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Research Article

Improvement of Corrosion Behavior of Nanostructured Ni Coating by Jet Electrodeposition and Laser Remelting

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An effective method to improve corrosion resistance for the nickel coating on the stainless steel(1Cr18Ni9) is described. The nickel coating was predeposited on the 1Cr18Ni9 by using the jet electrodeposition technology. Then the laser remelting was conducted on the predeposited Ni coating in order to strengthen the coating's microstructure and the interface between the substrate and the Ni coating. The experimental results revealed that, at current density of 40 A/dm^2, the deposited coating had the optimal corrosion resistance because of refined grains and dense interior-structure. After laser remelting, the bonding state between the coating and substrate evolved to a new metallurgical combination from originally mechanical combination. The corrosion rate comparison indicated that Ni coating with compound process of jet electrodeposition and laser remelting had higher corrosion resistance compared with bare 1Cr18Ni9 as well as jet electrodeposited Ni coating.

1. Introduction

Nanocoating technology has attracted wide attention in the surface engineering. As it is able to improve target material service performance including corrosion resistant by offering new mechanical and physical properties. Among nanocoating preparing methods, jet electrodeposition (JE) technology has special advantages and has been used for local coating reaction. Because electrolyte is impinged from the jet nozzle onto a cathode surface, high rate of mass transport is available to promote liquid-mass-transfer velocity of electrolyte. In comparison with other conventional electrodeposition manners, jet electrodeposition has two advantages. First, it allows increasing deposition rate as high as tens or even hundreds of times since a much higher current density can be used. Second, it provides nano-scaled refining grains of the deposited material because high current density in use greatly accelerates the nucleation rate and decreases the grain size as a result [1–7].

Laser remelting is another important technique to manufacturing high performance coating. By high-temperature melting the prefabricated coating material on a surface, high anticorrosion property or other well performance deposits can be formed over material surface [8]. Therefore, given the above experimental facts, combining laser remelting with jet electrodeposition, it is likely to be achieved that coating material structure may be strengthened after laser scanning and the deposit qualities, especially the corrosion behavior, are also likely to be improved [9, 10].

This study is proposed to provide a simple way of improving 304 stainless steel corrosion behavior. It first uses JE to prefabricate a nanostructured Ni coating on the substrate and then makes use of laser radiation to process the coated substrate to provide a dense crystalline Ni coating, which is closely combined with the substrate material. Their characteristic properties were evaluated by scanning electron microscope (SEM) for the crystal structures characterization and by hydrochloric acid corrosion test for the corrosion behavior determination.

2. Experimental Procedure

A self-developed jet electrodeposition setup (see Figure 1) was used to prepare the coating material. The setup is mainly composed of the computer control system, framework,

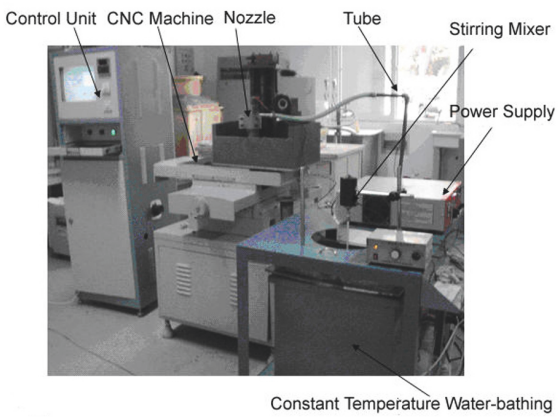


Figure 1: Experimental setup for nickel jet electrodeposition.

electrolyte circulatory system, nozzle and its hoisting mechanism, DC power, and other parts.

304 stainless steel (1Cr18Ni9) was chosen as substrate material, with specimen size 100mm×20mm×2mm. Pretreatment process for the specimens was needed before experiment as follows. First, the specimens were grinded and polished, consequently using 400, 800, and 1000 mesh metallographic sandpapers. Afterwards, polished samples were cleaned by using distilled water as well as acetone soaking for degreasing treatment, for about 5 minutes. The electrolytes compositions are as follows: nickel sulphate 250 g/L, nickel chloride 60g/L, and boric acid 40g/L, the buffer reagent which maintains the pH value in electrolytic solution. At the predeposition procedure, the Ni coating was scan-deposited on the surface of specimen using JE, with the rectangular nozzle (size 20 mm×1 mm) and electrolyte velocity (170L/h, 2.5 m/s). The scan-deposit for each specimen underwent 600 layers, at the scan rate 10 mm/s. Prior to the JE deposition, a thin nickel layer with a thickness of 150 nm was preelectroplated over the substrate surface in a standard sulphate watt bath for use as an interlayer, in order to enhance the adhesion between substrate and nickel coating. During the electrodeposition, a group of direct current was being applied at current density of 30, 40, 50, and 60A/dm^2, respectively.

