A NOVEL MULTI-LAYER SPRAY DEPOSITION TECHNOLOGY①

Chen Zhenhua, Huang Peiyun, Jiang Xiangyang
Wang Yun, Peng Chaoqun
Research Institute of Non-Equilibrium
Materials Science and Engineering,
Central South University of Technology, Changsha 410083

ABSTRACT A novel spray deposition technology with the characteristics of multi-layer deposition, the combination of forced external cooling and internal water-cooling of the substrate was developed. Compared with the conventional spray deposition technology, the novel technology exhibits the specific advantages, including larger solidification rate, higher dimensional precision, and ease to manufacture large preforms. The law of multi-layer deposition was studied, and a high-temperature Al-Fe-V-Si alloy with good mechanical properties was prepared using this novel technology.

Key words multi-layer spray deposition Al-Fe-V-Si alloy

1 INTRODUCTION

The general principle of spray deposition technology is that flows of liquid droplets of metals or alloys produced by atomisation of inertia gases directly spray onto water-cooling substrates and produce deposits through striking, adhering and solidification[1,2]. The spray deposition is a complex statistical process which is affected by many factors, but singer A[3] thought it can be described by a comprehensive parameter called spray density. The so-called spray density refers to the mass deposited on unit substrate area in unit time. Lawley A *et al*[4] indicated that the optimum deposition conditions depend on an ideal fraction of liquid phase.

The spray deposition technology is aimed at manufacturing preforms or products directly from molten alloys. It is a technology that lies between ingot metallurgy and powder metallugy; it combines some advantages and overcomes some shortcomings of both. Compared with the other two technologies, the spray deposition technology exhibits specific advantages, including higher cooling rate, lower degree of oxidation, better economic benefit. Although it is becoming riper day by day, but the existing spray deposition technology has its own limitations which lie in the following aspects: limit in solidification rate, low dimensional precision, and difficulty to manufacture high quality large preforms.

In order to eliminate the shortcomings of the existing spray deposition technology, a novel multi-layer spray deposition technology was developed by the authors.

2 THE NOVEL MULTI-LAYER SPRAY DEPOSITION TECHNOLOGY[5]

The novel technology and the conventional technology differ in the spray modes and constituents of the deposits. For the conventional technology, usually the heating crucible keeps motionless and only the substrate moves during manufacturing pipe and plate blanks,

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and the deposited preform is produced by one movement of the substrate. When spray depositing large plate blanks, V-type nozzles and vibrating nozzels are often adopted. The schematic diagrams of the novel technology for manufacturing pipe and plate blanks are shown in Figs. 1(a) and (b). The heating crucibles and the substrates move simultaneously, and the deposited preforms result from the superposition of multiple spray depositions. Common nozzles are adopted, and liquid nitrogen or inertia gases may be used for forced external cooling of every layer of the deposits.

The novel spray deposition technology have the following characteristics.

(a) The solidification rates of the deposited preforms manufactured by the novel technology are larger than those by the conventional technology. The formers may reach $10^3 \sim 10^4$ K/s when using liquid nitrogen or inertia gases for forced external cooling.

(b) Because they are produced by the combination of the reciprocal movements of the nozzles and the substrates under the novel technology, deposited preforms of large dimensions can be manufactured. Due to the use of common nozzles, the technological operations of the novel technology are also simpler. So far, the pipe blanks with the dimensions of d150 mm × 80 mm × 10 mm and the relative density of 96% theoretical density; the plate blanks of the dimensions of 500 mm × 350 mm × 10 mm; the tube blanks with the dimensions of d270 mm × 350 mm × 70 mm and the mass of 30 kg, were manufactured using the novel technology by the authors. From the technological tests, it is out of question to manufacture larger preforms.

(c) Because the motion velocities of the crucibles and the substrate can be regulated, the dimensional precision of the deposited preforms is higher. The surface of the deposit is smooth and uniform and the deposition rates of the atomized alloys are larger.

