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Electroplating system development 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 corrosion protection layer. The carbon/low alloy steel of a RPV bottom region was exposed to primary water due to an accident of a thermal sleeve detachment of cladding layer [1]. Carbon/low alloy steel is weak to corrosion when it is exposed to the primary water especially during refueling time, and the damaged area might be grown every year. It is a potential threat against the integrity of a reactor vessel. Though it is highly corrosion resistant in the operating conditions, the stainless cladding(SS 309) needs to be repaired for better operating performance, because the less corrosion resistant low alloy steel(SA 508) has been exposed to the primary water .

Repairing the inside of the reactor vessel is challenging because of high radiation levels, poor accessibility, and the underwater condition. One promising repair technology is an electrochemical deposition (ECD) of pure nickel [1].

Pure nickel plating has a lot more advantages than existing welding techniques such as excellent corrosion resistance, adhesion strength, no heavy thermal effect (near room temperature process), and proper mechanical properties for long-term nuclear operation. Moreover, it is applicable to underwater conditions [1].

Ni plating has been widely studied to improve the corrosion resistance, and mechanical properties [2,3]. The ECD technology used to repair the inside of the steam generator tube has been approved in the ASME code case N-569 entitled "Alternative Rules for Cladding Repair by Underwater Electrochemical Deposition in Class 1 and 2 Applications" [2]. It defines the requirements and variables controlled by the ECD in the underwater cladding repair application [1]. Based on the code case, a new Code Case N-840 entitled "Cladding Repair by Underwater Electrochemical Deposition in Class 1 and 2 Application Section XI, Division 1" was developed in 2013 [4].

The purpose of this study is to develop an electroplating system satisfying the requirements of the Code Case N-840.

2. Experimental Procedures

2.1 Specimen

The Coupon should be plated according to various conditions specified in the code case N-840. The coupon will be divided into four specimens by cutting and adhesion strength and mechanical properties will be evaluated through the side bend test [4].

The first thing to do is to select the size and shape of the coupon on which the Ni plating layer is formed. For this study, the clad(SS309)/Low alloy steel(SA508) base metal specimens that make up the reactor vessel will be manufactured in a shape of 290mm x 290mm according to the side bend test requirement in the Code Case. The thicknesses of the clad and low alloy steel are 6mm and 9mm, respectively as shown in Fig. 1.

The coupon simulating the damaged area will be machined. The clad plate located at the top of the coupon will be machined into a 120mm diameter circle at the center. And a 6mm clad plate will be machined so that the low alloy steel is exposed in a circle around the 80 mm, because the code case specifies the following: After cladding, a repair cavity shall be prepared by excavating into the clad deposit to expose base material. The size of the exposed base material shall be a minimum of 2 in. (50 mm) long by 1.5 in. (38 mm) wide [4].

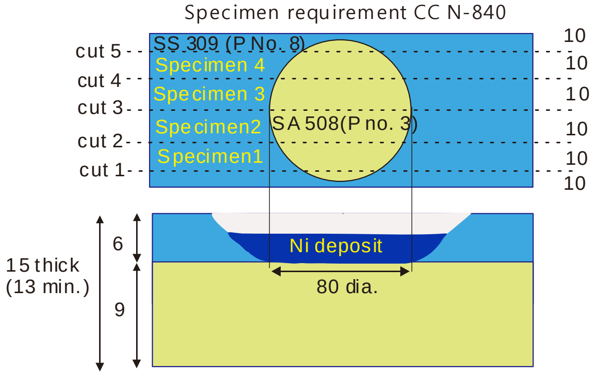

Fig. 1.Schematic of ECD test coupon

2.2 Surface Treatment

The surface treatment of the specimen plays an important role for obtaining a sound plating layer at the early stage of the plating process. The specimen undergoes a total of 5 steps of surface treatments [1].

As the first stage, degreasing with NaOH is to remove oil or foreign materials of the specimen before plating.

The second step is an activation process by using sulfuric acid(H_2SO_4) to remove oxides from the surface of the specimen. In addition, the second stage helps the surface to roughen the coating layer to increase the adhesion strength.

The third step is a strike layer formation for developing a firm bonding layer. In this case, $NiCl_2$ is used instead of Ni sulfamate, which is used for the subsequent plating process.

Finally, the Ni plating is performed in Ni sulfamate solution. In all steps, a process of washing and drying with distilled water is required. These processes will create a sound coating layer that will protect the carbon/low alloy steel.

3. Results and discussion

3.1 Electroplating variables

There are many parameters to form the strike layer and the Ni plating layer. The formation of strike layer by using $NiCl_2$ has various parameters such as temperature of the solution, the thickness of the strike layer, the addition of HCl, and the change of the activation solution. The formation of the plating layer using Ni sulfamate depends on parameters such as pH, current density, additives, and plating bath temperature [1].

There are several reasons why these parameters should be well controlled. Failure of the thickness control may cause delamination in the plated layer. Failure of the pH control may cause brittleness, and if the current density is low, the material becomes soft.

3.2 Electroplating chamber design

It is important to design a plating chamber. This is because the plating layer satisfying the Code Case can be obtained by considering the various conditions of the requirements.

The first criterion of chamber design is to develop a sealing mechanism to keep the plating solution inside the plating chamber. The integrity of the plating layer is determined by the purity of the plating solution, because the code specifies the following: Chemical compositions shall comply with the following requirements [4].

