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Porous Metal and Method for Preparation by the Scanning and Swinging Jet Electrodeposition

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The preparation of porous metals by a novel scanning and swinging jet electrodeposition (SSJED) technology with computer numerical control of the 3D motion trail of the jet nozzle was studied. The morphology and mechanical property of deposits prepared by SSJED under different scanning parameters were examined. The results indicated that porous metals could be produced by SSJED with excellent control of the structure by guiding the dendrites growth in desired directions. The dendrites in deposits failed to be connected and interweaved with each other completely with low swinging times of the nozzle. As swinging times increased, the connection and interweaving of dendrites were effectively achieved, following with the gradually coarse branches on the horizontal interweaving point.

Keywords: jet electrodeposition; porous metals; dendrites

1. INTRODUCTION

During the jet electrodeposition process, electrolyte is jetted directly to the cathode surface at a high speed. Compared with the traditional electrodeposition, this process shows advantages of selective and high-speed plating, and the grain refining effect is more efficient with a much higher overpotential of cathode [1-2]. However, until now, it is very difficult for JED to produce high-quality and large bulk of nanocrystalline. Parts greater than 0.5 mm in height could not be built without any leveling system [3]. This is because, the high current density and electrolyte flow rate of JED can severely promote outward growth of adatom clusters perpendicular to the surface and tend to generate large amount of nodules or dendrites, causing deposit surface always irregular during JED, and eventually yielding a nonuniform deposit [4-5]. However, from the opposite point of view, the characteristics of jet electrodeposition are very favorable to the study on dendrite growth kinetics.

In this paper, a novel scanning and swinging jet electrodeposition (SSJED) technology was proposed to prepare porous metals by fully exploring such characteristics above. In this technology, large current density was utilized to stimulate the growth tendency of dendrites in jet electrodeposition. Moreover, by controlling the motion trail of jet nozzle using a numerical controlling system, the dendrites were guided growing in desired directions. The porous metals were thereby successfully prepared. Structure and properties of the deposits were then investigated. No papers directly addressing this subject have been published so far.

2. EXPERIMENTAL

Experimental system. The electrolyte was injected locally onto the cathode surface from the nozzle which moved above the cathode in accordance with the CNC commands, and was continuously recirculated to electrolyte tank. After a deposit layer was formed in the eletrodeposition, the nozzle was raised to a certain height and started the next scanning process, and a new layer was formed by jet eletrodeposition. Further details similar to the geometry of traditional JED system can be found elsewhere [6-9].

Deposition experiments. The electrodepositing bath of Ni deposits was composed of $Ni_2SO_4 \cdot 6H_2O$ 250 g/L, $NiCl_2$ 40 g/L, H_3BO_3 38 g/L, and the bath of Cu deposits was composed of $CuSO_4.5H_2O$ 200 g/L, H_2SO_4 70 g/L without any additives. Graphite plates were used as cathodes. The current density for Ni electrodeposition was set at 400 A/dm^2, and the current density for Cu electrodeposition was set at 700 A/dm^2. A special narrow rectangular nozzle, in size of 0.5×10 mm, was used in scanning and swinging jet electrodeposition to prepare the bulk porous metals.

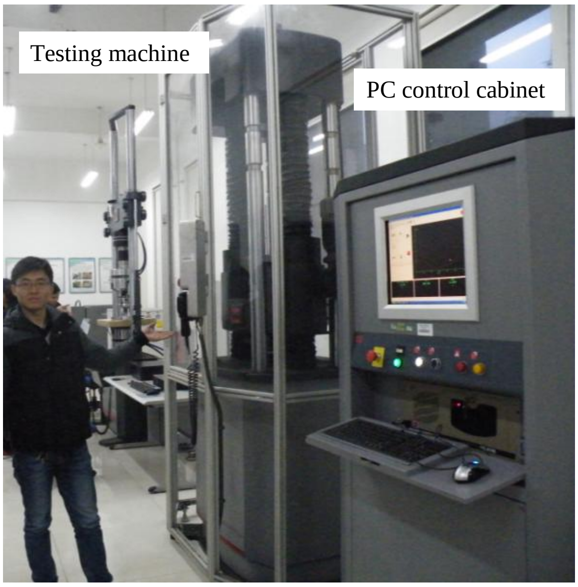

Figure 1. MTS universal testing machine used to test deformation behavior of porous metals.

