CORROSION PROTECTION AND CHACRACTERISTICS OF Ni-CeO_2-CuO ELECTROPLATING LAYER ON STEEL SUBSTRATE

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ABSTRACT

The particles of CeO_2 and CuO are capable of catalyzing the oxidation reaction of carbon monoxide and hydrocarbons at low temperature, especially at nanometer size. They can be deposited on the metal material surface by using electroplating method. This paper reports some results on corrosion resistance, wear resistance, adhesion strength and catalytic behavior of Ni-CeO_2-CuO composite by electroplating on steel substrate from nickel sulfate solution using CeO_2 and CuO particles with 40÷60 nm size.

Keywords: Ni-composite electroplating, Ni-CeO_2, Ni-CuO, Ni-CeO_2-CuO catalytic material, CO and C_3H_6 conversion.

1. INTRODUCTION

Composite electroplating is formed by the co-precipitation of very small particles of one or more substances with a metal forming a coating [1]. Composite electroplating technology is now able to produce coatings that combine the properties of plated metal and doped particles [1, 2]. As a result, composite electroplating improves certainly properties of single metal coatings such as increased hardness, better abrasion resistance and/or chemical catalysts, etc. [3 - 4]. The composite of Ni-CeO_2-CuO by electroplating is formed in a solution of nickel sulfate with dispersed nanoparticles of CeO_2 and CuO, improving some nickel plating properties such as: increased corrosion resistance, hardness and abrasion. In addition, Ni-CeO_2-CuO composite electroplating also can catalyze the conversion process of CO and C_xH_y with high efficiency.

2. EXPERIMENTAL AND METHODS

2.1. Materials

CeO_2 was provided by the Richest Group Ltd. (Shanghai, China) and CuO (99.9 %) by Nano Global (Shanghai, China). Both of them had nanometer size.

$NiSO_4$, H_3BO_3, NaOH, H_2SO_4, Sodium lauryl sulfate $CH_3(CH_2)_{10}CH_2OSO_3Na$ and NaCl were the pure chemicals from China.

2.2. Methods

2.2.1. Method of Ni-CeO_2-CuO composite electroplating

The Ni-CeO_2-CuO composite electroplating was formed in a electrolyte solution containing $NiSO_4$ (300 gL^{-1}), H_3BO_3 (30 gL^{-1}), CeO_2 (4 g L^{-1}) and CuO (4 g L^{-1}), with a current density of 2 A dm^{-2} under regarded conditions: plating time of 20÷60 min, temperature of 50 ^oC, stirring speed of 600 r min^{-1}. The total content of CeO_2 and CuO in the coating was changed from 14 to 16 %.

2.2.2. Test methods for evaluating the properties of the plating

Corrosion resistance of electroplating layer was determined by measuring the Tafel curve in 3.5 % NaCl solution using Autolab PG302 instrument at the Institute of Chemistry and Materials, Military Academy of Science and Technology.

Environmental resistance was being rapidly tested based on 2 standards:

- Salt spray (fog) resistance (TCVN 7699-2-52:2007), harshness level 3.
- Hygrothermal resistance (TCVN 7699-2-30:2007), environmental testing, part 2-30: Experiment Db: hygrothermal, (12 h + 12 h period), harshness a.

Microhardness was determined by microhardness tester Duramin at the Military Institute of Technology.

Wear resistance of plating layer was determined by wear tester Friction and Wear Demonstrator TE97 (England) at the Institute of Energy and Mining Mechanical Engineering according to ASTM-G77 standards.

3. RESULTS AND DISCUSSION

3.1. Corrosion resistance of the electroplating layer

Electrochemical characteristic on corrosion resistance of Ni-CeO_2-CuO composite electroplating layer is illustrated in Figure 1. From Tafel plots (Figure 1), it can be seen that the presence of CeO_2 and CuO particles in the composite plating changed the corrosion potential E_{corr}, polarization resistance R_P and corrosion current density i_{corr} of the coatings. The results in Table 1 show that the CeO_2 particles made increasing the polarization resistance of the nickel plating layer leading to reducing the corrosive current, while the CuO particles reduced the polarization resistance leading to increasing the corrosion current of the Ni-CuO plating. Compared to pure nickel electroplating (16.88 $\mu A/cm^2$), the corrosion current density of the Ni-CuO coating was 5.5 times greater (88.71 $\mu A/cm^2$), but that of the Ni-CeO_2 coating was only half (8.09 $\mu A/cm^2$) which shows a corrosion rate of only 0.1 mm per year. It means that the presence of CeO_2 particles played an important role in improving the stability of electroplating layer. Therefore, The Ni-CuO coating is better protected against corrosion if CeO_2 is present in it. So the corrosion density of Ni-CeO_2-CuO composite electroplating layer (16.01 $\mu A/cm^2$) was lightly lower than that of the pure nickel plating one indicating a durability could be lightly improved.

