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ASME code for RPV cladding repair by Ni electrodeposition

Seong Sik Hwang[a*], Min Su Kim[a], Eun Hee Lee[a], Dong Jin Kim[a],
[a]*Korea Atomic Energy Research Institute, 989-111 Daedeok-daero,Yuseong-gu, Daejeon 34057*
[*]*Corresponding author: sshwang@kaeri.re.kr*

1. Introduction

SA508 low alloy steel of a reactor vessel was exposed to primary water in a pressurized water reactor(PWR) plant because the cladding layer of type 309 stainless steel of the reactor vessel experienced damage by an accident of thermal sleeve detachment. Repairing the inside of the reactor vessel is challenging because of high radiation levels, poor accessibility, and the underwater conditions. One promising technology is the electrochemical deposition (ECD) of nickel. Nickel plating through ECD has a lot advantages such as an excellent corrosion resistance, no heavy thermal effect (near room temperature process), and proper mechanical properties for long-term operation. The ECD technology used to repair the cladding was approved in 2013 as the ASME code case N-840(CC N-840). The new code case is based largely on the groundwork of the CC N-569. Technical background of the new code case N-840 was published in some journals and the PVP2013-97857 paper. [1] The CC N-840 defines the requirements and variables controlled by the ECD in underwater cladding repair applications.

Based on the code case, a three-year project to develop a new application technology was started to repair the damaged cladding in 2017. The objectives of the project are (1) to set up Ni plating essential variables in terms of practical application, (2) to support a repair organization with cladding repair tool development. This includes work supporting the utility with permission from the regulatory organization.

This article aims to address the three-year effort of the code case development process in the ASME section XI committee and the current status of its application to develop a new application technology.

2. Damage of the cladding

A detachment of a thermal sleeve from the primary coolant nozzle in a PWR plant occurred in April 3, 2003. There was damage to the stainless steel clad at the bottom of the reactor vessel owing to a vibration of the thermal sleeve, and the base metal of SA 508 reactor vessel steel was exposed to primary coolant, as shown in Fig. 1

The utility has been monitoring the corrosion rate by using a replication method during every outage, and the corrosion rate is considered as 0.1mm/year, as shown in Fig. 2.

Based on a safety margin analysis, the vessel has a much thicker safety tolerance, as shown below.

Thickness of the vessel, 163.3 mm
Minimum safety margin, 103.5 mm
Tolerance , 59.8 (163.3-103.5) mm

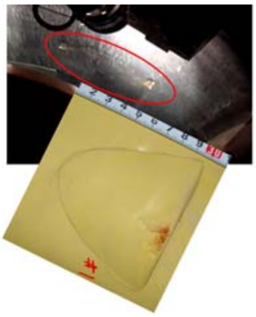

Fig. 1 Feature of the damaged clad at the bottom of reactor vessel

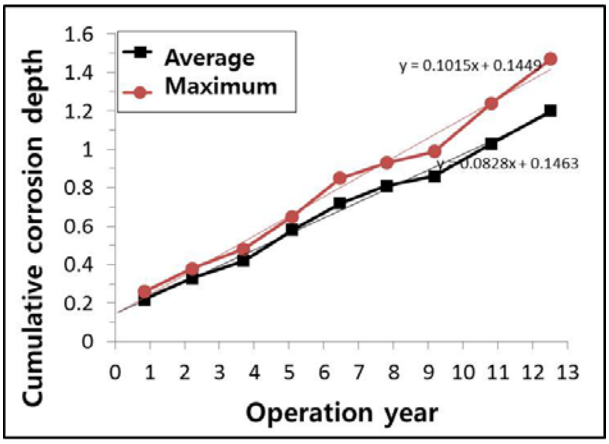

Fig. 2 Corrosion trend of the damaged area

When considering an operation of the reactor for 60 years, it seems that 6 mm deep corrosion is much smaller than the tolerance 59.8 mm.

Even if the safety margin is sufficiently secured and the some plants having cases outside the country have been operating the reactors without any other measures in similar cases, it is necessary to return to the original state so that the damaged material is not exposed to the cooling water. This will also help to reduce the burden of every cycle inspection and improve the soundness of a nuclear power plant

3. Code case development

Because there was no adequate repair procedure in KEPIC MI and ASME section XI, a process to develop a new code case in the ASME committees was suggested in 2010 based on a Ni electroplating technique that KAERI developed through a 5-year nuclear R&D program.

The first step to initiate the code development was to raise an inquiry regarding whether there was an adequate repair procedure in ASME section XI. The committee recommended the staff secretary to send us a response like 'ASME Section XI does not address this issue, but has initiated an action to address underwater cladding repair' in November 2010.

The second step was to set up a task group where technical details were discussed. Some members from the working group of repair and replacement activities (WGRRA)volunteered to join the task group called 'Underwater Clad repair by Ni Plating' in February 2011, and the technical discussion group continued for two years until October 2013 when the section XI standards committee finally approved the code case called 'Code Case N-840 Cladding Repair by Underwater Electrochemical Deposition in Class 1 and 2 Applications Section XI, Division 1'[2].

