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Preparation of large size aluminium alloy cylindrical preforms by multi-layer spray deposition①

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Abstract: Preparation of large scale aluminium alloy cylindrical preforms have been studied by the methods of vertical spray deposition and tilted spray deposition respectively. The results show that aluminium alloy cylindrical preforms of a size up to *d*320 mm × 500 mm can take shape well by applying multi-layer tilted spray deposition technology if the process is controlled properly. The spray system scans in a radius ranging from the center to the rim of the preform, and the velocity is inversely proportional to the displacement. The multi-layer deposited preforms exhibit high cooling rate. The larger the diameter is and the higher the cooling rate and yield are.

Key words: multi-layer spray deposition; vertical spray; tilted spray **Document code:** A

1 INTRODUCTION

Since it was developed from the late 1960s[1~3], the spray forming technology has made rapid progress these years.

In the 1990s, the manufacture of large scale spray-formed materials has developed in some enterprises of Europe, America and Japan etc, according to the 3rd international conference of spray forming held in Cardiff, England in 1996. In this field, the production of large diametrical preforms is an important research problem, and it is reported that Peak corporation in German has the ability to manufacture Al-alloy cylindrical preforms of a size of *d*400 mm × 1 300 mm by means of double-nozzled spray system and optimized deposition technology. Four corporations in Europe, including Osprey company, which aimed to producing steel billets with a diameter up to 400 mm[4], have co-operated in developing the formation of large diametrical special steel billets successfully. However, comparing to the achievements of foreign countries, the research of preparation for large-sized preforms is still in the rudimentary stage in China. Only in Beijing General Research Institute for Nonferrous Metals, preparation of *d*180 mm Al-Si alloy preforms has been reported[5]. This article will present the study of large scale billets produced by multi-layer spray forming in our institute. Now the authors have succeeded in preparing *d*320 mm × 500 mm Al-alloy preforms, and the next step is to prepare larger preforms with the size up to *d*600 mm × 1 000 mm.

2 EXPERIMENTAL

2.1 Vertical spray deposition

In order to obtain relatively large spray deposited cylindrical preforms, vertical spray deposition method was tried initially. The device schematic diagram is presented in Fig.1. Metal melt flows out of the crucible, then is atomized into fine droplets by the atomizer, and finally deposits on a rotating iron substrate a certain distance below. The crucible and atomizer scan back and forth within a definite range (little larger than the diameter of the disk-shaped substrate), so as to acquire large diametrical preform. At the same time, the spray system is uplifting slowly by a hydraulic pressure system to keep the spray height.

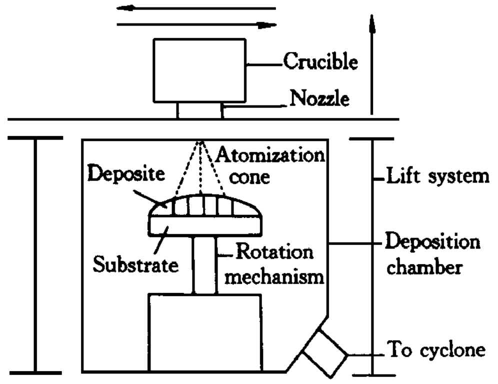

Fig.1 Schematic diagram of multi-layer vertical spray forming device for cylindrical preforms preparation

2.2 Tilted spray deposition

The device above was improved to carry out tilted spray deposition. The schematic diagram of the improved device is shown in Fig.2. In this device, crucible and atomizer scan along an inclined plane.

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And the experiments are carried on with tilt angle β of 15°, 25°, 30° respectively. Different from the vertical spray, the scanning range of the tilted spay is only half of the diameter of the substrate disk. When the preform grows up, the rotating substrate drops down constantly to keep the spray distance and control the height of the cylindrical preform.

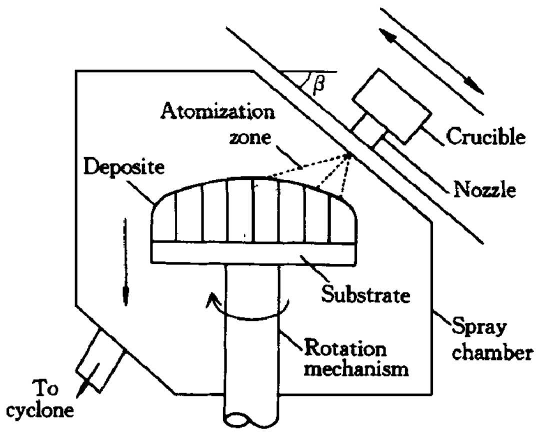

Fig.2 Schematic diagram of multi-layer tilted spray forming device for cylindrical preforms preparation

2.3 Process parameters

Table 1 shows the fundamental processing parameters applied in the preparation for d250 mm Al-alloy billets.

