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Preparation of tube blanks by atomization deposition process①

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Abstract: By using the method of mathematical calculation combined with experiment, the technological conditions of atomization deposition process for making tube blanks with even thickness were studied. The results show that in the case of the substrate rotating and translating simultaneously, when the ratio of the rotation frequency to the translational velocity is very large, and the other deposition conditions are suitable, tube blanks with even thickness and high density can be produced, and the actual deposition efficiency will be highest.

Key words: atomization deposition process; tube blanks; rotation frequency; translational velocity
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1 INTRODUCTION

The spray forming technology was first proposed by Prof. Singer[1] of Swansea University of England in 1969 and then developed by Osprey Metals Ltd. It became a progressively ripe rapid solidification technology by the end of 1980s. By using this technology, a cooling rate above 10^3 K/s can be obtained, the microstructure can be significantly refined, the segregation can be effectively eliminated, and as a result the mechanical properties can be improved substantially[2]. Compared with the conventional powder metallurgy, the spray forming technology has the advantage of single near-net shape forming, thus reducing many intermediate processes and depressing the oxidation degree. By now, while the development of this technology in many developed countries has become commercial and practical[3~5], its study in China is still in the stage of laboratory tests, therefore the key to make this technology practical is to develop the technologies for making deposits of certain shapes such as round billets, tube blanks and plate blanks[6]. In this article, by using the self-made PF-200 type large-scale atomization deposition equipment and by means of mathematical calculation, the technology for making tube blanks with even thickness was studied, and the stable technological conditions for obtaining tube blanks with even thickness were discussed.

2 CALCULATION OF BASIC CONDITIONS FOR OBTAINTNG TUBE BLANKS WITH EVEN THICKNESS

The tube blanks were prepared by vertical deposition with annular gas atomizer whose central axis is cross cut by the central axis of the substrate tube. The substrate tube rotates and translates at uniform velocities simultaneously. The basic pattern for producing tube blanks by atomization deposition process is shown in Fig. 1. R_s represents the radius of the substrate tube, R_a represents the radius of the orthogonal projection of the atomization cone on the plane comprising the central axis of the substrate tube,

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Fig.1 Basic pattern for producing tube blanks by atomization deposition process

v represents the translational velocity, f represents the rotation frequency, and a represents the atomization density along the central axis of the atomization cone. Assuming that 1) the distribution coefficient, b, of atomization density on any plane parallel to z-axis keeps constant; 2) the particles reaching the substrate tube will be deposited completely; 3) the atomization density function of the planes at different heights on the substrate tube can be approximately expressed by that of the axial planes perpendicular to z-axis, then the local deposition rate of a small ring with a distance of x from the spraying axis (see Fig. 2) satisfies the Gauss distribution[7,8] and can be written as

$$z(x, y) = a(x)\exp(-by^2)\,\mathrm{d}x\mathrm{d}y \qquad (1)$$

where

$$a(x) = a\exp(-bx^2) \qquad (2)$$

The deposition mass in $\mathrm{d}t$ time in this small area is

$$\mathrm{d}M_x(D) = a(x)\exp(-by^2)\,\mathrm{d}x\mathrm{d}y\mathrm{d}t \quad (3)$$

After the substrate tube has rotated for one cycle, the total deposition mass on the ring is

$$M(D) = \int_{y=-R_s}^{y=R_s}[a(x)\,\mathrm{d}x \cdot \exp(-by^2)\,\mathrm{d}y]\int_0^{\frac{1}{f}}\mathrm{d}t \qquad (4)$$

In eq.(4), let $\mathrm{d}x$ be the horizontal displacement of any point after the substrate tube rotates one cycle, then

$$\mathrm{d}x = \frac{v}{f} \qquad (5)$$

To ensure $a(x)$ to be a constant in the interval of $\mathrm{d}x$, $\mathrm{d}x$ must be small enough, i.e. $f \gg v$. Consequently, after the substrate tube has rotated one cycle, the deposition mass at any point on the ring is approximately equal and can be described by the average deposition mass, i.e.