A white paper to describe technical details on the ECD was another essential material to persuade the committee members through the whole code development process. There were lots of presentations to answer the comments or negative opinions issued during the previous meetings.

4. Ni plating technology development

Technical details to support the code case were published in PVP2013-97857 [1]. The process validation included a strike layer evaluation, tensile properties between Ni plate and substrate, bonding strength evaluation, and corrosion resistance evaluation.

As shown in Fig. 3, the optimum thickness condition of the strike layer was 5 um, and there was no bulging or detachment at the surface.

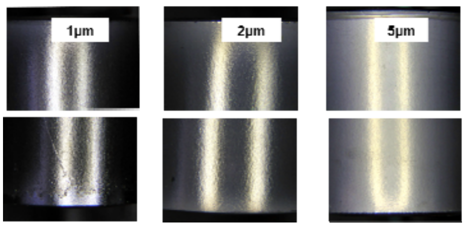

Fig. 3 Feature of strike layer having different thickness

The tensile strength of the ECD layer with an SS309 substrate was measured as 94.8 MPa or above. With this strength, the deposit layer adhered to the SS309 substrate after the tensile test. The measured adhesion strength was considered appropriate for considering the suitable integrity of the ECD deposition for plant operation/service conditions.

A corrosion resistance of the electrodeposited layer under the primary water chemistry was evaluated. C-ring testing demonstrated the ability to prohibit the crack propagation by SCC [3]. Another SCC test using a slow strain rate test (SSRT) was performed at 2×10^{-7}/s in a solution containing 40 wt% NaOH[3]. The surface of the Alloy 600 substrate was degraded by SCC, the ECD layer, however, had no SCC at the same condition. Pitting and crevice corrosion tests of the ECD layer were also performed in a solution containing a 6 wt% $FeCl_2$ solution[3]. The results showed that no pit or crevice was observed at the surface of the ECD layer after 12 hours.

With those laboratory-scale performances, it is necessary to develop practical Ni plating facilities that can enable the operator to control the deposition variables remotely in high radiation operating reactor condition. Then, the utility initiated a new research project including all steps from setting up the electrodepositing variables to resolving the regulatory issues with a plan to repair the damaged by 2020, as shown in Fig. 5.

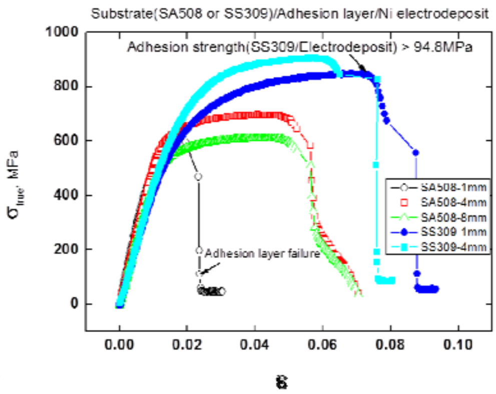

Fig. 4 Stress-strain curves with different adhesion area

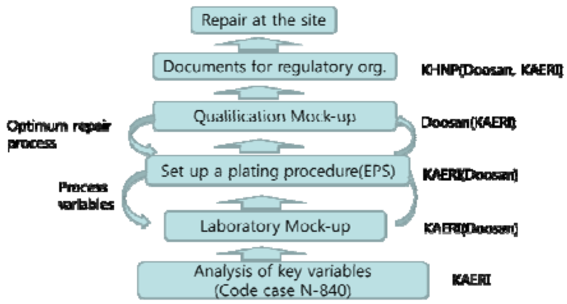

Fig. 5 General scheme of the project for field application.

5. Conclusions

- Damage to the stainless steel clad of the reactor vessel due to a detachment of the thermal sleeve was reported in 2003, and the base metal of the SA 508 reactor vessel steel was exposed to primary coolant for over 14 years.
- Corrosion rate monitoring has been conducted using a replication method during every outage.

- An ASME Section XI code case was developed in 2013.
- A new research project began to repair the damaged area in 2017.

REFERENCES

[1] Myong-Jin Kim, Dong Jin Kim, Joung Soo Kim, Hong Pyo Kim, Seong Sik Hwang, TECHNICAL BASIS FOR PROPOSED CODE CASE OF ALTERNATIVE RULES FOR CLADDING REPAIR BY UNDERWATER ELECTROCHEMICAL DEPOSITION IN CLASS 1 AND 2 APPLICATIONS, Proceedings of PVP2013, PVP2013-97857, July 14-18, 2013, Paris, France

[2] ASME code case N 840, Cladding Repair by Underwater Electrochemical Deposition in Class 1 and 2 Applications Section XI, Division 1.

[3] KAERI report, RR-3111, “Development of Proactive Technology against Nuclear Materials Degradation”, 2009.