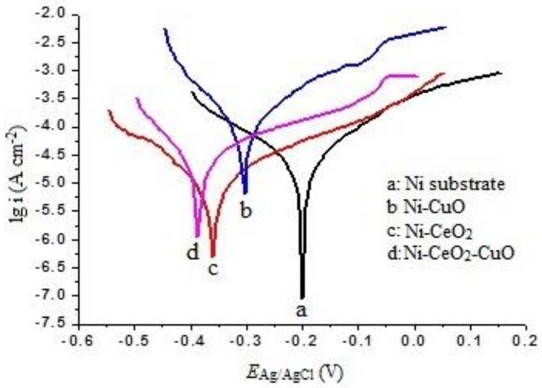

Figure 1. Tafel plots of Ni and Ni/CeO_2-CuO composite plating in 3.5 % NaCl solution.

Table 1. Corrosion potential, current and rate, polarization resistance and Tafel coefficient.

Samples	Materials	Corrosion current density i_{corr} (μA/cm^2)	Corrosion potential E_{corr} (V)	Polarization resistance R_P (kΩ)	Corrosion rate per year (mm/year)
a	Ni	16.88	-0.198	0.461	0.208
b	Ni-CuO	88.71	-0.303	0.070	1.093
c	Ni-CeO_2	8.09	-0.363	1.245	0.100
d	Ni-CeO_2-CuO	16.01	-0.339	0.616	0.197

3.2. Salt spray and hygrothermal testing of electroplating layer

Table 2. Observation results from experiments of salt spraying and hygrothermal testing for different electroplating layers.

Sample number	Experiment condition	Results of electroplating layers: Ni electroplating	Results of electroplating layers: Ni-CeO_2-CuO electroplating
1	Salt spraying resistance (TCVN 7699-2-52:2007) harshness level 3	- The plating was not blistered - Rusty and abnormal spots do not present on the plating surface.	
2	Hygrothermal resistance TCVN 7699-2-30:2007	- The plating was not blister - Rusty and abnormal spots do not present on the plating surface.	

Results in Table 2 show the environmental resistances of Ni-CeO_2-CuO composite electroplating layer on CT3 steel substrate by salt spraying and hygrothermal testing. It indicated that this Ni-composite based on CeO_2 and CuO particles was not affected by salinization of corrosion factors from environment.

3.3. Wear resistance of the electroplating layer

The results in Table 3 illustrates the wear resistance of Ni-CeO_2-CuO composite and Ni layers by electroplating. We found out that the wear intensity of Ni layer was 4.2 times larger than that of Ni-CeO_2-CuO composite one, so that the wear resistance of Ni-CeO_2-CuO composite electroplating layer was 4.2 times better than pure Ni one.

Table 3. Results of wear resistance measurement.

Electroplating layers	Load (N)	Rotation speed (rpm)	Diameter (mm)	Test time (s)	Wear intensity (g/N.m)		
					Time 1	Time 2	Average
Ni	20	10	34	169	17.10	21.60	19.35
Ni-CeO_2-CuO	20	10	34	169	2.30	6.90	4.60

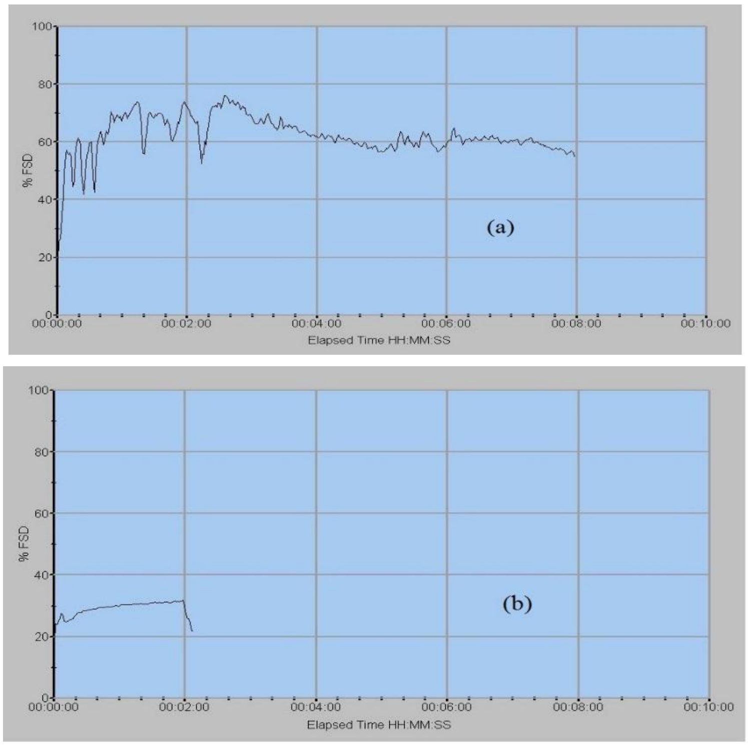

Figure 2. Friction coefficients of Ni (a) and Ni-CeO_2-CuO composite (b) by electroplating.

