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Effects of process parameters on mechanical properties of abrasive-assisted electroformed nickel

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Abstract A cathode mandrel with translational and rotational motion, which was supposed to obtain uniform friction effect on surface, was employed in abrasive-assisted electroforming for revolving parts with complex profile. The effects of current density, translational speed and rotational speed on the deposit properties were studied by orthogonal test. The tensile strength, elongation and micro hardness value were measured to find out how the factors affected the properties. The optimized results show that changes of current density affect the tensile strength of nickel layer most, while translational speed has the most remarkable influences on both elongation and micro hardness. The low rotational speed affects the properties least. In this experiment, a smooth nickel layer with tensile strength 581 MPa, elongation 17% and micro hardness 248HV is obtained by the orthogonal test.

1. Introduction

Metallic thin-wall parts of complex surface manufactured by electroforming are heavily required by modern industry, for electroforming is a precision manufacture technology or by far the most efficient way to produce these parts. By employing the principle of electrodeposition, electroforming can copy microscopic detail, reproduce accurate dimensions, and form components of controllable material property for desirable functions in applications such as precision mould, shaped charge liner, cryogenic upper stage main engine,[1–5] etc.

However, the applications of traditional electroforming process always go with some drawbacks at the electroformed layer, for example, pinholes and nodules on the surface, coarse grain size and long electroforming cycle. So far, a majority of researchers have been engaged in various kinds of additives, some of which could really reduce the grain size and enhance the strength of the deposits in electroforming process, and others could eliminate the pits and make the deposited layer surface smooth.[6,7] However, it is difficult to maintain the electrolyte baths because the additive agents are consumed during the electrodeposited process by decomposition and being absorbed on the cathode which leads to code position of sulfur and carbon.[8,9] Researchers have blamed the high-temperature

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ductility losses in nickel on sulfur and carbon that are supposed to give rise to the embrittlement of deposits.[10]

Studies made by researchers have shown that abrasive-assisted nickel electroforming process could effectively eliminate pinholes, remove nodules, positively affect crystal nucleation, and refine the grains of layer, and thus near-mirror electroformed layer was obtained without any organic additives.[11,12]

Generally speaking, there are two independent cathode motions in the abrasive-assisted electroforming process to obtain friction effect on cathode surface. A pure rotational motion was designed for revolving parts electroforming, and a designed translational cathode in horizontal type was employed in complex shaped non-rotating parts electroforming. However, for revolving parts with complex surface in abrasive-assisted nickel electroforming process, neither of the two single cathode motions would be carried out. Firstly, there are different linear velocities along the axial direction of cathode because of diverse curvature radius in pure rotational motion. Secondly, the varying electric field intensity on cathode surface for pure translational motion should be taken into consideration because it will lead to the nonuniformity in thickness of deposits. Naturally, the friction effect would also be inhomogeneous. To solve the problems mentioned above, a horizontally positioned cathode with complicated movement in combination of translation and rotation is proposed in this paper. The complex effects of current density, translational speed and rotational speed on the deposit microstructure and properties were studied by orthogonal test. The tensile strength, elongation and micro hardness values were also measured.

2. Principle and experiments

Fig. 1 shows the scheme of experimental principle of abrasive-assisted electroforming process with moving cathode. $\boldsymbol{n}_1$ and $\boldsymbol{n}_2$ are the rotation directions of ceramic beads. V is translational speed. V' is rotational speed. A cylinder mandrel is translated as well as rotated in horizontal type. In the nickel electroforming process, nonconductive hydrogen bubbles usually adhere to cathode surface impeding nickel ion deposition. The free ceramic beads filling in the space between cathode and anode were forced to polish the growing deposited layer slightly and uniformly, driving the hydrogen bubbles away, during the electroforming process.[13,14] The rotation of cathode was set at low speed, while the translational speed was set much higher and played the key role in driving the beads. The orbital movement of cathode mandrel was a circle. The reasons are presented below.[11,12] On one hand, different parts of the cathode have the same linear velocity during the cathode's translation to make sure the polishing effect on the whole surface in uniformity. On the other hand, the rotation of cathode could maintain the cathode surface in the same electric field intensity, and achieve uniform polishing effect on circumference surface.

Fig. 2 illustrates the schematic diagram of the experimental apparatus. The cathode's translational movement was carried out by a planar worktable driven by stepper motor in X/Y axis linkage. And a speed control motor was employed to drive the rotation of the cathode via transmission mechanism. Nickel pellets were used as anode. A stainless steel cylinder mandrel was used as cathode in horizontal type whose deposit area was $\varnothing 70$ mm × 100 mm. Free ceramic beads in 0.8–1.2 mm diameter were chosen as the abrasive medium filling the space between the electrodes to maintain continuous friction on the cathode's surface in the process of electroforming. The electrolyte was pumped from the storage bath to the electroforming unit and flowed through the gap between cathode and anode. Both the electrolyte flushing and the moving cathode motion served as the agitation of the electrolyte. The electrolyte's temperature was controlled by a heater and temperature controller. Before deposition, the cathode was

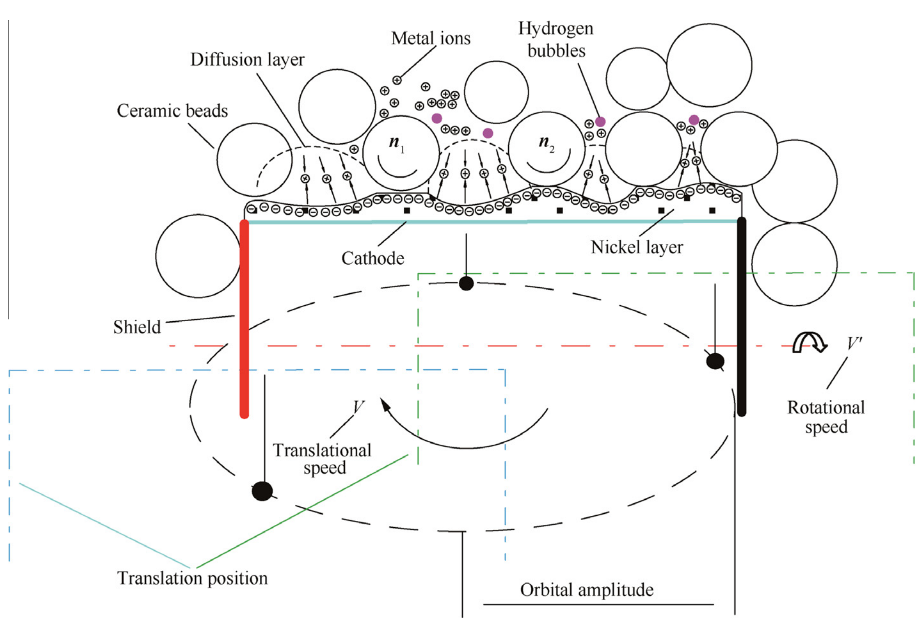

Fig. 1 Scheme of experimental principle of abrasive-assisted electroforming process with moving cathode.