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Development of Ni alloy electrodeposition process for steam generator tube repair

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1. Introduction

Due to occasional occurrences of localized corrosion such as SCC and pitting in steam generator tubing(Alloy 600), the degraded tube is removed from service by plugging or repaired for re-use. Typical sleeving has introduced welding and mechanical expansions leading to a residual stress into the parent tube which should be relieved to improve in-service life[1,2]. However, the electrodeposition inside tube does not induce a parent tube deformation and hence a significant residual stress.

In order to perform the electrodeposition inside tube successfully, many processes should be developed. Among these processes, an anode to be installed inside tube, a degreasing condition to remove a dirt and grease, an activation condition for a surface oxide elimination, a strike layer forming condition to be adhered tightly between the electroforming layer and the parent tube and a condition for an electroforming layer should be established.

It is natural that Ni alloy electrodeposition is selected as a proper electrodeposition system because Alloy 600 is mainly composed of nickel and nickel electroplating has been widely studied to improve corrosion resistance, mechanical and magnetic properties[3,4].

This work deals with the process development for tube repair and is especially focused on an anode development, findings of a strike layer forming condition and material properties for the layer formed by an electrodeposition condition.

2. Experimental

For plate specimen, Ti plate coated with Pt and stainless steel plate with a surface area of 3x10cm^2 were used as an anode and a cathode, respectively. For tube specimen, the developed anode was installed inside tube using air pressure and then solution was circulated using a solution pump at a flow rate of about 100ml/min.

Strike layer was formed in an aqueous solution including the nickel chloride of 1.6 mol and the boric acid of 0.65 mol with/without hydrochloric acid. Temperature and thickness were varied in the range of 40~60^{o}C and 1~20 μm, respectively.

Regard to an electrodeposition layer, Ni sulphamate, phosphorus acid, Fe sulphamate and DMAB(dimethyl amine borane) are used as a Ni source, a P source, an Fe source and a B source, respectively. The bath was composed of Ni sulphamate of 1.39mol and boric acid of 0.65mol with/without additives. Contents of P, Fe and B sources were varied in the range of 0~0.007mol. The pH and temperature of the prepared bath were controlled to be 2 using sulphamic acid and 60°C, respectively.

During electrodeposition, the applied average current density and duty cycle were varied from 50 to 200mA/cm^2 and from 30 to 100%(DC), respectively. Duty cycle(%) is defined as the ratio of on-time to one period(on-time + off-time) and the one period is constant to be 10msec in this study.

Alloy composition analysis of the deposit was performed using an ICP analyzer(Model JY80C(Jobin Yvon)).

Hardness was measured by applying a 50g load for 10sec, 10 times. The average was used as the hardness value.

Stress-strain curve for the specimens prepared by EDM(electro discharge machining) was obtained with a strain rate of 1mm/min using Instron 8872.

For SCC(stress corrosion cracking) test, the C-ring specimens were fabricated using the tube specimen where an electrodeposit was formed and stressed up to 150% with reference to yield strength of KSNP steam generator tubing. SCC test was carried out for the prepared C-ring specimens applying 180mV above an open circuit potential in 40wt% NaOH solution at 315^{o}C for 7 days, followed by optical microscopy examination.

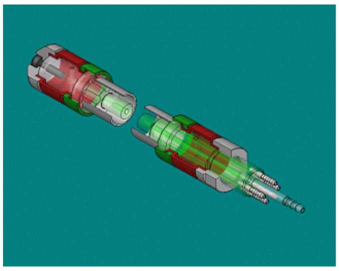
Thermal stability was evaluated from the change of the hardness value induced by heat treatment duration up to 2 months.

3. Results and discussion

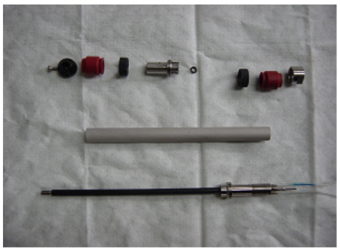
Figs. 1(a) and (b) show the schematic design and actual parts for an anode probe. The anode can be positioned at desired location and insulated from the cathode(Alloy 600) using two seals expanded by the air provided through air line. Through two inlets and three outlets, a solution is refreshed continuously. Pt coated tube inside the anode probe and Alloy 600 tube are used as the anode and the cathode, respectively.

Fig. 2 presents the optical micrograph examined after C-ring test for Ni-P-B electrodeposit. It was observed that stress corrosion crack was initiated on the outer surface of Alloy 600 and propagated through the inner surface, followed by SCC arrest on the electrodeposit surface, which indicates the excellent SCC resistance of the electrodeposit.

Fig. 3 illustrates the hardness value obtained as a function of heat treatment duration at 343^{o}C. Nearly constant hardness values for the pure Ni and Ni-P-Fe electrodeposits appeared, irrespective of heat treatment duration at 343°C while the hardness value for Ni-P-B electrodeposit increased slightly with heat treatment duration, which may be related to solid solution hardening of nickel boride. It is worthwhile to note that the deterioration of hardness value was not observed for Ni-P-B electrodeposit as well as pure Ni and Ni-P-Fe electrodeposits indicating the superior thermal stability of the electrodeposits.



(a)



(b)

Fig. 1. Schematic design for an anode probe and actual parts assembled into an anode probe.

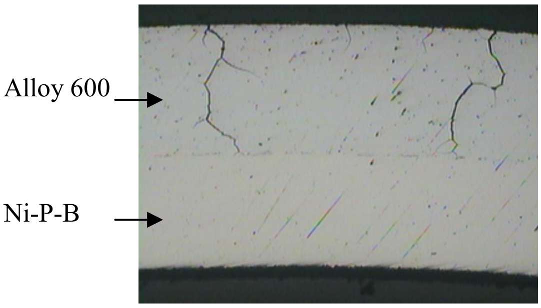


Fig. 2. Optical micrograph examined after C-ring test for Ni-P-B electrodeposit. C-ring test was carried out by applying 180mV above an open circuit potential in 40wt% NaOH solution at 315°C for 7 days.

4. Summary

For tube repair using electrodeposition inside steam generator tubing, an anode probe to be installed inside tube, a degreasing condition to remove a dirt and grease, an activation condition for a surface oxide elimination, a strike layer forming condition to be adhered tightly between the electroforming layer and the Alloy 600 tube and a condition for an electroforming layer were developed. Using the developed anode, the electrodeposition inside tube was performed successfully. Tensile test, SCC test and thermal stability for the electrodeposits were evaluated.

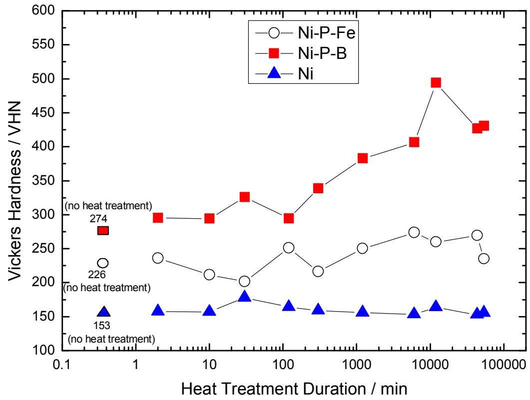


Fig. 3. Vickers hardness value for Ni, Ni-P-Fe and Ni-P-B electrodeposits as a function of heat treatment duration at 343°C.

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