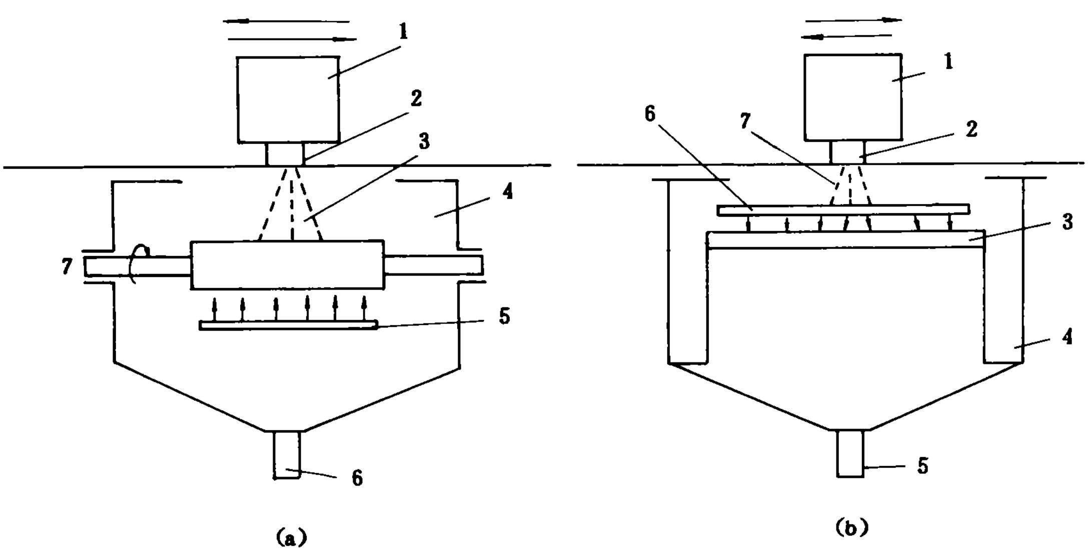

Fig. 1 The schematic diagram of the novel spray deposition technology for manufacturing pipe blanks (a) and plate blanks (b)

In Fig. 1(a): 1—heating crucible; 2—nozzle; 3—molten alloy; 4—chamber; 5—forced external cooling unit; 6—exhaust; 7—rotating internal water-cooling unit;

In Fig. 1(b): 1—heating crucible; 2—nozzle; 3—carriage in reciprocal motion; 4—chamber; 5—exhaust; 6—forced external cooling unit; 7—molten alloy

(d) Because multi-layer deposition is adopted, the novel technology has advantages in preparing metal-oxide composites, functional gradient materials, mutual non-soluble bimetals, and other special materials.

3 THE CHARACTERISTICS OF THE MULTI-LAYER SPRAY DEPOSION TECHNOLOGY

3.1 *The Motion Paths of the Spray Deposited Liquid Droplets*

In the multi-layer spray deposition process, the crucible and the substrate move simultaneously, the motion paths of the spray deposited liquid droplets are relatively complex. In manufacturing a pipe blank, the crucible makes uniform rectilinear motion and the substrate makes uniform circular motion. The superposition of both motions give a cylindrical helix, as shown in Fig. 2(a); changing the phase and repeating the operation for many times give a uniform multi-layer deposited pipe blank. In manufacturing a plate blank, the crucible makes uniform rectilinear motion and the substrate makes reciprocal rectilinear motion. The superposition of both motions gives a sinusoid, as shown in Fig. 2 (b); changing the phase and repeating the operation for many times gives a uniform multi-layer deposited plate blank.

The motion rates of the crucibles and the substrates determine the helical pitch of the cylindrical helix and the wave length of the sinusoid. In order to gain compact and uniform deposited preforms, computers may be used to stimulate the motion paths. The results show that there exist a series of optimum ratios of substrate motion rate-to-crucible motion rate; the motion rate of the crucible when it is at the center of the substrate should be a little smaller than those at the ends.