Deposit analysis. The morphology of deposits was characterized by an Olympus SP-820UZ iHS digital camera. As shown in Figure 1, the deformation behavior was measured by a MTS-C64.106 electro hydraulic servo universal testing machine (MTS Systems Corporation).

3. RESULTS AND DISCUSSION

The surface irregularity of deposits was significant with large current density in jet electrodeposition. Dendrite were firstly observed growing on edges of the jet liquid column and the dendrite growth was suspended and even declined in the center of the liquid column [10-11]. Moreover, such irregularity, which was mainly caused by the nonuniform distribution of flow field, was intensified with the increasing of current density. Figure 2 shows that the dendrites on the two long edges of the liquid column were given priority in growth. After the impact on cathode surface, liquid flow is in two directions perpendicular to the long edges of jet liquid column, and the electrolyte flow smoothly on the periphery, especially on two long edges, while poorly in the center and two short edges of the jet liquid column [12]. Therefore, the metal ions carried by electrolyte in the center and two short edges of the liquid column were in serious deficiency under large current density, which resulted in the difficulty grain nucleation and grain growth. While the growth of the dendrites on the two long edges was greatly enhanced.

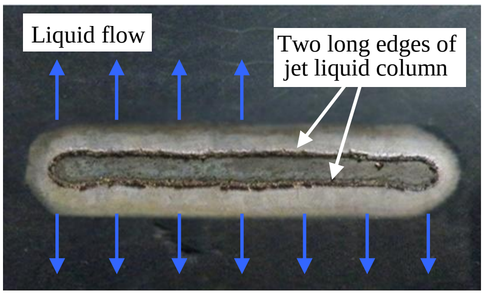

Figure 2. Preferential growth on two long edges of the jet liquid column in jet-electrodeposition.

Here, a question is posed, that is, what will be resulted if the nozzle is driven by a numerical controlling system to realize some special scanning motions? In the experiment, a narrow rectangular nozzle swung for certain times in certain swinging step length in case of one scanning step advance. Figure 3 shows the porous metals prepared by scanning jet eletrodeposition. In the experiment, nozzles scanned in step length of 0.5 mm and swung for 50 times and in swinging step length of 0.25 mm. After reaching to the scanning terminal, the nozzle was raised to a certain height and started the next scanning jet eletrodeposition with reverse scanning direction and same swinging direction under control of the computer. The jet eletrodeposition lasted for 2 hours. Figure 4 displays the microstructure of the porous metals. It can be seen that, a structure of porous metals is finally yield by the regular extension, connection, and interweaving of the dendrite branches according to the scanning and swinging trail of jet nozzle.

