Development of plating standard conditions for RPV cladding repair

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1. Introduction

A reactor vessel consists of carbon/low alloy steel (SA508) as the structural material, and a cladding layer (SS309) as a protective layer. The internal space of the reactor is very difficult to repair if it is damaged by external forces because of high radiation levels and poor accessibility [1].

Welding, a common repair technique, requires heat treatment because it has high heat input and causes residual stress due to deformation. On the other hand, the advantage of the Electro Chemical Deposition(ECD) Ni plating technique is that the reactor pressure vessel(RPV) can be repaired without significant thermal effects, and Ni has strong corrosion resistance that can withstand boric acid. In addition, adhesion that is not separated from the substrate has been verified in previous results [2].

The ECD technology used to repair the cladding has been approved in 2013 as the ASME code case N-840 [3].

The purpose of this article is to provide an experimental result that creates standard conditions for integrity plating in the RPV, and a completed plating systems based on the ASME code case N-840.

2. Plating process and conditions

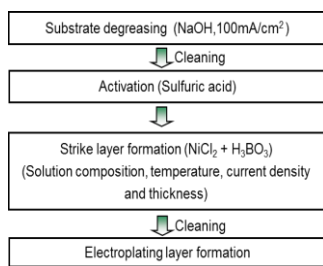### 2.1 Plating results of initial process conditions.

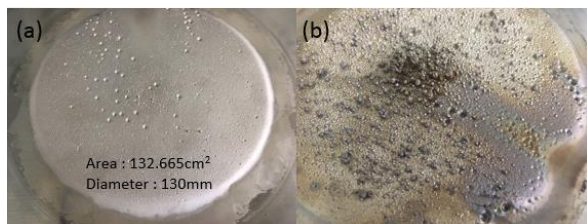Fig. 1. Flow chart of Ni plating process.

Fig. 2. Plated Ni on Type 304 stainless specimen (a) for 10 h and (b) for 30 h.

Plating was performed in the order of flow chart in Fig. 1. The plating solution was prepared using Ni sulfamate. The nickel ion concentration was 80.8 g/l and the boric acid content was 40 g/l. The current density was 10 A/dm^2, the bath temperature was 60℃, and the pH was maintained in the range of 3.0 to 3.4.

Fig. 2 (a) is the result of plating for 10 h. The surface is smooth, but a lot of pits are found. The pits are particularly concentrated on the inlet side of the plating liquid. This is because the bubbles are not removed on the surface of the specimen during plating. A strong circulation or wetting agent (SNAP) should be used in the plating solution for improvement.

In Fig. 2 (b), plating was carried out for 30 h and the burning was concentrated on the center portion of the surface, the specimen was blackened at the inlet where the solution came in. There is a possibility that the depletion of the nickel ion concentration and the solution stirring are insufficient. And the burning is a side reaction created by the impurities generated when the electrolytic nickel anode is oxidized on the specimen.

2.2 Improvement of plating system.

From the results of Fig. 2, the plating amount proportional to the plating time did not reach the theoretical plating amount. When the average solubility of the electrolytic nickel used as the anode was 54 % on average, the anode could not replenish the nickel ion in the solution and the nickel ion concentration of the plating solution was likely to be exhausted. In order to solve the less anode solubility, agitation problems, burning and pits raised in the previous test, the plating system was modified and improved, as shown in Fig. 3.
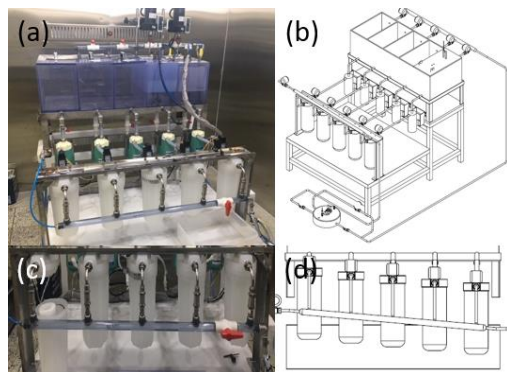
Fig. 3. Improved plating system (a) system in use (b) system design (c) applicable housing filter, pipe inclination (d) housing filter, pipe design

