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Letter

Electroplating Ni–P films and their corrosion property

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1. Introduction

Electroplated Ni–P films as corrosion protection coating layers have been one of the earliest industrial applications of amorphous materials [1, 2]. Maraging steels, despite their ultrahigh strength nature [3], often have corrosion problems, especially when used as nuclear enrichment rotors (centrifugal machine) because of possible chemical reactions. Earlier work [4] showed that the electroplated Ni–P films have different structures according to their different phosphorus concentrations. Ni–26at.%P is in a crystalline state, Ni–23at.%P is a typical amorphous material and Ni–11at.%P is a mixture of crystalline nickel and amorphous Ni–P. The amorphous Ni–23at.%P film has a high hydrogen penetration resistance and a relatively high microhardness. The electroplating process for nickel and Ni–P films has no degradation effect on the tensile strength of the maraging steel substrate.

2. Experimental details

Electroplating of nickel and Ni–P films was carried out on plates of 350 klbf in^{-2} grade maraging steel substrate of 10 mm×20 mm×20 mm in dimensions. The solutions for pure nickel and Ni–P are shown in Tables 1 and 2 [2]. For pure nickel electroplating, the temperature was kept at 55 °C, pH 4–4.5 and current density 500 A m^{-2}. For Ni–P electroplating, the pH was maintained between 1 and 1.5. H_3PO_4 was added during long-time electroplating. The resultant film thickness was between 40 and 50 μm. The corrosion experiments were carried out using the weight loss method in 40% HF for 48 h and 3 wt.% NaCl for 576 h (both water solutions) at room temperature and atmospheric pressure.

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TABLE 1

Solution concentration (g l^{-1}) for pure nickel electroplating

Solution				
$NiSO_4 \cdot 6H_2O$	$NiCl_2 \cdot 6H_2O$	H_3BO_3	$C_7H_5O_3NS$	$C_9H_6O_2$
250	25	40	0.8	0.3

TABLE 2

Solutions for Ni–P electroplating and the resultant phosphorus contents in the films measured by scanning electron microscopy

Solution	Amount of the following					P content in film (at.%)
	H_3PO_3 (g l^{-1})	H_3PO_4 (85%) (ml l^{-1})	Na_2CO_3 (g l^{-1})	$NiCl_2 \cdot 6H_2O$ (g l^{-1})	$NiSO_4 \cdot 6H_2O$ (g l^{-1})	
1	30	35	5	46.0	153.8	26
2	10	35	5	49.8	166.3	23
3	3	35	5	51.1	170.6	11

3. Results

Ni–P coatings can be obtained under the above electroplating conditions. An X-ray experiment showed that the electroplated layer obtained from solution 1 consisted of a series of metastable Ni–P phases which were not of any identified phases. The electroplated layer from solution 2 had a typical amorphous structure, while the film obtained from solution 3 was a mixture of crystalline nickel and amorphous Ni–P. There is not a sufficient amount of phosphorus in the Ni–11at.%P film to make it completely amorphous.

Shiny smooth Ni–P coatings could be obtained under a wide range of electroplating current density. It was shown that the best current density ranged from 200 to 800 A m^{-2}. Electroplating with too large a current density (over 1000 A m^{-2}) resulted in poor quality films, sometimes with inhomogeneous surfaces.

There is no observable difference of film structure after electroplating for different times. The influence of electroplating temperature is also small. Using solution 2, uniform amorphous films can be obtained with temperature ranging from 40 to 70 °C. The substrate is ready to electroplate after only modest cleaning, probably because of the self-cleaning effect of the electroplating solution.

Table 3 gives the results of the corrosion experiments. The amorphous Ni–P has good corrosion resistance in both strong (HF) and modest (NaCl) corrosion environments.

TABLE 3

Comparison of corrosion rate at room temperature and atmospheric pressure

Material	Corrosion rate (g m^{-2} h^{-1})	
	In 40% HF	In 3wt.%NaCl ($\times 10^{-2}$)
Maraging steel	18.7	4.1
Maraging steel with Ni plating	1.6	2.0
Maraging steel with Ni–11at.%P plating	0.6	1.3
Maraging steel with Ni–23at.%P plating	0.2	0.4

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