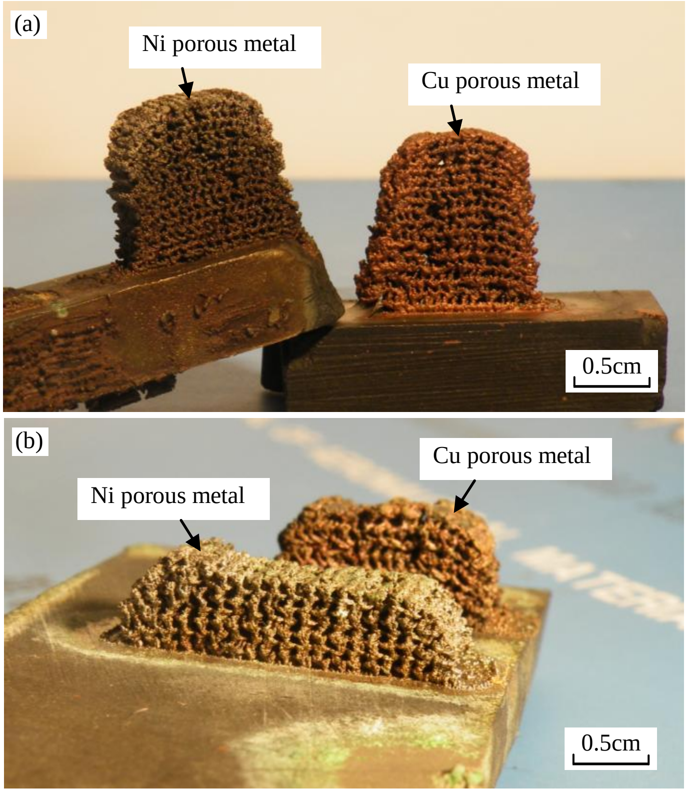

Figure 3. Bulk porous metals (a) and (b) electrodeposited by SSJED

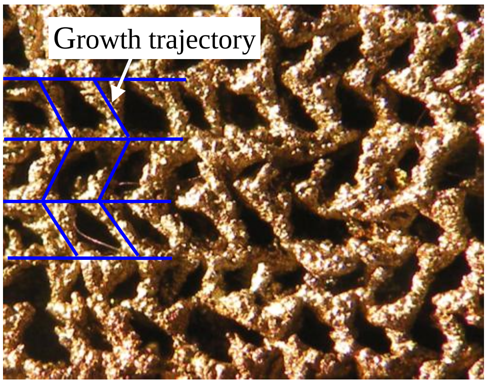

Figure 4. Micro morphology and growth trajectory of Ni porous metals electrodeposited by SSJED.

As shown in Figure 3 and 4, the porous metals prepared by jet electrodeposition present very uniform and consistently arranged long pores. Such structure is similar with the lotus-type porous metals structure prepared by metal-gas eutectic directional solidification ("Gasar" process) [13]. Since the effective controlling on the solidification process has not been realized at present, it is hard to obtain lotus-typed porous metals bearing pores in uniform distribution, consistent size, and large enough length-diameter ratio. The performance of lotus-typed porous metals obtained was greatly weakened thereby [14]. The jet electrodeposition technology introduced in this study definitely may provides a new way for preparing similar lotus-typed porous metals. Using this technology, the similar lotus-typed porous metals of a variety of metals or alloys are achievable. In addition, due to the excellent controlling ability of this technology in the preparation process, the structure of porous metals can be conveniently controlled by adjusting processing parameters or the motional way of nozzle.

Figure 5 presents the porous metals prepared by jet electrodeposition at different swinging times of nozzle, and the process lasted for 1 hours. In figure 5(a), the connection and interweaving of dendrites fail to be realized completely at fewer swinging times. With the increase of swinging times, the growing ability of dendrites was strengthened to effectively support the horizontal connection and interleaving of adjacent dendrites. Moreover, the branches on the horizontal interweaving point gradually got coarse.