Afterwards, laser remelting process was conducted using a SLCF-X12 25 type of CO_2 laser. Remelting process parameters were as follows: laser power 1500 W, 2 mm spot diameter, scanning rate 850 mm/min, and overlapping amount 20%. Prior to the laser scanning, coating surface is painted black in order to increase laser absorption rate. Ar gas protection was used during laser scanning.

The corrosion resistance was determined through a mass loss mensuration, with each value being derived from average of three specimens. The corrosion test was performed in a large tank containing 5 L of 10%HCl aqueous solution as corrodent with room temperature (25°C) and not stirred or aerated. After each specimen was degreased and cleaned, they were all set suspended in the corrosive solution to achieve full corrosion. The coated samples were cut into small specimens with dimensions of 20mm×10mm×2mm. The corrosion rate curve was plotted as function of the ratio of mass loss to the corrosive area and time. The mass loss was examined by a precision electronic balance with an accuracy of 10^{-4}g.

3. Results and Discussion

The morphology of electrodeposited nickel coatings (Figures 2(a)–2(d)) displays Ni microstructures at nanometer scale under different current densities. The deposit coating appears mainly compact but still contains some macroscopical pores and defects. An uneven surface and rough grain size (see Figure 2(a)) were observed under relatively low current density of 20 A/dm^2. As current density increased, the deposit surface became more and more smooth till the current density reached 40 A/dm^2 (see Figure 2(c)). Afterwards, the overall deposit layer underwent a cellular-like growth and grew into a larger grain size and deteriorative surface flatness.

As shown in Figure 2, nanocrystalline nickel coating was electrodeposited on the substrate material-304 stainless steel(1Cr18Ni9). In the next procedure, high-energy density laser beam would be used to scan and melt the Ni coating over the specimen. During the rapid solidification generated by laser beam, the specimen surface formed a new layer of coating, as seen in Figure 3, that quite differed from substrate material composition, which provided substrate material surface with better performance such as corrosion resistance. Figure 3 also shows the cross-section of the specimen after laser remelting. It can be clearly seen that there were three zones over the cross-sectional surface: tempered zone, phase transformation hardening zone, and remelted zone [8]. The variation of the coating's microstructure after laser remelting, as shown in the Figure 3, is actually caused by laser's unique characteristics, rapid heating and cooling. When the laser beam is scanning, the coating was cooled dramatically from the melting state. The nucleus has no sufficient time grown-up and therefore forms a dense and fine crystal structure in the remelting layer. Simultaneously, under the laser radiation, the metal atoms of the deposit layer and the matrix mutually diffuse each other, which becomes a new metallic bond between atoms. This transition successfully generates a metallurgical bonding between the substrate material of stainless steel and the Ni coating, from the originally mechanical bonding, so that the adhesion of the protective coating with the substrate will be strengthened [9].

Figure 4 illustrates the corrosion kinetics of samples including substrate material-1Cr18Ni9, laser-processed specimens, jet electrodeposited specimens, and the specimens with jet electrodeposition and laser scanning process. As seen in the corrosion rate curve, during the first 8 h of exposure, the substrate material was in a very quick corrosion and then the corrosion rate became slow. In the first 20 h, substrate material appeared to deteriorate rapidly while the nanocomposite-coated ones seem to keep a gradually declining trend. Based on such results, it may be assumed that the nanocomposite exhibits an initial and transient corrosion stage that is different from the corrosion of 1Cr18Ni9 counterpart. At the onset of corrosion, the alloy may form a NiO scale containing many defects, such as pores and microcracks. In this case, the corrosive liquid penetrates