3.2 *Conditions of the Deposit to Adhere to the Substrate*

According to the results of multiple tests, it is indicated that the material and the surface temperature of the substrate are the principal factors that affect the adhering and shedding of the deposited layers. The spray density in the multi-layer deposition process is small, the increase of the temperature of the substrate is small, therefore it is difficult for the deposit to adhere to the substrate. In order to avoid the shedding of the deposit from the substrate, it is necessary to preheat the substrate before spray deposition. In addition, the welding properties of the substrate material and the deposited alloy also have some effects on the adhering of the deposit to the substrate. Table 1 lists the results of deposition tests under different conditions[6].

3.3 *The Optimum Deposition Conditions of the Multi-layer Spray Deposition*

As indicated by lawley A[4], the gaining of the optimum depositions conditions for the conventional single spray deposition depends on the preservation of an ideal fraction of liq -

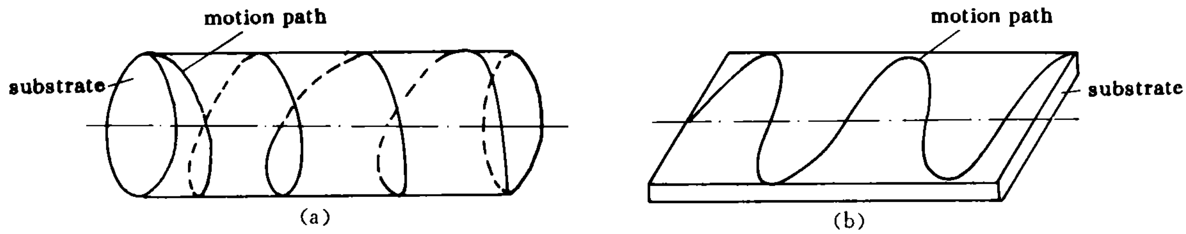

Fig. 2 The motion paths of the liquid droplets of alloys in the multi-layer spray deposition process

(a)—in manufacturing pipe blanks; (b)—in manufacturing plate blanks

Table 1 Effects of the materials and temperatures of the substrate on the adhering of the deposits to the substrates

Deposited material	T_s /℃	Material of substrate				
		Al	Cu	Steel	Stainless steel	Cast iron
Al	100			×		√
	150			√	×	
	200	×	×		√	
	250	√	√			
Cu	150	×				×
	200	√				√
	300				×	
	350			×	√	
	400		×	√		
	450		√			
Al-33%Cu	220	×				×
	250	√	×	×	×	√
	300		√	√	√	
Al-10%Fe	350				×	×
	400	×			√	√
	450	√	×	×		
	500		√	√		

uid phase, while the ideal fraction of liquid phase is determined by the overheating degree, the mass ratio of gas-to-molten alloy, and the spray distance. But for the multi-layer spray deposition process, the optimum deposition conditions are relatively more complex. The main characteristics of the multilayer deposition process are that the spray distance is very short and the mass ratio of gas-to-molten alloy is relatively small. In view of these, it is known by analysis that the optimum deposition conditions for the multi-layer deposition process depend on the spray distance, the motion rates of the substrate and the crucible, the overheating degree, the mass ratio of gas-to-molten liquid, and so on. In addition, the forced external cooling is an effective way of dissipating heat, thus helping to adjust the optimum deposition conditions and gain the double effects of spray deposition and rapid solidification.

4 SPRAY DEPOSITION OF A HIGH-TEMPERATURE Al-Fe-V-Si ALLOY

4.1 *Effect of the Deposition Technology on the Microstructure of the Deposits*[7]

The good high temperature strength and thermal stability of the Al-Fe-V-Si alloys result from the fine and dispersed intermetallic compound-$Al_{12}(Fe, V)_3Si$ precipitates produced during the rapid solidification process. The volume fraction of the precipitates may reach as high as 24 to 37 per cent and their coarsening rates are very low, therefore they can effectively impede the dislocation movement, growth and recrystallization of grains, thus significantly improving the high temperature and thermal stability of the material.