In order to increase the flow rate of the plating solution, the metering pump of the Ni tank was replaced with a magnetic pump. A ball valve was installed to prevent the Ni plating solution from spreading widely in the horizontal pipe while circulating. The inclination of the pipe is to allow the sediment in the pipe to be washed away. A housing filter was installed to prevent the plating solution from being contaminated by the oxide of the anode. The solenoid valve was completely replaced with Teflon valve due to corrosion caused by the plating solution.
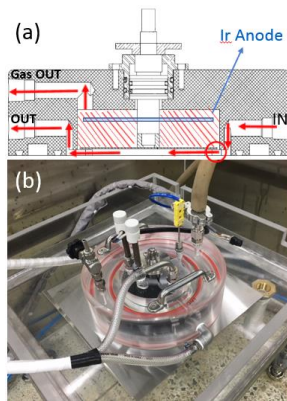

Fig. 4. Improved plating chamber (a) chamber design (b) chamber in use

The gap between the anode and substrate in the plating chamber was designed to be 12 mm maximum. Since this is so small as to interfere with the flow of the plating liquid coming in from the inlet, the distance between the anode and substrate was increased to 22 mm. The inlet hole of 1 mm in diameter changed to 5 mm. Fig. 4 shows the plating chamber.

After the improvement of the plating system, in order to increase the anodic solubility, a beaker plating experiment was performed using a sulfur-containing Ni in a titanium basket as an anode, and concentration of Ni increased also.

3. Standard implementation of plating conditions

3.1 Effect of electrolytic nickel anode on pH change

Fig. 5 shows the change in pH when electrolytic nickel was used. The pH can be seen to drop sharply, which is related to the anodic dissolution reaction. When using electrolytic nickel, the oxidation amount was only 54 % compared to the final amount of plating. This is because oxygen generation occurred at the anode and thereby pH decreased.
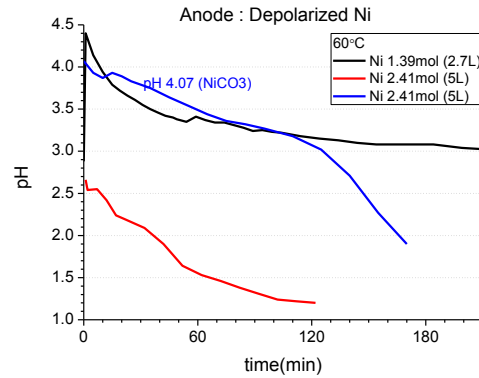

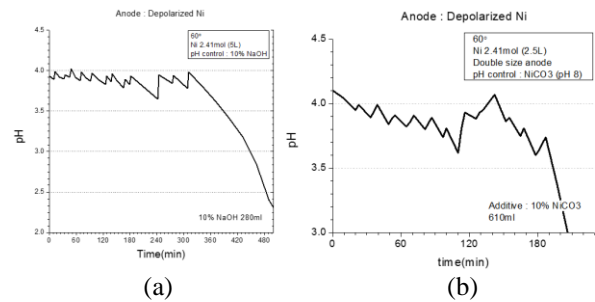Fig. 5. Change in pH when electrolytic nickel is used as anode.

Fig. 6. Effect of pH adjuster when electrolytic nickel anode is used (a) with NaOH (b) with $NiCO_3$

Fig. 6 shows that the pH was controlled when an electrolytic nickel anode was used. Fig. 6 (a) is the result of using NaOH as pH increasing agent, and Fig. 6 (b) is the result of maintaining pH by using nickel carbonate. It seems that maintaining the pH by nickel carbonate is more difficult than NaOH and the pH is not maintained for long and then decrease again.

3.2 Effect of S-Ni anode on pH change

S-Ni(sulfur containing Ni anode) was used to observe the pH change by different nickel concentration and strike layer formation method.

Fig. 7 shows that the pH does not deviate significantly in the designated range for 10 h. And this is clearly different from the case of pH drop for just 180 min when the electrolytic nickel was used as the anode as shown in Fig. 6. The pH change curves using S-Ni are cascaded, and this is because the addition of sulfamic acid to decrease the pH and pure water to replenish the evaporated solution at 1.39 mol of Ni. At a concentration of 2.41 mol of Ni, only the addition of pure water in order to replenish the evaporated solution makes the solution pH relatively constant.

