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Preparation of 6066/ SiC_p composites by multilayer spray deposition[①]

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[Abstract] SiC particulate reinforced 6066 aluminium alloy metal matrix composites (MMCs) were prepared by multi-layer spray forming. The preparation technology and process parameters were discussed. It is shown that SiC particulate can be continuously and evenly fed and co-deposited in the spray forming process. The reciprocally scanning movement of spraying system can make the SiC particulates distribute homogeneously in the composite. The ratio of SiC particulates captured by the metal matrix is influenced by process parameters, especially the metal flow rate. 6066/ SiC_p composite preforms of d300 mm × 540 mm and tubes with a size of up to d650/ d300 mm × 1 000 mm were made by the same process. After extrusion and T6 heat treatment, the multi-layer spray deposited 6066/ SiC_p composites can achieve improved properties.

[Key words] multi-layer spray deposition; 6066 aluminium alloy; SiC particulate reinforced MMCs
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1 INTRODUCTION

Spray forming has been considered to be a suitable technology for the preparation of particulate reinforced metal matrix composites (MMCs), and has been widely investigated recent years[1~3]. Composite materials prepared by spray forming process exhibit attractive characteristics. The reinforcing particulates can be uniformly distributed with no agglomeration and combined well with the metal matrix without any harmful brittle reaction products. These characteristics are unlikely to be realized when prepared by conventional casting technology. Moreover, rapid solidification can be achieved and fine grain microstructure with no segregation can be obtained by spray forming. In comparison with powder metallurgy, spray forming technology is a much simple process and has lower cost, as well as lower oxygenation which may result in better ductility. Although the composites prepared by spray forming have many advantages, much work still needs to be done in order to realize the continuous preparation of large-sized uniform composite preforms, and finally to apply the technique to commercial production. In this work, multi-layer spray deposition technique[4~7] is used to prepare particulate-reinforced 6066 aluminium alloy matrix composites.

2 EXPERIMENTAL

2.1 Feeding of reinforced SiC particulates

In the preparation process of spray co-deposited composites, the obtaining of continual and stable feeding of reinforced particulates is a very important problem. In this technology (see Fig. 1), the container for reinforcers is the opened type and SiC particulates can be added into it directly and continuously in the spray forming process. SiC particulates in the container are sent out by a screw system and inhaled into a fluidization device under minus pressure formed by high velocity nitrogen gas stream. After being fluidized, the SiC particulates are delivered into the atomization system through a pipe and co-deposited to form a product with certain shape. The deviation in per minute of the flux of SiC can be controlled no more than 2%, and the flux is convenient to be adjusted at will. All kinds of particulates, including different sizes of SiC, Al_2O_3, graphite, even alloy powder can be fluidized and sent out by this feeding system. Through experiments, the relationship between flux of different reinforcers and rotating speed of screw can be obtained, which can be used to control the volume fraction of the reinforcers in the composites.

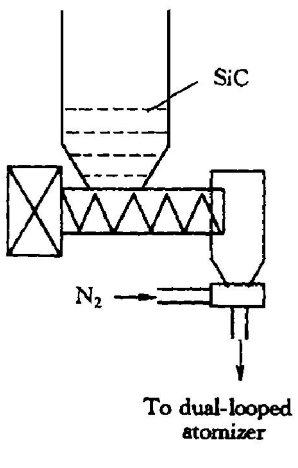

Fig. 1 Schematic diagram of SiC feeding device

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2.2 Injection of reinforcers into atomization cone

Two different adding methods of reinforcers in the preparation of spray co-deposited MMCs were investigated (see Fig. 2). The first one (see Fig. 2(b)) was adopted and studied widely[3, 8], of which SiC particulates are imported into the atomization cone by gas through one or two pipes after the alloy melt has been atomized. In this way, the capture of reinforcers is strongly affected by multiple parameters such as the injection pressure, distance, and angle, which may lead to complicated control. And if the size or the kind of the reinforcers are changed, all the injection parameters should be adjusted. Moreover, particulates injected only from two pipes are not distributed uniformly in the atomization cone of matrix alloy.

