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The effects of parameters on the mechanical properties of Ni-based coatings prepared by automatic brush plating technology

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Abstract

The pure nickel coatings were prepared by using a newly developed automatic brush plating system. The microstructure of the coatings was characterized using SEM and the crystalline size of the coatings was determined by XRD based on Scherrer's formula. The hardness, elastic modulus and wear performance of the coatings were also investigated. The results showed that the microstructure and performance of the coatings were greatly affected by the processing parameters such as current density, relative motion and contact pressure. Pure nickel coatings prepared at lower current density possessed smoother, denser and more uniform microstructure, and exhibited higher microhardness, elastic modulus and better wear resistance. Pinholes were eliminated from the coatings when the relative speed exceeded a critical value. Coatings prepared at higher contact pressure were smoother and denser. However, high internal stress was generated and resulted in crack somewhere in the coating. The results presented here revealed that we can adjust the electrodepositon parameters properly to improve the mechanical and tribological properties of the coatings.

Keywords: Coating; Mechanical property; Brush plating; Nickel

1. Introduction

Electroplating has long been a widely used method to prepare materials with tailor-made properties. As detailed in Ref. [1], electrodeposition has many advantages such as the ability to deposit a number of pure metal, binary and ternary alloys as well as nano-structured metal matrix composites, few shape and size limitations, high production rates, low initial capital investment requirements and easy technology transfer from the research laboratory to existing infrastructure in electroplating and electroforming industries. Importantly, the method is usually employed at ambient temperature and common pressure. It is well known that the microstructure and mechanical properties of a plated coating depend upon the plating conditions such as current density, temperature, concentration, electrolyte pH and stirring rate. For direct current (DC), pulse current (PC) and pulse reverse current (PRC) electrodeposition, the processing parameters can be precisely controlled and optimized, whereas it is impossible for the operator to ensure all these important parameters during the brush plating process, in which the operator dips the plating tool in the solution and brushes it against the surface of the workpiece that is to be finished. When the anode touches the work surface a circuit is formed and an electrodeposit is produced. During the process, the plating tool is always kept in motion whenever it is in contact with the work surface. Therefore, the operator's experience dominates the plating process to a great extent. In fact, even for correctly trained operator, stable deposit quality can not be ensured. Due to its portability, flexibility and easiness to operate, brush plating has found increasing use in industry. However, the effects of parameters on the brush plated deposit quality have not been well understood yet.

In order to eliminate the disadvantages resulting from the human nature, we developed an automatic brush plating system and primary work showed that automatically plated coatings have even dense and fine microstructure [2]. In this work, this system was employed to investigate the influences of the parameters such

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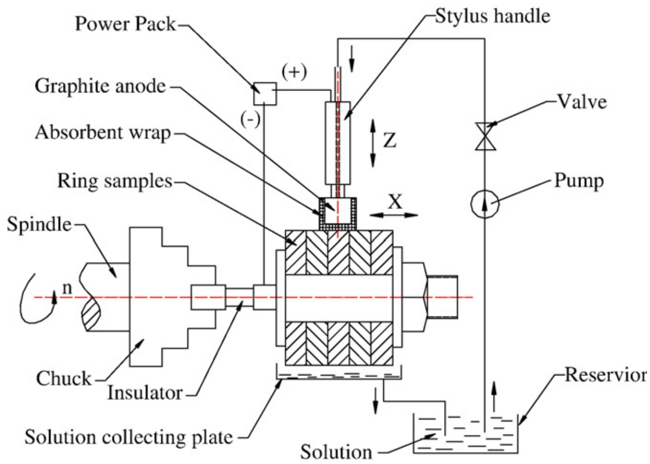

Fig. 1. Schematic of brush plating process.

as current density, relative anode to cathode speed and contact pressure between anode and cathode on the surface morphology, microstructure, Young's modulus, microhardness and wear-resistance property of the plated coatings.