The X-ray diffraction patterns and TEM morphologies of the deposits produced using the conventional and novel technologies are shown in Fig. 3 and Fig. 4, respectively. Fig. 3 shows that the deposit produced using the conventional technology comprises both $Al_{12}(Fe,V)_3Si$ and $Al_{13}Fe_4$ precipitates, while the deposit produced using the novel technology with the combination of forced external cooling and internal cooling of the substrate only consists of $Al_{12}(Fe,V)_3Si$ precipitates. Fig. 4 shows that the former deposit has relatively larger $Al_{12}(Fe,V)_3Si$ precipitates and needle-like $Al_{13}Fe_4$ precipitates, while the later deposit contains only fine $Al_{12}(Fe,V)_3Si$ precipitates.

4.2 *Effect of the Deposition Technology on the Mechanical Properties of the Deposits*[8]

Table 2 lists the mechanical properties of the deposits produced using the conventional and novel technologies at room temperature and high temperature after hot rolled at 723 K with an accumulative deformation of 50%～

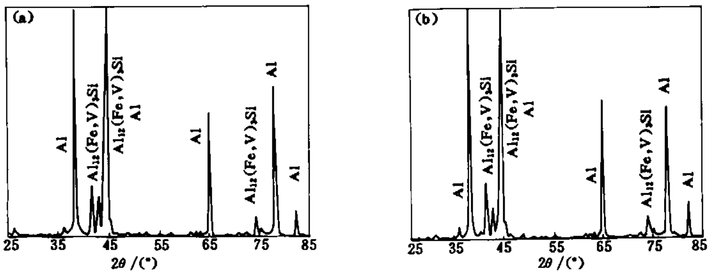

Fig. 3 The XRD patterns of the deposits produced by the conventional technology and the novel technology
(a)—the conventioanl technology; (b)—the novel technology

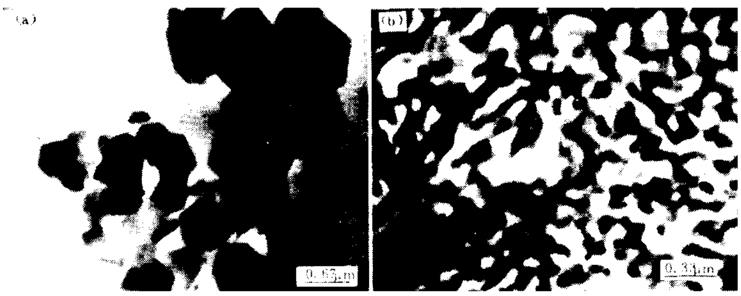

Fig. 4 The TEM morphologies of the deposits produced by the conventional technology and the novel technology
(a)—the conventional technology; (b)—the novel technology

Table 2 The Properties of a Al-8Fe-2V-2Si alloy produced by the conventional technology and the novel technology (rolled at 723 K)

Technological Conditions	Density /g·cm^{-3}	Room temperature			623 K, 7 min	
		σ_b/MPa	δ/%	HB/MPa	σ_b/MPa	δ/%
conventional technology	2.83	409	4.1	1410	—	—
novel technology	2.84	545	5.7	1580	210	4.1

60%. It is known from the comparisons in Table 2 that the properties of the deposit produced using the novel technology is obviously better than those of the deposit produced using the conventional technology.

5 CONCLUSIONS

(1) A novel spray deposition technology with the characteristics of multi-layer deposition and the combination of forced external cooling and internal water cooling of the substrate. Compared with the conventional technology, the novel technology exhibits specific advantages, including larger solidification rate, higher dimensional precison and ease to manufacture large preforms.

(2) The optimum deposition conditions of the multi-layer deposition process depend on the spray distance, the motion rates of the substrate and the heating crucible, the overheating degree of the molten alloys, and the mass ratio of gas to molten alloy. Compared with the single spray deposition technology, it is easy for the multi-layer spray deposition to gain optimum deposition conditions.

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(*From page 48*) the crystalline phase easily, thus the EEB was promoted. They are valid additive agents.

(2) The structure of slag was modified by addition of TiO_2. A lot of $[B_2O_5]$ and $[BO_3]$ which were favourable to make the crystal of $2MgO \cdot B_2O_3$ and $3MgO \cdot B_2O_3$ precipitate were produced.

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