Nickell 99.0% minimum
Silicon 0.01% maximum
Sulfur 0.01% maximum

If the primary cooling water is introduced into the chamber during the plating process, it will act as an impurity and adversely affect the plating layer. For this reason, a double O-ring device was designed at the bottom of the chamber.

A vacuum hose connects the vacuum generator outside the reactor vessels to the vacuum absorption rubber and maintains the vacuum inside the chamber. This can isolate the plating solution from the outside water environment.

The second criterion is anode design. The shape of the anode is directly related with the shape of the plating layer as shown in Fig. 2. Because the exposed low alloy steel having a diameter of 80mm is flat, the anode must have the same bottom shape of 80mm in diameter. Since the repaired part of the clad is a curved surface, it is limited to design the shape of the anode.

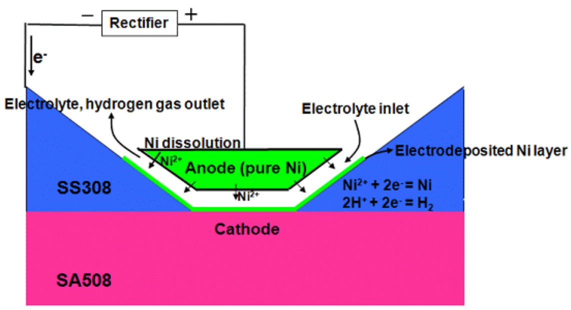

Fig. 2. Schematic of the anode for efficient plating.

Because the current is focused on the edge, a protrusion may be formed on inclined surface. This may violate the code case requirement because it says 'Transitions at the edges of the deposit shall have a slope not exceeding 1:3, and the surface of each deposit shall be suitably smooth to facilitate nondestructive'. A concept of a shielding basket was introduced into the anode in order to develop a smooth edge plated region.

The third criterion is to set up a sequential process apparatus. As stated earlier, the plating process consists of five steps including degreasing through main Ni plating process. The whole process apparatus should be designed so that these processes can be performed continuously. The processing apparatus circulates the plating liquid by manual valve operation as shown in Fig. 3.

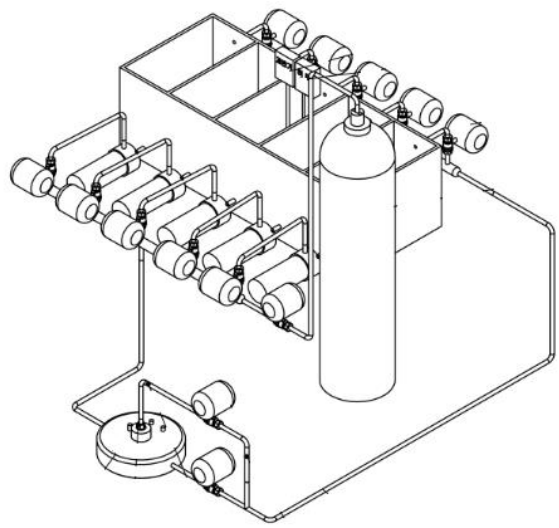

Fig. 3. Plating liquid circulator with five water tanks

In the plating process, it is very important to prevent contamination of the surface layer of the plating object before plating. During the plating process, unnecessary long-term contact of the material with oxygen causes corrosion. Therefore, the plating liquid circulating apparatus continuously circulates the surface treatment liquid. It is also necessary to control the time so as the damaged area not to be exposed to the air for long time. The plating liquid in each tank is supplied and discharged through manual valve operation into the plating chamber. When plating, the solutions should be thoroughly separated from each other to prevent impurities from forming.

After the solution is drained, nitrogen gas is blown into the hose connected to the chamber so that no solution remains in the chamber.

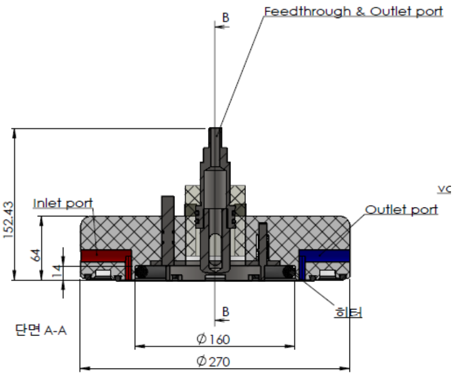

Fig. 4. Electroplating chamber for Ni electrodeposition system

The solution is supplied and discharged through the inlet port and the outlet port from the plating liquid circulation apparatus. And the hose connected to the vacuum generator will make the inside vacuum. And an outlet for discharging the hydrogen gas generated during plating is also designed at the top of the chamber. A shielding basket will be placed inside the chamber with the anode wrapped around it. In the feed through, a rotary drive system will be positioned to rotate the shielding basket vertically.

4. Summary

A plating chamber and specimen are designed for satisfying the requirements of the Code Case N-840. It is of the utmost importance to control variables such as temperature, pH, and plating layer thickness in the plating experiments.

A sealing mechanism to keep the plating solution inside the plating chamber was designed. A concept of a shielding basket was also introduced into the anode in order to develop a smooth edge plated region.

A sequential process apparatus was developed for the five-step electroplating process. The soundness and integrity of the plated specimens will be evaluated through side bend test.

REFERENCES

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