Since boric acid is not easily dissolved at room temperature, strike layer formation process should carried out at high temperature around 40℃. We tried a room temperature strike layer formation process also because controlling the temperature is another burden during the Ni plating process. It is necessary to judge

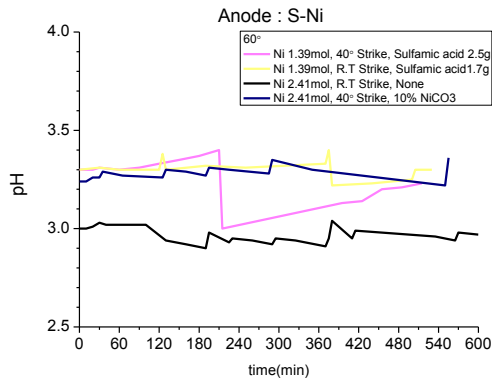which process is better based on the adhesion strength by the side bend test.

Fig. 7. Maintaining pH by using S-Ni anode.

Fig. 8 (a) is the plated surface by using the S-Ni as anode as seen in Fig. 7. Despite magnetic stirring was applied, pits remained on the surface, but both the plating efficiency and the anode efficiency are close to 100 %.

Fig. 8 (b) shows the result of adding 1 ml/L of SNAP (wetting agent) into 2.41 mol solution. The surface was greatly improved, and the plating efficiency was consistent with the theoretical plating amount 99.5 %. It is noted that the wetting agent SNAP does not evoke and side effect.
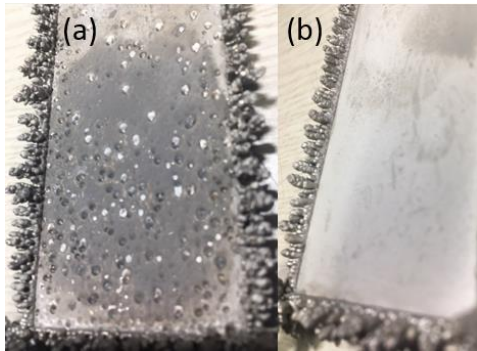

Fig. 8. Surface of plated specimen using S-Ni (a) without SNAP (b) with SNAP.

From the results of conditional experiments up to present, two conditions of Ni ion concentration are acceptable for future experiment. The reason is that the S-Ni anode is dissolved and replenished Ni ions even at 1.39 mol, and the plating efficiency is not different from 2.41 mol solution. Therefore, the anode maintains Ni concentration while keeping the pH.

However, the temperature of the strike layer formation should be confirmed through the side bend test to see what kind of property change occurs. All the four experiments in Fig. 7 were carried out for same period (2.5 min) with the strike layer thickness of 5 μm.

Fig. 9 shows the experiment setup to see the pH change as seen in Fig. 7, and the S-Ni anode concealed with an anode bag is facing with the plated specimen.
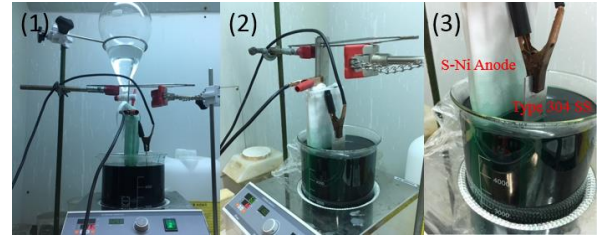

Fig. 9. Beaker experiment using S-Ni.

4. Conclusions

- Maintaining the pH by nickel carbonate or NaOH is difficult when electrolytic nickel anode is used.
- Wetting agent SNAP is effective in removing pits.
- S-Ni anode maintains Ni concentration while keeping the pH.

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, 2013 ASME Pressure Vessels and Piping Division Conference, PVP2013-97857, 2013

[2] Dong-jin Kim, Myong Jin Kim, Joung Soo Kim, Hong Pyo Kim, Material characteristics of Ni-P-B electrodeposits obtained from a sulfamate solution, Surface & Coatings Technology, Vol. 202, p. 2519, 2008.

[3] Code Case N-840, cladding repair by underwater electrochemical deposition in class 1 and 2 applications section XI, division 1, Jan. 23, 2014.