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Jet electrodeposition of nanocrystalline nickel assisted by controllable friction

Xia Liu, Lida Shen *, Mingbo Qiu, Zongjun Tian, Yihao Wang, Kailin Zhao

College of Mechanical and Electrical Engineering, Nanjing University of Aeronautics and Astronautics, Yu Dao Street, 210016 Nanjing, China

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ABSTRACT

A controllable friction auxiliary method (CFAM) was developed to improve the quality of a coating surface prepared through flexible friction-aided jet electrodeposition (FFAJED) at a high current density. A rolling nozzle was also designed. This nozzle can provide controlled pressure constantly during deposition so that the proposed method can forcibly restrain the rapid growth of the coarse grains. The influence of different pressures and cathode scanning speeds on coating surface quality was discussed, and the optimum parameters of the method were determined. With the optimum parameters, the effect of different current densities on coating surface quality was studied. Results show that when the rolling pressure is 5 N and the scanning speed of the cathode is 860 mm/min, the surface quality of the coating is excellent. No obvious coarse grains, defects (e.g., pinhole or nodules), and apparent traces of friction were observed. The magnetic properties of Ni coating were improved too. The upper limit of current density in the preparation of Ni coating by CFAM reached 200 A/dm^2, which is 1.54 times that of traditional jet electrodeposition (130 A/dm^2) and 1.43 times that of FFAJED.

1. Introduction

Mechanical attrition [1–6], supersonic shot peening [7], and ball milling [8] are nanometer technologies related to mechanical effects. Flexible friction-aided jet electrodeposition (FFAJED) was introduced in 2000 [9]. Dong Xueliang [10] utilized the vibration of glass balls on the cathode surface to cause friction. In Biao Lv's [11] experiments, three classes of non-conductive materials, namely, polymers, bio-bristles, and natural fibers, were selected as flexible friction media. These materials were made into brushes to rub the coating surface. Among the three classes, bio-bristles are the strongest friction medium; it has the highest impaction strength and the best inhibition of grain growth. Zhu Jun. [12] half submerged a cathode in ceramic balls and found that the average grain size is 10.9 nm, which is 4.7 nm smaller than that obtained with the traditional method. Although mechanical attrition by hard particles or friction blocks can refine the grain size, smoothen the coating surface, enhance the hardness [13–16] of the deposits, and so on, the mechanical leveling effect of flexible friction will weaken gradually with the increase in current density [17]. Zhu Jun. [18] performed Ni plating on a graphite rod and discovered that when the current density on the cathode is 80 A/dm^2, coating surface quality is excellent because of the good balance between the friction effect and the growth of the crystal. When the current density is more than 140 A/dm^2, the growth rate of defects exceeds the removal rate of friction and causes a significant reduction in the friction effect; consequently, island-shaped crystals appear. The deposition rate can be increased by improving the current density, but doing so may aggravate the hydrogen evolution reaction [19] and could result in a decrease in coating surface quality if the current density is increased to a very high value. To compensate for the shortcomings of FFAJED under high current densities, a rolling nozzle was designed in this study to provide controlled pressure continuously in the process of deposition. This method can help improve the quality of the coating surface through mechanical attrition, increase the limiting current density, and enhance deposition efficiency.

2. Experiment

2.1. Experimental device

A schematic of the electrodeposition apparatus that employs controllable friction is shown in Fig. 1. The machining region is shown in Fig. 2. This electrodeposition platform was designed by our team, it can monitor scan times, scan lengths, and deposition time.

2.2. Rolling nozzle

A nozzle with a ceramic rod hanging outside was designed to provide periodic rolling friction on the coating surface during

* Corresponding author.
E-mail address: ldshen@nuaa.edu.cn (L. Shen).