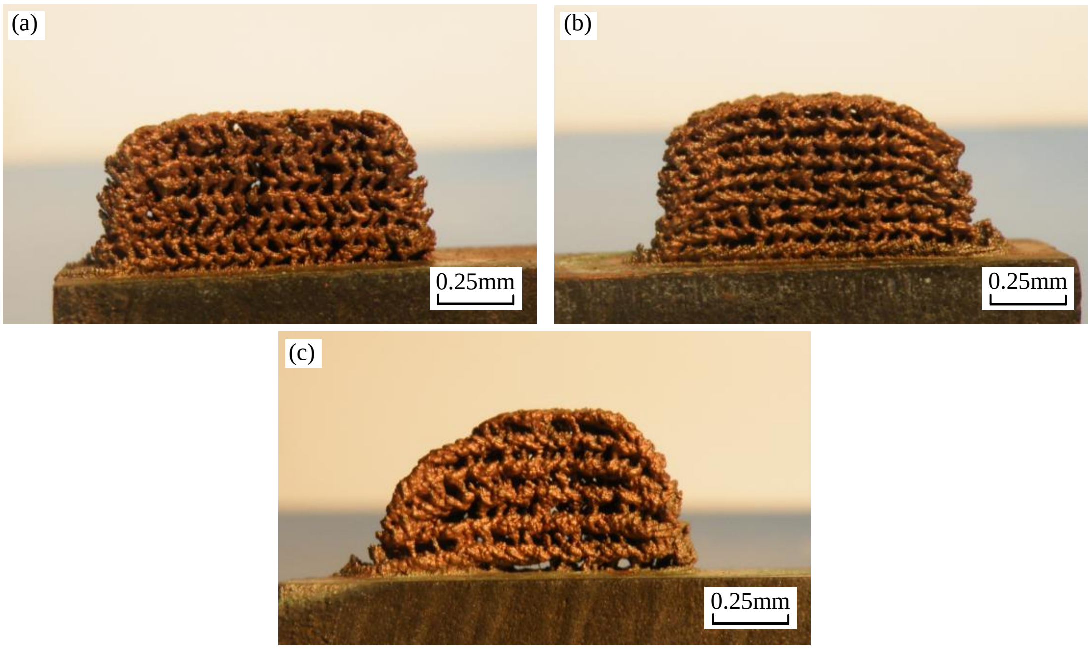

Figure 5. Bulk Cu porous metals electrodeposited by SSJED at different swinging times: (a) 40, (b) 50, (b) 60.

Under large current density, the metal ions needed in the growing process of dendrites are in great deficiency since a large number of cations in the electrolyte are consumed. As a result, dendrites tend to grow along the direction of electrolyte flow to seek the metal ions in the electrolyte. As shown in Figure 6, on step 1, the swinging of nozzle induces the changes of the position and direction of electrolyte flow and thereby guides the dendrites on the two long edges of jet liquid column growing obliquely. On step 2, electrolyte rapidly flows in two horizontal directions perpendicular to the long edges of jet liquid column when reaching to the cathode surface. Due to the changes of flow field direction, the dendrites that obliquely developed on step 1 grew horizontally on this step to complete the connection and interweaving with adjacent dendrites. The analysis above is merely a preliminary discussion on the formation mechanism of the porous metals. The detail formation mechanism still needs further profound investigation.

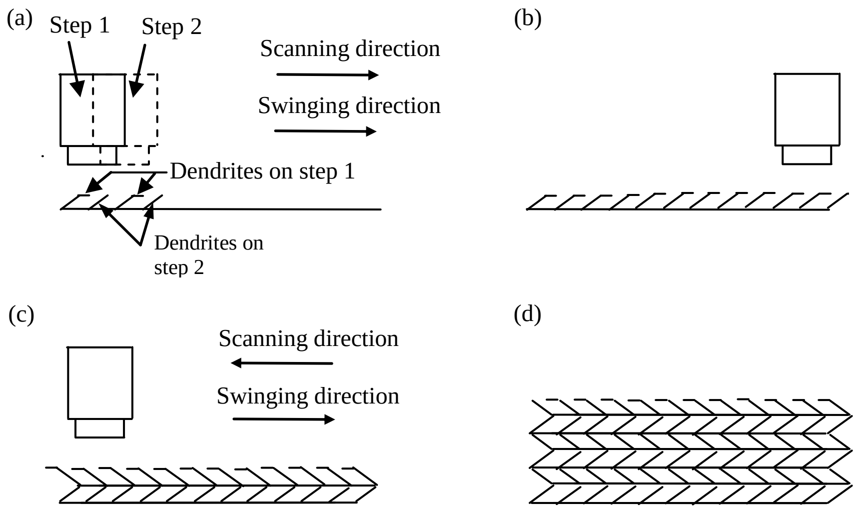

Figure 6. Formation mechanism of bulk porous metals in SSJED process

There are various processes available for manufacturing porous metals now. Typical processes include casting, powder metallurgy, metallic deposition and sputter deposition [15]. It is very important to improve the manufacturing processes in order to be able to furnish a wider variety of products of porous metals at a lower cost. This would permit a more large-scale industrial use of these materials. This SSJED technology is an entirely new method capable of preparing bulk porous metals, rather than methods above such as traditional electrodeposition, that is also capable of preparing porous metals must using a porous polymer which will be later removed, but is not an easily process. The SSJED technology could enable the creation of bulk porous metals with desired geometry combined with the rapid prototyping technology using a CAD model.

