Copper Casting Layer Prepared by Jet Electroforming

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Jet electroforming technology was used to make copper casting layer. The effects of current density, electrolyte jet speed and nozzle scanning speed on the surface morphology of copper casting layer have been investigated. Results show that higher current density, scanning speed and lower jet speed produced a compact and smooth copper casting layer with finely deposited particles. However, for opposite electroforming conditions, the copper casting layer was composed of cellular particles growing in dendrite morphology with poor surface smoothness. [doi:10.2320/matertrans.M2013114]

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1. Introduction

The mass transfer process for deposition reaction changed due to high velocity flow of electrolyte on the surface of cathode in jet electroforming.1) Hence, limiting current density was greatly intensified and thus electrodeposition reaction continuously proceeded under very high current density which may reach 100 times higher than in normal slot electroforming. The electroformed grains were extremely refined and formation of nano-crystal sediment is very rapid.2,3) The fundamental principles and related forming law of jet electroforming has been discussed previously.4-6) In this paper, the influence of the relevant technological parameters such as current density, electrolyte jet speed and nozzle scanning speed on the evolution of the surface of the copper casting layer have been analyzed in detail.

2. Experimental

A schematic representation of the jet electroforming equipment is shown in Fig. 1. The electrolyte was pumped from the vessel with invariable temperature electrolyte then refloowed to the vessel from the output of electrodepositing room via the bump of filter, and the flowmeter. The electrolyte temperature was measured using the heater and temperature transducer. The jet speed was adjusted using the flow meter.

During the jet electroforming process the electrolyte was jetted directly onto the cathode surface. The deposition took place only on the local cathode surface area onto which the jet impinges. Thus, jet electroforming produced a high depositing rate.

A electrolyte was used to deposition on the flat stainless steel substrate under the following composition (g/L): CuSO4·5H2O—250, H2SO4—40. The electrodeposition took place in the bath at a temperature 30°C.

The surfaces of the copper layer were observed by using a field emission scanning electron microscope (FESEM, LEO-1530VP).

3. Results and Discussion

3.1 Effects of the current density on the surface morphology

Figure 2 shows the surface morphologies of the casting layers obtained at different current densities. The electrolyte jet speed of 2 m/s was used with a nozzle scanning speed of 7 mm/s and with 100 scanning layers. When a lower current density of 200 A/dm² was used a smooth casting layer surface was produced. However, when the current density was higher than 200 A/dm² evidently particles with cellular shape were grown. When current density reaches 400 A/dm², the surface was composed completely of mushroom-shaped cellular particles with a large top and a small bottom. This may be due to a high current density and the growth speed of cellular particles was variable. The growth rate of large particles was significantly higher than that of small particles. Hence, numerous small particles gradually stop growing and...
are submerged in large particles due to electric field
shielding. Pores generated between the large particles caused
significant decrease in the compactness of the casting layers.

Relevant theories indicate that the surface growth
morphology of casting layer to be closely related to the
current density. At low current density the electroforming
speed was slow, so casting layer surface produced was dense
and smooth, and resulting fine deposition particles. When
current density was high, electroforming speed was very
rapid. Thus, the consumption rate of metal ions should be
higher than the transport rate of the metal ions in electrolyte.
This may lead to the concentration polarization on cathode
interface and a thick diffusion layer. It is likely that the
casting layer was produced through cellular processes and
with a rough surface and containing a higher pore density.
We know that the current density in jet electroforming can
be very high, the dendritic structure tended to grow under a
higher current density.

3.2 Effects of the electrolyte jet speed on the surface
morphology

Figure 3 shows the surface morphologies of the casting
layers obtained at different electrolyte jet speed. The current
density is 200 A/dm² with a nozzle scanning speed of
7 mm/s and with 100 scanning layers. When electrolyte jet
speed was low (0.5 m/s) the casting layer surface was
composed of coarse cellular particles containing larger cracks
and pores between particles on the layer. In addition, casting
layer grew in the dendrite mode with poor smoothness,
thereby subsequent deposition was difficult. When jet speed
was increased to 1 m/s, casting layer still formed by cellular
particles, but the size of these particles and the pores
decreased. There is also some improvement in the surface
smoothness. Further increases in the jet speed caused the
smooth and compact casting surfaces and compact and
cellular particle characteristic not obvious. At low electrolyte
jet speed the feed rate of copper ions to cathode was lower
than the ion deposition rate, thus concentration polarization
was obvious. This phenomenon resulted in the formation of
coarse cellular particles on casting layer surface. Moreover,
the cellular particles showed a very irregular distribution
causes the electric field distortion around the deposition area
region. This distortion produces a non-uniform electric field
intensity distribution. The electric field is strongest and the
growth speed is faster at the top of cellular particle, whilst the
electric field is weaker and growth speed is slower at the
bottom. Moreover, the tops of cellular particles gradually
become sharper and cause the formation of dendrite.

The related theory has illuminated the thickness of
diffusion layer, δ, is related to kinematical viscosity v,
diffusion coefficient, D, electrolyte tangential velocity on the
surface of electrode, u, electrolyte jet distance, h, by the
following equation:  
\[ \delta \approx D^{1/3} u^{1/6} h^{1/2} u^{-1/2} \]  
where D and v are constant. For the electrolyte jet
electroforming processing, the increasing of electrolyte
tangential velocity u results in the decrease of thickness of
diffusion layer. Increasing electrolyte jet speed is equivalent
to the increasing of electrolyte tangential velocity. This
results in the reduction of the diffusion layer thickness,
greatly weaken concentration polarization and improve the
surface growth morphology of the casting layer.

3.3 Effects of the nozzle scanning speed on the surface
morphology

Figure 4 shows the surface morphologies of the casting
layers obtained at different nozzle scanning speed. The current
density is 200 A/dm² with electrolyte jet speed of
2 m/s and with 100 scanning layers. At low scanning speed,
the casting layer surface was constituted of distinct cellular particles and had poor smoothness. When the scanning speed was high, the particles on casting layer surface were relatively fine and the surface became smoother. The influence of nozzle scanning speed on the surface morphology of casting layer resulted from the electric field acting on the deposition area. At low nozzle scanning speed, time of the applied electric field on deposition area was long, hence the number of metal ions consumed in this deposition area being relatively large. So, concentration polarization is likely to be produced causing apparent cellular particle growth morphology on the layer surface yielding poor smoothness. At high nozzle scanning speeds the acting time of electric field on deposition area being very short. Before the formation of thicker effective diffusion layer, the nozzle has left the area, thus concentration polarization cannot be produced easily.

4. Conclusion

(1) In jet electroforming, current density has an obvious effect on the growth morphology of the casting layer surface.
When current density is low, casting layer surface is smooth with fine particles. With an increase in the current density, the surface begins to present cellular particle growth morphology. When the current density is high, the whole surface presents an obvious cellular particle growth with coarse particles. Thus the compactness and surface smoothness of casting layer become poor.

(2) Increasing the jet flow of electrolyte can effectively inhibit the formation of cellular particles to produce a smooth surface. The surface quality of casting layer is thus improved.

(3) In jet electroforming, the growth morphology of casting layer is directly related to the nozzle scanning speed. To obtain a thicker layer at a high current density, higher nozzle scanning speed is required.

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