

Electrophoretic Deposition of Ni Nano-particles for Self-repairing of Heat Exchanger Tubes

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Abstract

The electrophoretic deposition process of Ni nano-particles was employed for self-repairing of heat exchanger tubes. For electrophoretic deposition of Ni nano-particles on pitted Ni alloy specimen, a constant electric field of 100 V cm^{-1} was applied to the specimen for 180 s in Ni-dispersed solution. It was found that as electrophoretic deposition proceeded, the size of the pit remarkably decreased due to the agglomeration of Ni nano-particles at the pit. This strongly suggests that the electrophoretic mobility of the charged particles is larger for the pit with a higher current value rather than outer surfaces with a lower current value.

Keywords : Electrophoretic Deposition, Self-Repair, Pitting Corrosion, Agglomeration, Nano-particle

1. Introduction

Since the discovery of pitting corrosion in heat exchanger tubes of Inconel alloy 600 [1,2], a number of methods to solve the problems arising from the pitting corrosion of heat exchanger tubes have been developed. Among those, recently, the electrophoretic deposition method has attracted considerable attention in repairing the pit due to higher deposition rate, short processing time, process simplicity, easier composition control, low cost and selective deposition of uniform film.

The electrophoretic deposition consists of two processes: the movement of the charged powder particles in a suspension under the applied electric field between the working electrode and the counter electrode, i.e., electrophoresis followed by the deposition of these particles on the working electrode. For the pitted electrode specimen, since the current value is higher for the pit rather than the outer surfaces of the specimen, the more charged particles notably move to the pit, leading to the self-repairing of the pit.

In this respect, the present work is aimed at employing the electrophoretic deposition of Ni nano-particles to self-repair the pit of heat exchanger tubes and exploring the electrochemical behaviour of Ni nano-particles during the electrophoretic deposition process.

2. Experimental and Results

Ni nano-particles prepared by levitation-gas condensation [3,4] were dispersed into the solution of ethanol with the addition of dispersant, Hypermer KD-2 (Uniqema, UK).

The pitted Ni alloy specimen was prepared by applying a potential of 0.9 V (vs. Ag/AgCl) to the Ni alloy plate for 60 s in aqueous 0.1 M NaCl solution. A two-electrode electrochemical cell was employed for the electrophoretic deposition. The pitted Ni alloy specimen and Pt plate were used as the working electrode and the counter electrode, respectively. The above Ni-dispersed solution was used as the electrolyte.

A constant electric field of 100 V cm^{-1} was applied to the specimen for 180 s by using a PE 1649 DC power supply (Philips, Belgium). The changes in pit morphology of the specimen with electrophoretic deposition time were examined using scanning electron microscopy (SEM, XL 30 SEFG).

Fig. 1(a) illustrates the SEM micrograph of pit morphology on the surface of Ni alloy plate specimen subjected to a constant anodic potential of 0.9 V (vs. Ag/AgCl) for 60 s in aqueous 0.1 M NaCl solution. The pit was smaller than ca. $50 \mu\text{m}$ in size and many micropits with the size of several micrometers are distributed over the periphery of the pit. In order to repair the pit of the specimen by using electrophoretic deposition, a constant electric field of 100 V cm^{-1} was applied to the specimen in Ni-dispersed solution for 180 s. Figs. 1(b) and (c) show the SEM micrographs of pit morphology on the surface of the specimen subjected to a constant electric field of 100 V cm^{-1} for 90 s and 180 s, respectively.

It was noticeable that the Ni nano-particles were predominantly deposited on the pit of the specimen. As the electrophoretic deposition time increased, the size of the pit remarkably decreased due to the agglomeration of Ni nano-particles at the pit. It is well known [5] that the pitting corrosion leads to irregular rough surfaces because of the

formation and decay of a protective layer, resulting in the increase of the electrochemical-active surface area. In addition, the current value is higher for the pit rather than outer surfaces of the specimen. This implies that the electrophoretic mobility of the charged particle is larger for the pit rather than outer surfaces of the specimen due to the higher current value.

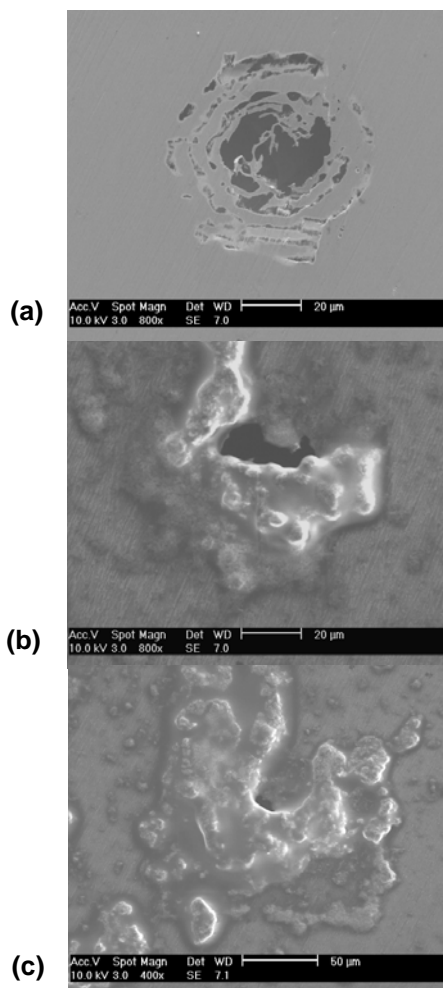


Fig. 1. SEM micrographs of pit morphology on the surface of Ni alloy plate specimen subjected to a constant electric field of 100 V cm^{-1} for (a) 0 s, (b) 90 s and (c) 180 s in Ni-dispersed solution, respectively. The pit in (a) was prepared by applying a constant anodic potential of 0.9 V (vs. Ag/AgCl) to Ni alloy plate for 60 s in aqueous 0.1 M NaCl solution.

The counter-ions in a suspension form a charge cloud around the charged particle. This ionic atmosphere is called the 'diffuse double-layer' or 'lyosphere'. Considering negatively charged nano-particles, when an electric field with the positive value is applied to the specimen, the charged particle moves to the specimen with distorted double-layer, thinner ahead and wider behind the particle.

Anions in a suspension also move to the specimen along with the negatively charged particles, and then the counter-ions in the extended tail of charge cloud will react with these accompanying anions in high concentration around them. The double-layer behind the particle will be so thin that the next incoming particle with a thin double-layer ahead can approach more closely to it.

In a colloidal suspension, the force at any point between the particles consists of two components, i.e., an electrostatic component which is called van der Waals attraction force and osmotic pressure component which is called double-layer repulsion force. As the distance between the charged particles decreases, van der Waals attraction forces become dominant, causing the extensive agglomeration of the nano-particles.

From the above statement, it can be inferred that the deposition, i.e., agglomeration of the Ni nano-particles at the pit of the specimen occurs via lyosphere distortion. As the electrophoretic deposition proceeds, the pit becomes smaller in size, and hence the current is more concentrated on the pit of the specimen. Subsequently, the more nano-particles aggregate at the pit by lyosphere distortion with progressing electrophoretic deposition time.

3. Summary

In the present work, the pit on the surface of Ni alloy plate was successfully repaired by using electrophoretic deposition method. From the SEM micrographs, it was revealed that as the electrophoretic deposition time increased, the size of the pit remarkably decreased due to the agglomeration of Ni nano-particles at the pit. Consequently, it is suggested that as the electrophoretic deposition proceeds, the pit becomes smaller in size, and hence the nano-particles more extensively aggregate at the pit by lyosphere distortion.

4. References

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