It is often quite difficult to find applications for a new material. As shown in figure 7, porous metals poses a series of excellent properties owning to its special structure. The existing applications of porous metals cover a wide field and new uses are continually arising. They are applicable to the functional and structural materials in multiple fields, such as chemical catalyst carrier, orthopedic implant, silencing wall, car cushion, impact energy absorbers, and the protect shell of space shuttle etc. [16]. The properties of porous metals greatly depend on the characteristics of the pores distributed throughout them. These characteristics, which include the type, shape, size, number (volume percentage), uniformity and surface area of the pores, may be quite different in porous metals produced by different processes, thus resulting in different properties of the materials [17]. Therefore, it is in urgent need to carry out researches concerning the properties and application fields of the porous metals prepared by jet electrodeposition.

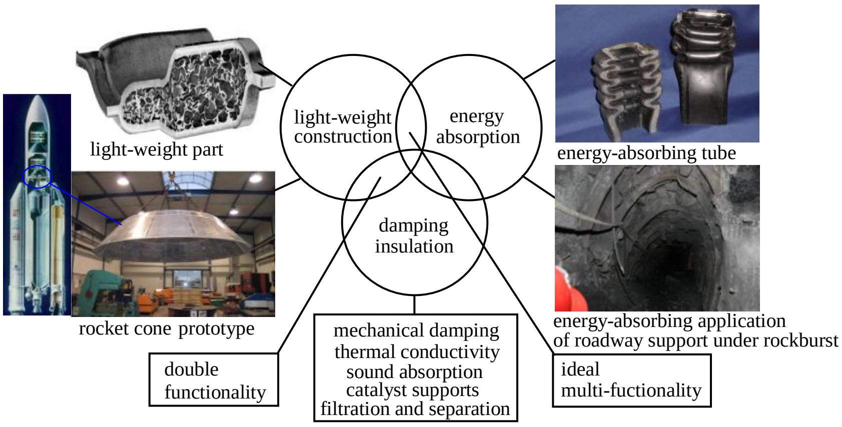

Figure 7. A series of excellent properties and application fields of porous metals.

Figure 8 describes the compressive stress-strain curve of the porous metals prepared at different swinging times. It can be observed that the compressive stress-strain curve of porous metals prepared by jet electrodeposition has an obvious stress platform compared with pure copper. These compressive properties are similar with those of the lotus-typed porous metals [18]. Further testing of porous metals prepared under a variety of tailored design material parameters in SSJED process will be the subject of our future work.

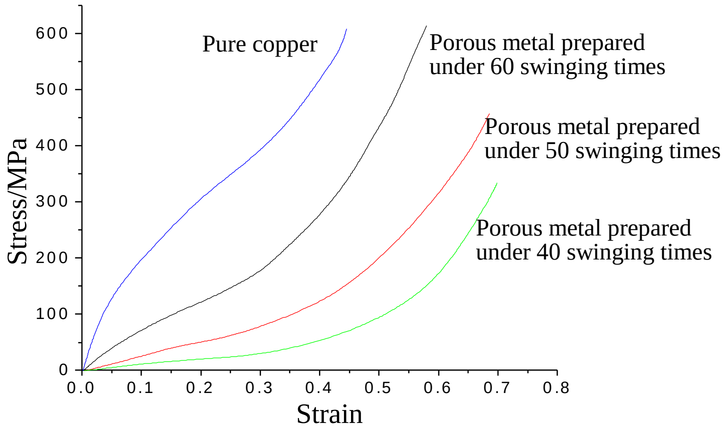

Figure 8. Compressive stress-strain curve of porous metals prepared at different swinging times obtained by MTS universal testing machine.

4. CONCLUSION

Porous metals could be produced by SSJED with excellent control of the structure by guiding the dendrites growth in desired directions. This technology is an entirely new method capable of preparing bulk porous metals with desired geometry combined with the rapid prototyping technology using a CAD model. The dendrites in deposits failed to be connected and interweaved with each other completely with low swinging times of the nozzle. As swinging times increased, the connection and interweaving of dendrites were effectively achieved, following with the gradually coarse branches on the horizontal interweaving point.

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