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Improvement of deposition uniformity in alloy electroforming for revolving parts

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Abstract

The ability to control the nonuniformity of electrodeposition is a key to successful application of electroforming technology. In this paper, an experimental system is developed to electroform the thin-walled revolving parts. Some measures are employed to improve the uniformity of deposition distribution, such as conformal anode, cathode shield and high-frequency pulse current. The profile of the conformal anode is precisely designed by using the function of electric field analysis of ANSYS software, so as to reduce the experimental works and increase the application effect of conformal anode. The deposition thickness, alloy composition and microhardness of the electroforms are measured to reveal the actual deposition distribution. The results show that the electroforms have a satisfactory deposition distribution, the patterns of which are similar to the current density distribution on cathode.

Keywords: Electroforming; Alloy; Deposition distribution; Conformal anode; Electric field analysis

1. Introduction

In electroforming process, a metal layer is electrodeposited upon the cathode or the mandrel of an electrolytic cell. When the deposit attains a desired thickness, it is usually then separated from the mandrel to become an independent metallic product. Recently, electroforming process has been used in the various manufacturing fields such as general machinery, electronics, aerospace, automotive, etc. [1,2].

It is well known that one of the major industrial problems associated with the general electroforming process is to keep and increase the quality of uniform deposition ratio of metal products when the mandrel surface has a general curvature shape. The current distributions in the typical electroforming process are generally nonuniform over the intricate shape of cathode that inherently has some protuberances and recesses. Actually, the distribution of current density is varied even on flat cathode placed parallel to a flat anode. In the electroforming process, a considerable amount of metal is usually deposited at the regions of projections, corners and edges where the current density distribution is normally higher than the other areas. Faster deposition characteristic in these areas consequently increases the current density and thus the effect of deposition rate becomes more and more pronounced. The nonuniform current distribution may also significantly affect alloy composition and microstructure and so the properties of the deposited material. New material processing idea and technique to control the nonuniformity of electrodeposition is a key to the successful application of electrodeposition technologies, such as electroforming and electroplating.

A number of techniques have been investigated in the literature and are being employed for achieving uniformity of deposits. Some commonly referred methods include the following: (1) selection and control of electrolyte composition [3–6]; (2) modification of current density and application of modulated current, such as pulse, pulse reverse and

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superimposed pulse current [5,7,8]; (3) suitable agitation [6]; (4) careful control of anode properties, including the anode shape, size and placement [6,9–12], Yang et al. [10] provided a conformal anode, a kind of shaped anode conforming to the shape of the mandrel, for use during electroform deposition; (5) shields and baffles [13–15]; (6) auxiliary cathode [16–23]; (7) auxiliary anodes [13]; (8) modification of mandrel geometry [4], etc.

The design methods based on practical experiences require a lot of experiments for obtaining the uniform current distribution for the various shapes of cathodes. Therefore, the numerical simulation methods have been applied as important means in order to increase the quality of current distribution. Some researchers have employed typical numerical approaches, such as finite element method (FEM) and boundary element method (BEM), to investigate the distribution of current density and deposition thickness [24–26], to obtain the optimal electrodeposition condition [23], to evaluate the influence of shield shape and position on the deposition uniformity [15] and to optimize the size and shape of auxiliary cathode [16].

In the present study, alloy electroforming of a kind of nozzle is considered as a method to investigate improving the uniformity of deposition distribution. When similar nozzles were electroformed, Malone et al. employed cathode shields and small auxiliary anodes that are located at the mandrel throat and structurally adjustable to improve the deposition uniformity [13]. However, many experiments were needed with this method to achieve satisfactory results. If the slotted or holed baffles are placed between cathode and ordinary anode, similar to Ref. [14], it is difficult to determine the distribution and size of the slot or hole on the baffles, and a higher voltage is required for the passage of a given current as well. In this paper, some of the techniques listed above are employed, especially the application of conformal anode. Moreover, the anode profile is precisely designed by using the finite element software of ANSYS to increase the uniformity of the current density distribution on the cathode.