2. Experimental

All pure nickel coatings were made at room temperature (25 °C) on 45 carbon steel ring specimens with outside diameter of 40 mm, inside diameter of 16 mm and width of 10 mm. The schematic diagram of the apparatus made for brush plating is shown in Fig. 1. Prior to plating, five ring samples were assembled and then grinded simultaneously. When plating, the samples rotated with the spindle rotating and the brush tool moved along the *X* direction. The contact pressure between the brush tool and the surface to be plated was controlled by adjusting the distance between them along the *Z* direction. The solution was pumped continuously from the reservoir to the graphite anode wrapped by absorbent material through the channels in the stylus handle. A series of small and uniformly spaced holes were drilled within the anode through which the solution reached the absorbent material and then the surface to be plated. The cotton textile was used as diffusion medium allowing the cations to migrate to the surface to be plated. Each experiment was carried out with a fresh solution and a step-by-step plating procedure was listed in Table 1. The nickel electrolyte composition used for all experiments was 254 g/l $NiSO_4 \cdot 7H_2O$, 105 g/l $NH_3 \cdot H_2O$, 56 g/l $(NH_4)_3C_6H_3O_7$, 23 g/l CH_3COONH_4 and 0.1 g/l $(COONH_4)_2 \cdot H_2O$. For nickel plating, the deposit time was 30 min and the layer with a deposit thickness of about 60 μm was obtained.

Surface morphological examinations were carried out by employing a Quant 200 scanning electron microscopy (SEM). Structure characterization of the deposit was carried out by XRD using a Bruker D8 Diffractometer. The microhardness of the brush plated samples was determined using a NanoTest 600 Nanoindenter (Micro Materials, Ltd., Wrexham, U.K.). Nanoindentation experiments were conducted to a maximum load of $P = 15$ mN. The loading and unloading steps of indentation were carried out over a time span of approximately 20 s in all the experiments. At the maximum load, a dwell period of 5 s was imposed before unloading so as to correct for any thermal drift in the system. Five indents with the adjacent indents separated by 10 μm were made on the polished cross section.

Table 1
A step-by-step procedure for plating on 45 steel

Step	Operation	Solution	pH	Polarity	Voltage/V	Time/min
1	Electroclean	Cleaning solution	11	Forward	10	0.5
2	Rinse	Water				
3	Activate 2	Activating solution 2#	0.7	Reverse	12	0.5
4	Rinse	Water				
5	Activate 3	Activating solution 3#	4.1	Reverse	18	0.5
6	Rinse	Water				
7	Special Ni preplate	Special nickel solution	2	Forward	12	2
8	Rinse	Water				
9	Pure Ni plating	Nickel solution	7.55	Forward	8, 10, 12, 14	30
10	Rinse	Water				

Wear-resistance performance was examined under lubricating condition in air at 25 °C by a MM200 testing machine (Fig. 2). Quenched 45 carbon steel blocks with hardness HRC 53–55 were used as static partners. The tests were run by using loads of 300 N for 2 h. After the tests, the wearing weight losses were examined and the friction coefficients were calculated.

3. Results and discussion

3.1. Effect of current density

The current density is an important factor affecting the deposit quality of plated coatings. However, it is difficult to keep it stable during the whole pure nickel brush plating process. Although it is dominantly determined by the working voltage and the contact area between the anode (cover) and the surface to be plated, it is also affected by the temperatures of the solution and workpiece. For pure nickel

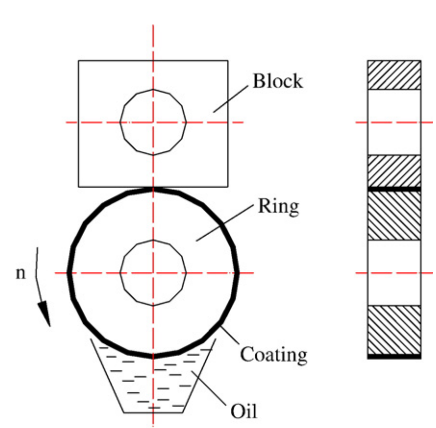

Fig. 2. Schematic diagram of MM200 block-on-ring testing machine.