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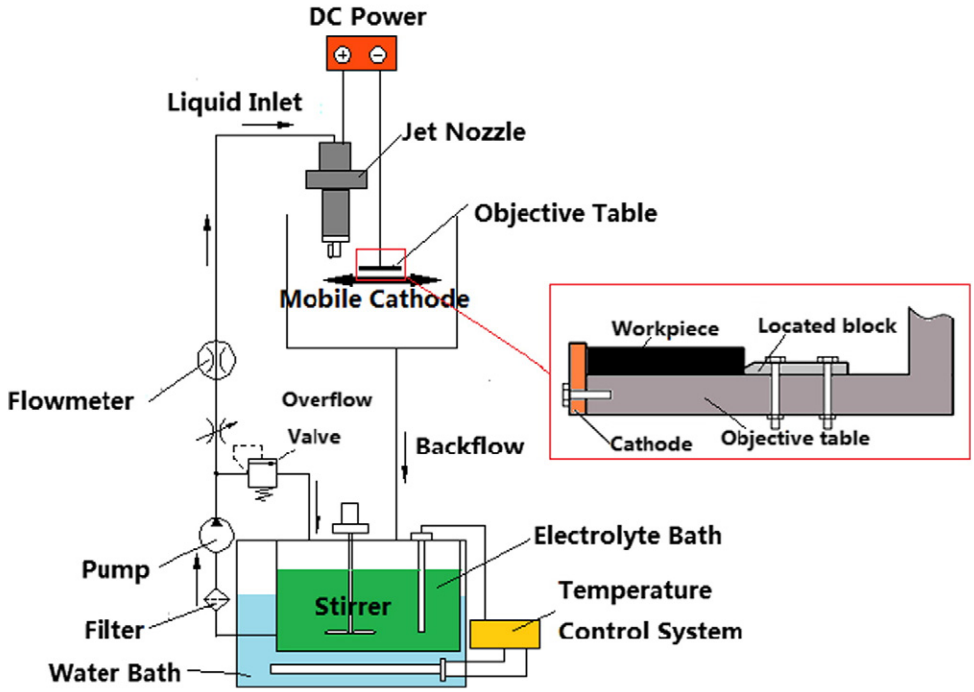

Fig. 1. Schematic of controllable friction aided jet electrodeposition (CFAJED).

electrodeposition on the premise that doing so would not affect the process. 3D printing technology was used to prepare the nozzle. The pressure provided by the nozzle can be adjusted by setting the number and shrinkage of the spring. The structure of this device is shown in Figs. 3 and 4.

As shown in Fig. 3, the ceramic rod and the bottom guide plate are in contact. Given that the bottom guide plate was made from resin through stereolithography, the plate's surface was extremely rough that it hindered the rolling of the ceramic rod during deposition. The friction in this case is the sliding type. During the installation of the external device, the position of the stop block and bottom guide plate were fixed. Thus, the machining gap and the amount of initial compression on the spring can be adjusted. The pressure can also be changed by placing a spacer between the top guide plate and the stop block. The theory is shown in Fig. 5.

The stiffness coefficient of the spring used in the experiment is $K = 200$ N/m and the spacer thickness is 2 and 3 mm. Two plans were adopted. In Plan A, the initial amount of compression on the spring (a gap exists between the ceramic rod and workpiece) is $d_{01} = 2$ mm. In Plan B, when the 2 mm spacer is used, $d_{02} = 4$ mm; when the 3 mm spacer is used, $d_{02} = 5$ mm. The effective lift height of the ceramic rod is $h = 2.56$ mm (Fig. 4), and the mass of the ceramic rod is $m = 5.4$ g. Under the assumption that the machining gap is d (at this time, the total deformation of the spring is $d_0 + h - d$) and the number of springs installed is n, the pressure provided by one spring can be calculated with Hooke's law as follows ($g = 9.8$ m/s^2):

$$F = K(d_0 + h - d) \tag{1}$$

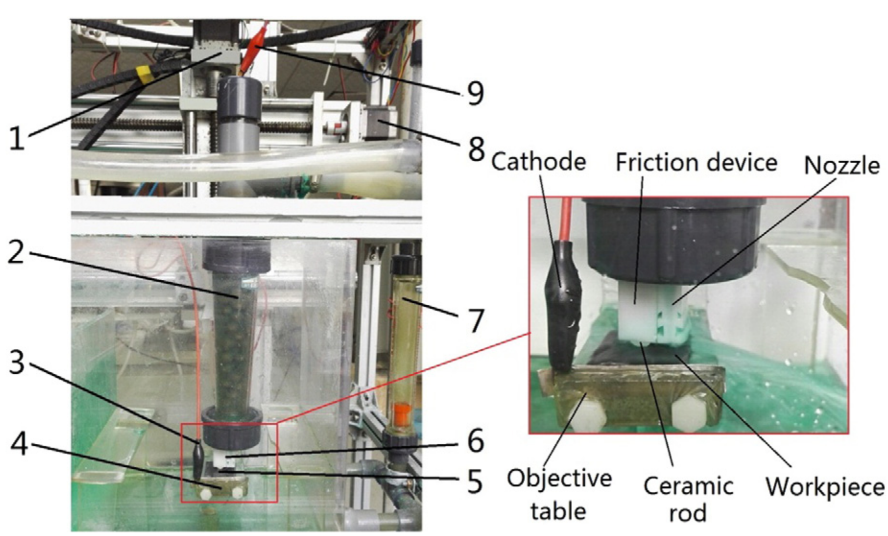

Fig. 2. Machining region.