$$\overline{M_x(D)} = \frac{M(D)}{S_c} = \frac{\int_{y=-R_s}^{y=R_s}[a(x)\,\mathrm{d}x\exp(-by^2)]\,\mathrm{d}y\int_0^{\frac{1}{f}}\mathrm{d}t}{2\pi R_s\mathrm{d}x} \qquad (6)$$

where S_c represents the area of the ring. Because $\int_0^{\frac{1}{f}}\mathrm{d}t = \frac{1}{f} = \frac{\mathrm{d}x}{v}$, Eq.(6) can be simplified as

Fig.2 Schematic drawing of atomization deposition process

$$\overline{M_x(D)} = \frac{1}{2\pi R_s v}\int_{y=-R_s}^{y=R_s}[a(x)\,\mathrm{d}x]\cdot \exp(-by^2)\,\mathrm{d}y \qquad (7)$$

After any point on the ring has past through the atomization cone, the total deposition mass can be expressed by

$$M(D) = \frac{1}{2\pi R_s v}\int_{x=-R_a}^{x=R_a} a\exp(-bx^2)\,\mathrm{d}x\cdot\int_{y=-R_s}^{y=R_s}\exp(-by^2)\,\mathrm{d}y \qquad (8)$$

After the radius of the substrate tube, R_s, the parameter of the atomizer (which affects R_a), the translational velocity, v, and rotation frequency, f, have been determined, $M(D)$ is not related to the selections of x and y, namely it is a constant. In other words, when the movement of the substrate tube satisfies $f \gg v$ and the substrate tube is outside the atomization cone before spray deposition, the deposition mass at any point on the substrate tube after it passes through the atomization zone each time should be equal. This is the basic condition for making tube blanks with even thickness.

It can also be seen from Eq.(8) that after the substrate tube has past through the atomization cone, the deposition mass at each point on the substrate tube is related to its translational velocity v: by reducing v, tube blanks with large thickness can be produced; by changing v during passing through the atomization cone, tube blanks with varying external diameter (internal diameter constant) can be produced. Additionally, it can be seen from Fig.2(b) that increasing the radius of the substrate tube, R_s, will be beneficial to reduce overspray and increase the actual deposition efficiency.

3 EXPERIMENTAL

3.1 Experimental procedure

The test alloy for atomization depositing tube blanks is ZA27 alloy whose chemical composition (mass fraction, %) is Al 26.0 ~ 28.0, Cu 2.0 ~ 2.5, Mg 0.6 ~ 1.0, and Zn balance. Nitrogen gas (14.7 MPa) is used as atomization gas.

The tests were carried out on the self-made PF-200 type large-scale atomization deposition equipment. The vertical deposition mode was used and the technological parameters are atomization distance 450 mm, the translational velocity of the substrate tube 9 mm/s and the rotation frequency of the substrate tube 5 Hz. During the tests, the melt flux was kept at 81 g/s by controlling the height of the melt level in the tundish. In the meantime, the temperature of the melt in the intermediate crucible was kept at 630 ± 5 ℃. The pressure and flux of the atomization gas were changed so as to find the technological conditions for obtaining optimum shaping and density of deposits.

3.2 Results and discussion

Fig.3 shows the photographs of the deposited tube blanks before and after peeling off the skin. It can be seen from Fig.3 that when the movement of the substrate tube satisfies the basic condition of tube shaping, tube blanks with very even thickness can be produced, and that the internal diameter of the deposited tubes can be adjusted by selecting the substrate tubes of different diameters, and when the internal diameter is determined, the external diameter is adjusted mainly by changing the translational velocity of the substrate tube.

Table 1 shows the effects of the gas pressure and flux on the shaping and density of the deposits.