The data in Figure 2 show the friction coefficient of Ni electroplating that was 1.318, approximately five time larger than that of Ni-CeO_2-CuO composite one (0.274). So it can be seen that the Ni-CeO_2-CuO composite electroplating layer had more wear resistance than Ni one.

3.4. The hardness of electroplating layer

The data in Table 4 demonstrate the microhardness of Ni-CeO_2-CuO composite and Ni electroplating layers. It indicates that the hardness of the composite electroplating layer depended on various factors such as: (i) nature of the metal substrate (structure and mechanical properties), (ii) morphology of the electroplating layer surface, (iii) characteristic of composite particles (composition of solid particles, size and shape of the solid particles).

For the Ni-CeO_2-CuO composite electroplating, the first two factors have little effect on the hardness of the electroplating layer, so the hardness depends mainly on the third factor. With the presence of CeO_2 and CuO particles, the hardness of this composite is greater than that of pure Ni electroplating layer.

Table 4. Results of microhardness (HV) of Ni and composite electroplating layers.

Electroplating layers	Time 1	Time2	Time3	Time 4	Time 5	Average
Ni	164.7	157.8	168.2	162.0	163.1	163.2
Ni-CeO_2-CuO	220.0	241.0	258.0	246.0	238.0	240.4

3.5. The conversion of CO and hydrocarbon catalytic abilities

Figure 3 shows the experiment results of the conversion of CO and hydrocarbon C_xH_y (C_3H_6 in this case) catalyst abilities of Ni-CeO_2-CuO composite electroplating layer.

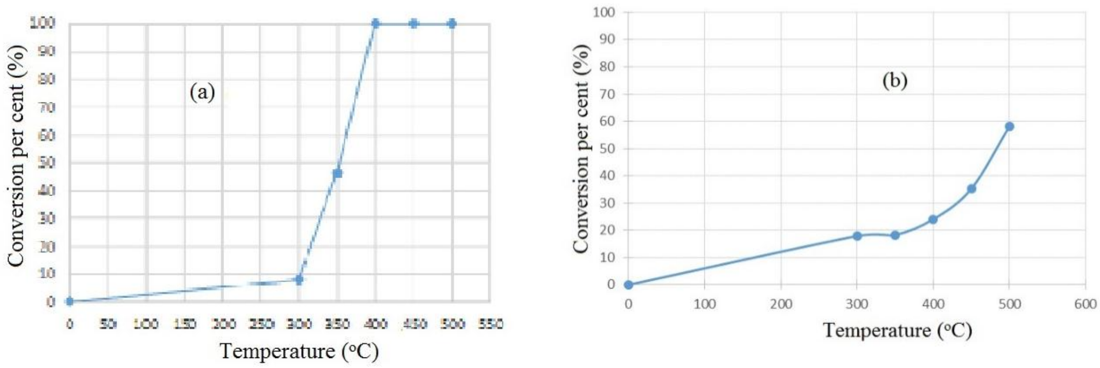

Figure 3. Catalytic properties of NiCeO$_2$-CuO composite electroplating layer for conversion of CO (a) and C_3H_6 (b).

Results from Figure 3a show that the catalytic ability of Ni-CeO_2-CuO composite electroplating layer was very good for the conversion of CO. A low efficiency of it was found at low temperature area from 100÷300 ^oC, at about 8 %. From 300 to 400 ^oC, it had a steep increase at 350 ^oC with an efficiency of 46.5 % and reached 100 % at 400 ^oC. So by electroplating method, we can say that the CeO_2-CuO composite was deposited successfully onto the steel surface. The interaction between Ni substrate and catalytic particles (CeO_2 and CuO) resulted to increasing the catalytic activity of the electroplating layer for the conversion of CO. The results from the figure also show that the conversion ability of C_3H_6 (b) was lower than that of CO (a). It increased steeply until 18.28 % at temperature from 0 to 350 ^oC, but slowly at 300÷350 ^oC, then steeply by 58.16 % at 350÷ 500 ^oC.

4. CONCLUSION

The Ni-CeO_2-CuO composite was successfully deposited on steel substrate by electroplating. It had a good corrosion resistance in 3.5 % NaCl solution and under salt spraying as well hygrothermal environment. This composite also had invaluable properties such as the hardness and wear resistance increasing 1.47 times and more than 3 times, respectively, compared to those of pure Ni electroplating layer. Its catalytic efficiency obtained 58.16 % for the C_3H_6 conversion at 500 ^oC, but, 100 % at 400 ^oC for CO conversion. So we can say that the Ni-CeO_2-CuO composite electroplating layer is potential catalytic material for preparing the catalytic conversion device to treat exhaust gas from combustion engine.

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