3 RESULTS

In vertical spray experiments, as the height of the preform grows up, the upper diameter becomes smaller, and finally the ingot converges into a cone, which makes the succeeding depositing process impossible and a low yield, about 40 % ~ 50 %.

When applying the technique of tilted spray deposition with 30°, the shape of the billet can be well controlled. And the billet can grow up stably in term of cylinder, and achieves higher yield up to 70 % ~ 80 %. The larger the billet be made, the higher the yield can be gotten. The photographs of large-sized spray-deposited Al alloy cylindrical preforms up to 320 mm in diameter, which are made by this kind of device and technology, are shown in Figs.3 and 4.

4 DISCUSSION

4.1 Vertical spray and tilted spray

In vertical spray deposition, from the experimental results, it is known that regular cylindrical preforms can hardly be produced. The rim of the preforms is difficult to grow up equicontinuously and the preform is to be cone-shaped. The reasons are listed as follows:

(1) Because of the uniform revolving motion of substrate, the receiving area at any position of the scanning range is different from each other. At the rim of the billet, there is the largest receiving area; and the closer the distance to the center, the smaller the receiving area is. In order to gain even growth rate at any position of the preform, the scanning velocity should be slow at the rim and fast at the center. If not be controlled properly, the cylindrical preforms can not be shaped.

(2) Because the spraying melt has a relatively constant deposition zone on the surface of the preform, supposing its diameter is d (see Fig.5), the growth at any point of the preform surface is due to the to-and-fro scanning of the above spray system in a range of d. In order to make the spray system have the same scan range above the rim point O as above the central point, the spray system should overspray from point A to point B, otherwise the growth rate at point O will be too slow and the preform will be cone-shaped. However, in this condition, there will be too much oversprayed powder and the yield will be low.

(3) Supposing the angle included between the spray direction and the normal direction to preform surface is θ, if θ increases, the sticking efficiency will decrease[6]. When the spray direction is normal to the preform surface, that is to say, $\theta = 0°$, the sticking efficiency will be the largest. And when the spray direction is parallel to the preform surface ($\theta = 90°$), the sticking efficiency will be almost equal to 0. So, when the spray system scans above the rim of the deposit, because the spray axis is parallel to the billet side, the growth at point O (see Fig.5) will be almost only in normal direction, while hardly in radial direction. Therefore, it is difficult to maintain the diameter of the deposited preform. Once the diameter become small, it can not be recovered and the preform will be cone-shaped.

By the application of the tilted spray technology (see Fig.6), when the spray axis scans to the rim of the deposit at point O, it can grow up in the normal direction ($\theta_1 = 30°$) and radial direction ($\theta_2 = 60°$) simultaneously. The growth in radial direction can maintain the diameter of preform and keep cylinder

Table 1 Fundamental processing parameters of Al alloy cylindrical preform preparation by multi-layer spray deposition

Atomization temperature/ ℃	Gas pressure / MPa	Fluid diameter / mm	Deposition distance/ mm	Rotation velocity r/ min	Scanning velocity/ (mm·s^{-1})	Atomization angle/ (°)
800 ~ 1200	0.5 ~ 2.0	2.0 ~ 6.0	100 ~ 300	30 ~ 200	0 ~ 100	15 ~ 30

* Scan Distance: Vertical spray(280 mm), Tilted spray(110 mm).

Fig.3 d320 mm × 500 mm AlFeVSi high temperature Al alloy cylindrical preform

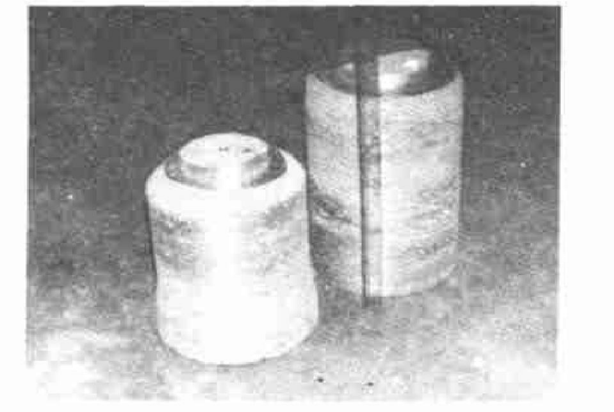

Fig.4 d320 mm 6013Al/SiCp composite cylindrical preforms

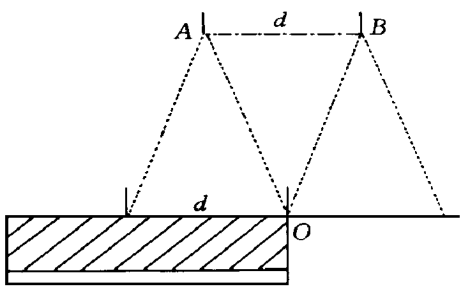

Fig.5 Schematic diagram of vertical spray deposition

figuration. At the same time, because of less overspraying, the yield is much larger than that in the vertical spray forming. These are the advantages of the tilted spray forming technology.

