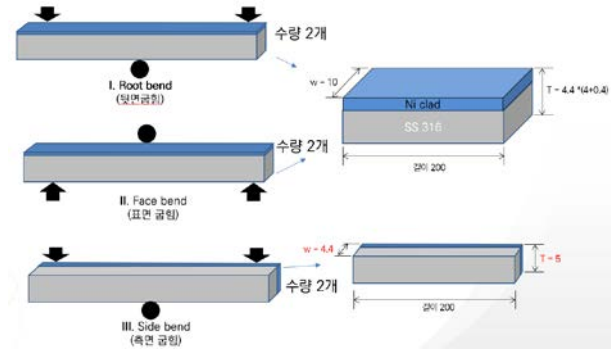


Fig. 3. Adhesion and durability evaluation test plan

4. Conclusions

To overcome the material limitations for use in molten salt high-temperature reactor design, a study was conducted to create a Ni cladding on the surface of Type 316H stainless steel.

- Based on existing Ni plating technology, the applicability of a Ni forming technique that significantly improves the cladding thickness was confirmed.
- The purity of the Ni cladding was secured at a level of 99.96%
- The adhesion of the cladding was verified to be robust, meeting the technical standards of ASME.

ACKNOWLEDGEMENTS

This work was partly supported by Korea Research Institute for defense Technology planning and advancement (KRIT) grant funded by the Korea government(DAPA(Defense Acquisition Program Administration)) (KRIT-CT-22-017, Next Generation Multi-Purpose High Power Generation Technology(Liquid Fueled Heat Supply Module Design Technology), 2022) and the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT) (RS-2023-00259713).

REFERENCES

- [1] American Society of Mechanical Engineers. Section III, Division 5. In ASME Boiler and Pressure Vessel Code. 2022.
- [2] Seong Sik Hwang, Dong Jin Kim, Ni Plating Technology for PWR Reactor Vessel Cladding Repair, *Corrosion science and technology*, vol.18, No.5(2019), pp.190~195