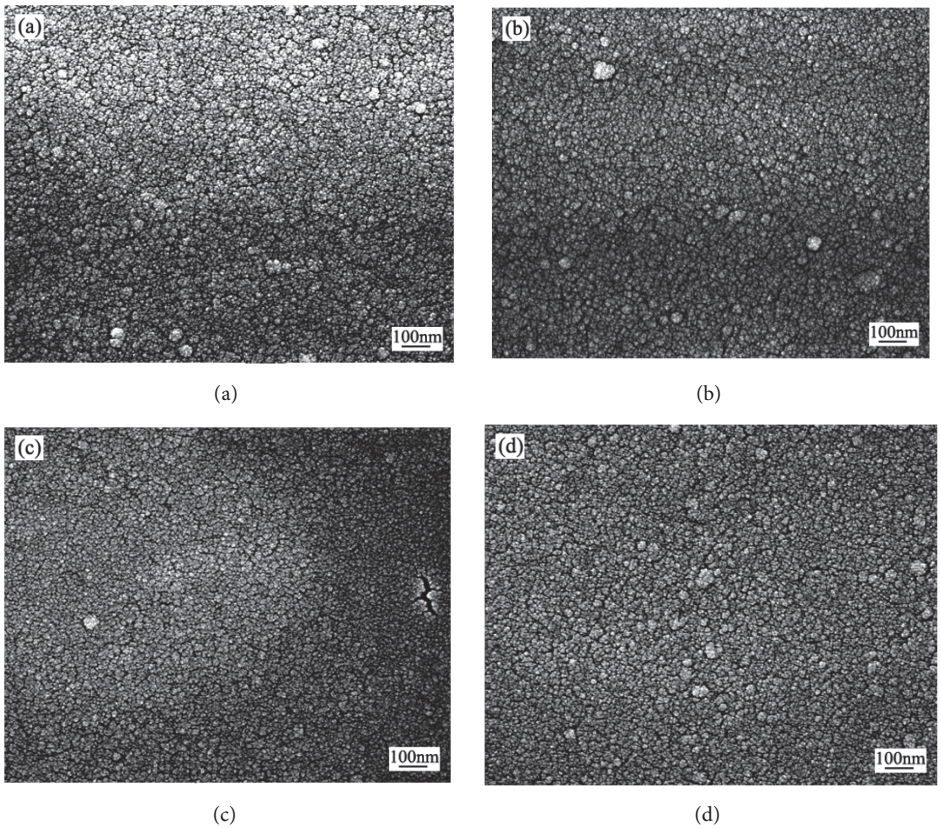


Figure 2: SEM micrograph under different current densities: (a) 20 A/dm^2; (b)30 A/dm^2; (c) 40 A/dm^2; (d) 50A/dm^2.

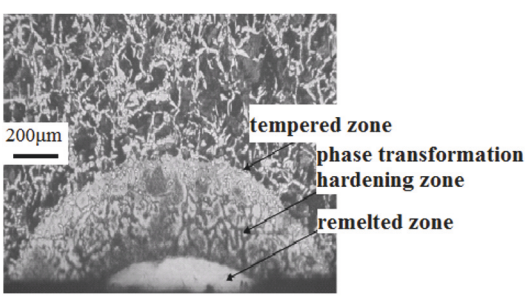


Figure 3: Laser melting area micrograph at view of 400 x metallographic microscope 200μm.

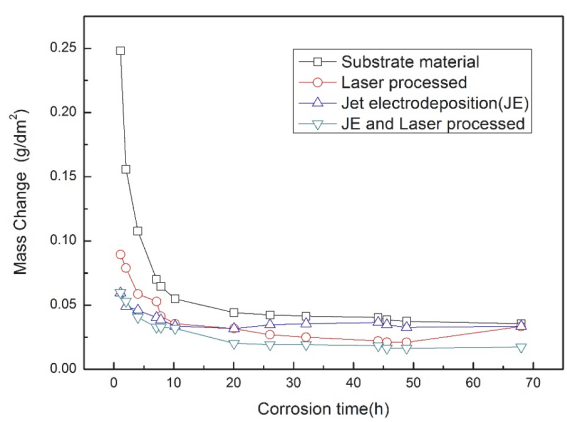
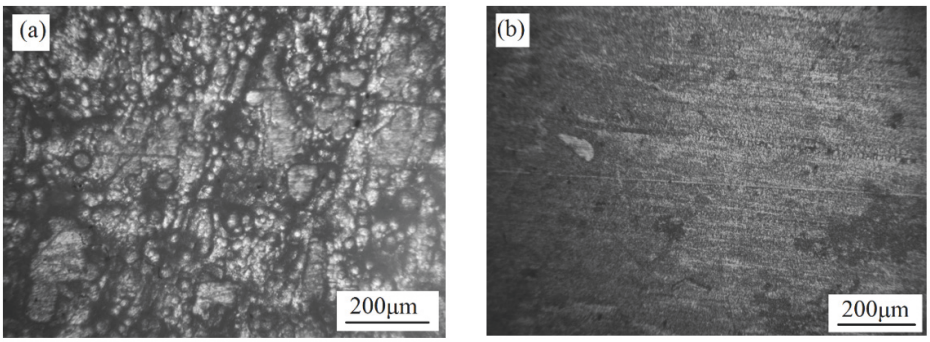