In the tilted multi-layer spray forming of this experiment, the scanning range is about half the diameter of the preform or substrate disk, from the center of the preform to the rim. Compared to full range (little larger than diameter) scanning, the overspraying loss decreases doubly and the yield increases prominently. The larger the preform is, the less the relative overspraying will be, and the higher the yield can be achieved.

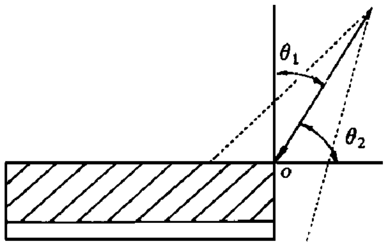

Fig.6 Schematic diagram of tilted spray deposition

4.2 Fixed spray and multi-layer scanning spray

Because the deposition range is limited by the spray zone, large diametrical preform can not be made by fixed spray forming. Preform larger than d200 mm in diameter are difficult to be prepared up to now by the tilted and fixed spray deposition using one atomizer. In order to manufacture large diametrical preform, co-spray technology of double atomizers can be used, but the device is complicated and hard to control, simultaneously the diameter is still limited.

In this experiment, by the application of multi-layer sliding scan technology, the deposition range is greatly expanded and larger diametrical preform can be prepared. On the other hand, because of the characteristics of multi-layer spray deposition, the metal melt sprayed down in unit time covers a large area, forming a thin layer with fairly long cooling time, so the cooling rate in this process is much higher than in traditional Osprey technology. Therefore, the deposited material exhibits fine microstructure and high mechanical performance after succeeding process[7~11]. Moreover, with the enlargement of diameter, because the cooling time between layers lengthens, the cooling rate increases.

4.3 Motion control in tilted multi-layer spray forming

The formation of cylindrical preforms in multi-layer spray forming is mainly controlled by two movements. They are the scanning motion of spray system and dropping down motion of the preform. Therefore, scanning velocity changing curve is of vital importance to the control of the shape. The dropping down speed is decreased with increasing the diameter of the preform. If the preform drops down too fast, the preform will become cone-shaped. On the contrary, it will be drum-shaped if too slowly. To get a suitable dropping down speed is also a key of the shape control.

Ignoring the change of deposition height due to the tilted spray, supposing metal melt mass flow rate remain constant and spray density in the spray cone is identical, in order to gain the same growth rate from the center to the rim of the preform surface and keep cylindrical figuration, the scanning velocity curve should meet the following equation (see Fig.7):

$$\frac{m \cdot dt}{2\pi \cdot r \cdot v, \cos\beta \cdot dt} = h \qquad (1)$$

where m is the metal melt mass flow rate (kg/s), r is the distance from the center of the spraying deposition zone to O' of the preform (m), v is the scanning velocity of the spray system (m/s), β is the angle included between the spray inclination and the horizontal plane (°), h is the growth height at any point on the surface of the preform at a period of time dt. In order to gain the same growth rate at any point of the preform surface, h should be a constant (m).

So, we can deduce that:

$$r \cdot v = k \qquad (2)$$

$$x \cdot v = k' \qquad (3)$$

k, k' are constants; x is the scanning displacement of the spray system (from the left end point O), X (OB) is the scanning range (m).

So the scanning velocity of spray system is an inverse proportional to the displacement. When scans to the rim, the velocity should slow dowm; and when scans to the center, it should accelerate. Proper velocity curve can be gained by the design of cam curve or by the application of programmable controller.

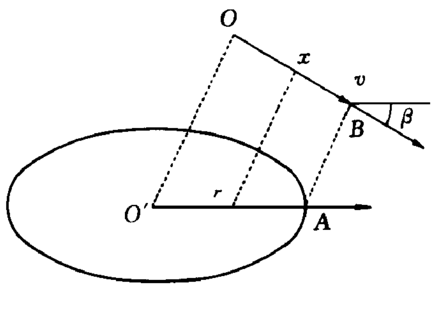

Fig.7 Schematic diagram of relationship between scan velocity and displacement in multi-layer tilted spray forming

5 CONCLUSIONS

(1) Cylindrical billets can not be produced well by vertical spray deposition, while by the application of the tilted multi-layer spray forming technology, large size Al-alloy billets of the size up to d320 mm × 500 mm are prepared well with good profile.

(2) It is impossible to obtain large-sized preforms by fixed spray forming. However, large diametrical preforms can be prepared by multi-layer sliding scan spray forming. The larger the diameter is the higher the cooling rate and yield are.

(3) In the preparation of large size Al-alloy preform by multi-layer spray forming, the spray system scans in a radius range from the center to the rim of the preform, and the velocity is inversely proportional to the displacement.

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