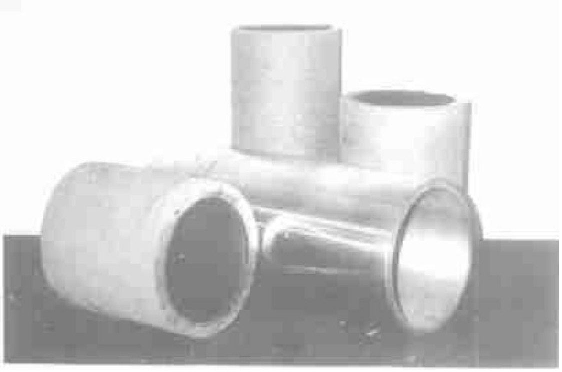

Fig.3 Photographs of tube blanks made by atomization deposition process

Table 1 Effects of gas pressure and flux on shaping and density of deposits

Gas pressure / MPa	Gass flux / (g·s^{-1})	Shaping of tube	As-cast density/ %
0.5	32.3	Poor	-
0.7	45.2	Ordinary	80
0.8	51.7	Good	96
1.0	64.6	Good	90

It can be seen from Table 1 that when the ratio of gas flux to melt flux (G/M) is too low, the liquid content on the deposit will be too much, thus the liquid will be thrown away from the deposit surface and can not take shape. When the ratio of G/M is too high, the total density of the deposits will be reduced, and solidfied particles on the deposit surface will increase, thus the probability of elastic collision on the deposit surface will increase, then the actual deposition efficiency will also be reduced. Therefore, only when the ratio of G/M is suitable, can the optimum density and actual deposition efficiency of the deposits be realized.

Figs.4(a) and (b) show the microstructures of as-cast ZA27 alloy and as-deposited ZA27 alloy, respectively. It can be seen that compared with the as-cast ZA27 alloy, the as-deposited ZA27 alloy has finer grains and more homogeneous microstructure, thus it has better mechanical properties.

4 CONCLUSIONS

(1) The mathematical calculation shows that in the case of the substrate tube rotating and translating simultaneously, the basic condition for preparing tube balanks with even thickness is that the ratio of the rotation frequency to the translational velocity is very higher.

(2) The shaping and density of the deposit is significantly affected by the ratio of gas flux to melt flux (G/M). When the nozzle structure and the other atomization parameters are determined, the optimum density and actual deposition efficiency of the deposits can be obtained by

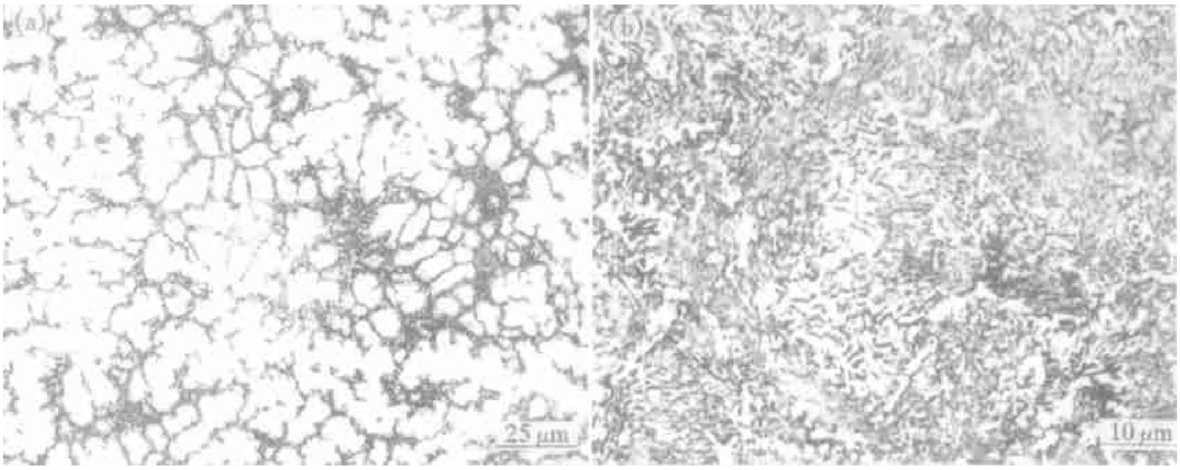

Fig.4 Microstructures of ZA27 alloy in different conditions

(a) —As-cast; (b) —As-deposited

adjusting the ratio of G/M.

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