Figure 4: Corrosion rate versus time curve.

through the growing scale through these defects and reaches the scale/alloy interface.

Also from Figure 4, the corrosion rate is seen to be greatly reduced after 20 h. This is possibly associated with two factors. Firstly, the loss of the coated salt that was formed by corrosive liquid penetration would occur in the later exposure stage. Secondly, Cr-rich oxides are progressively formed below the NiO layer, which may significantly mitigate the continuous corrosive attack. With regard to the influence of laser, in contrast with other three curves in Figure 4, the curve representing compound process, namely, those specimens processed by both jet electrodeposition and laser scanning, can be observed to have better performance, while those specimens only receiving the treatment of jet electrodeposition show higher corrosion rate than the ones merely processed by laser. The specimens only treated by jet electrodeposition have much higher corrosion rate after 26h, which is better only than the substrate material, unprocessed 304 stainless steel. This phenomenon might be related to the infiltration of the corrosive medium. On one hand, the laser enhancement refines the grains of electrodeposited coating. On the other hand, the corrosive medium from infiltrating is hardly to travel to the substrate material through the interface



(a) (b)

Figure 5: A metallographic image of the surface of the Ni coating after corrosion at view of 400×: (a) without laser processed and (b) with laser processed.

of coating and substrate which have already become denser metallurgical bonding [11, 12].

In terms of the corrosion failure mechanism of deposit coating, many researchers believe that it is the corrosion medium entering along the pores into the deposit that leads to the corrosion of metal substrates as well as the material peeling [13, 14]. In general, the key to improving the erosion of the deposit layer is to reduce the amount of the through-holes that actually plays an important role as corrosion medium penetrating path. However, nickel deposits are more susceptible to erosion due to the its special high porosity. If the porosity was decreased in an appropriate way, the corrosion resistance of the Ni coating might be improved.

In fact, in the use of jet electrodeposition and by laser strengthening effect, all are in favor of the decrease of the porosity. This variation of microstructure favorably restrains corrosive medium from entering inside the coating. Simultaneously, many research results show that the laser remelting can eliminate the deposit's lamellar structure and make deposits into isometric and dendrites, therefore contributing to eliminating loose, porosity, and other defects in the coating layer. These strengthening effect prevents the infiltration of corrosive medium as well. However, in the process of laser remelting, laser, coating, and substrate have very complex interaction mutually. There exist not only thermal reactions between laser and nanocrystalline deposits, but also mutual infiltration between the deposit and substrate material. The compound process anticorrosion mechanism still needs to be further explored.

Figure 5 displays the morphology of the specimens after corrosion. According to Figure 5(a), the corrosion pits evenly are distributed on the surface of the specimen, indicating that most of corrosion occur at the surface of the specimens. In comparison, according to Figure 5(b), the specimen after laser remelting seems relatively smooth and flat, proving that laser remelting after jet electrodeposition can improve the corrosion resistance of the specimens.

4. Conclusions

We herein demonstrated that the corrosion resistance of stainless steel substrate can improve considerably by coating their surfaces with Ni coatings using Jet electrodeposition. With the current density reaching 40 A/dm^2, a dense and grain-refining coating was achieved in favor of prevention of corrodent infiltrating. The Ni coating underwent the following laser treatment to form remelting area, which can further accelerate the formation of dense and fine structure and transform the originally mechanical combination between substrate and coating to the metallurgical combination, thus enhancing anticorrosion behavior again. The specimens processed by jet electrodeposition and laser scanning have the well corrosion performance, better than the specimens Ni coated by jet electrodeposition and the bare substrate material.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

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