2. Electroforming cell

The experimental equipment used to electroform the revolving parts is shown in Fig. 1. A set of specially designed conformal anodes is employed to improve the uniformity of deposition distribution in the axial direction of the electroformed parts. Four anode baskets are placed around the mandrel. On the side of the basket facing the mandrel, several pieces of conformal rail are installed at intervals. The other sides of the basket are constructed with nonmetal plates that are temperature resistant. The conformal rails are fabricated with thin nonmetal plates by NC milling. The profile, inside the basket, of the conformal rails is designed according to the mandrel profile, so that the formed anode can produce a uniform electric field distribution on the cathode. When the commercially available nickel pellets are loaded into the baskets, the nickel pellets can adapt themselves to the shape of the inner profile of conformal rails well and then become a set of conformal anodes. The nickel pellets are connected to the positive pole of electroforming power supply. An electric field will form between anode and cathode through the space between conformal rails. The nickel pellets can be compactly loaded in the baskets because of their approximately spherical shape. They can also automatically sink after they are dissolved during the electrodeposition, and keep the shape of the conformal anodes well.

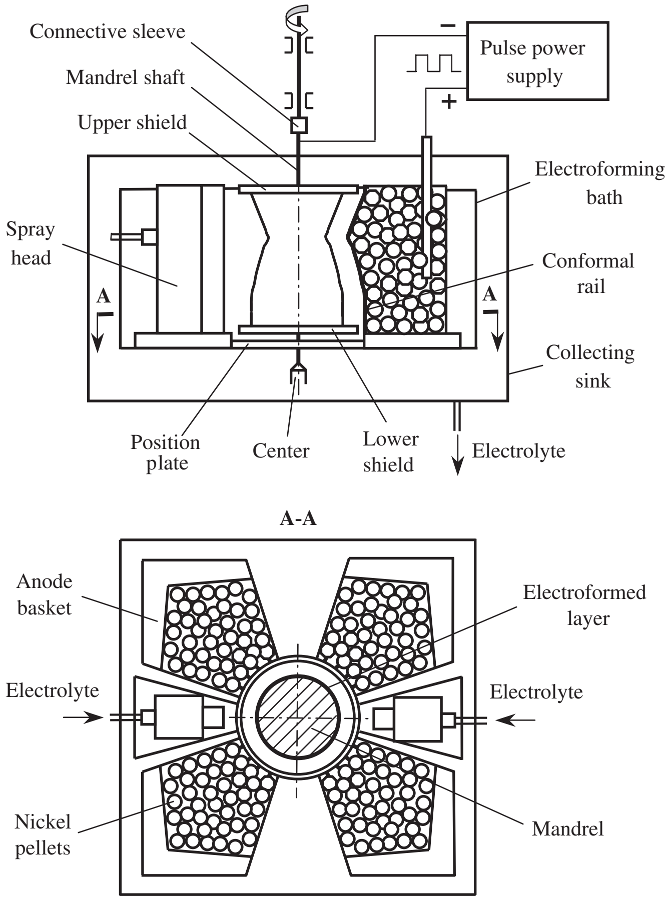

Fig. 1. Schematic diagram of the electroforming cell for revolving parts.

The cathode mandrel revolves at a low speed driven by a motor. This revolution can enhance the deposition uniformity around the periphery of the electroformed parts. Two spray heads are placed oppositely between the anode baskets. The electrolyte spouting from the long and narrow opening of the spray heads flushes to the cathode surface. Both the flushing of the electrolyte and the revolution of the cathode serve as the agitation for electrodeposition. The electrolyte, overflowing from electroforming bath into collecting sink, flows back into electrolyte tank, and circulates continuously after heated and filtered by an electrolyte flow system.

3. Optimization design of anode profile

According to Faraday's law, in the electrodeposition under the condition of other factors remaining constant,