Another adding method of reinforcers is applied in the preparation of multi-layer spray formed MMCs, the schematic diagram of which is shown in Fig. 2(a). A special atomizer is used in this method, in order that the reinforcing particulate can be incorporated into the metal melt before atomization. The atomizer is of confined dual-looped structure (see Fig. 3). Atomization gas and SiC particulate current spurt out from two different loop apertures, so SiC can be delivered into the spray cone more easily than injected by two pipes. By the application of this dual-looped atomizer, the whole procedure of spray co-deposition becomes easy to be controlled, and the capture of reinforcers is influenced only by atomization parameters.

3 PROCESS PARAMETERS

3.1 Movement control parameters

The movement control parameters are the same as those in the preparation of matrix alloy blank, including scan range, velocity and period of the spray system, rotating speed of the substrate, and withdrawing speed of the preform. These parameters determine the formation of preforms and tubes[9, 10].

3.2 Deposition technological parameters

Selection of appropriate deposition technological parameters is the key in preparing high quality multi-layer spray-formed blanks. When co-deposited composites are prepared, they have great effect on the capture of SiC particulates by the metal matrix as well. Table 1 shows the fundamental deposition parameters applied in the preparation for 6066/ SiC_p composites.

In comparison with traditional Osprey technology, multi-layer spray forming has its own natures. The surface of the preform is almost full solid state, its temperature is even far below the solidus temperature, while the atomized droplets contain much larger proportion of liquid phase just before they impact on the preform surface, even be almost full liquid state in the preparation of tubes. When a 6066/ SiC_p composite tube is prepared, the preform surface temperature maintains at about 300 ± 30 ℃ due to small spray density and long cooling time between layers in multi-layer spray forming. Therefore, as particulate-reinforced composites are prepared, few particulates are captured by the solid surface of the preform. The reinforcements are mainly captured by metal droplets during the flight course or when bouncing back from the solid preform surface.

The experimental data reveal that metal flow rate has the greatest effect on the capture of SiC particulate. Metal flow rate is mainly determined by fluid diameter, and affected by atomization tempera-

Table 1 Fundamental deposition parameters in preparation for 6066/ SiC_p composites by multi-layer spray deposition

Atomization temperature / ℃	Gas pressure / MPa	Fluid diameter / mm	Deposition distance / mm	Particulate injection pressure / MPa	Atomization angle / (°)
800~ 1 000	0.8~ 1.2	2.5~ 4.0	150~ 300	0.4~ 0.5	15~ 45

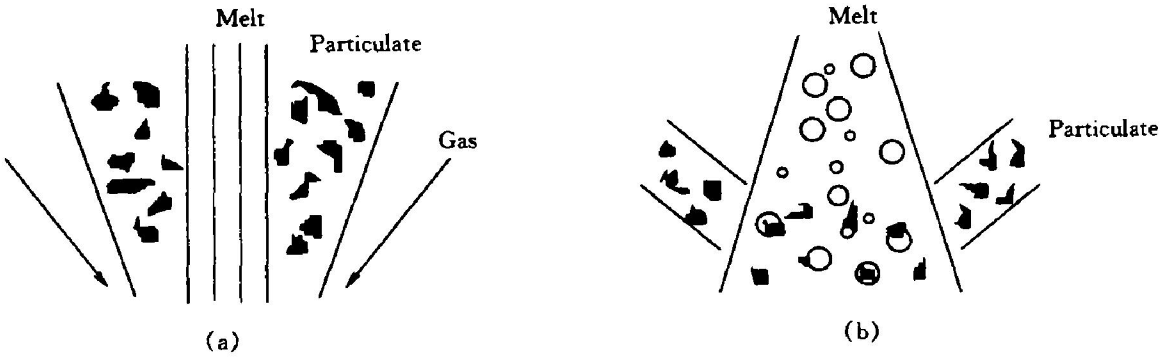

Fig. 2 Two different adding methods of reinforcing particulates in spray co-deposition
(a) —Adding before atomization of melt; (b) —Adding after atomization of melt

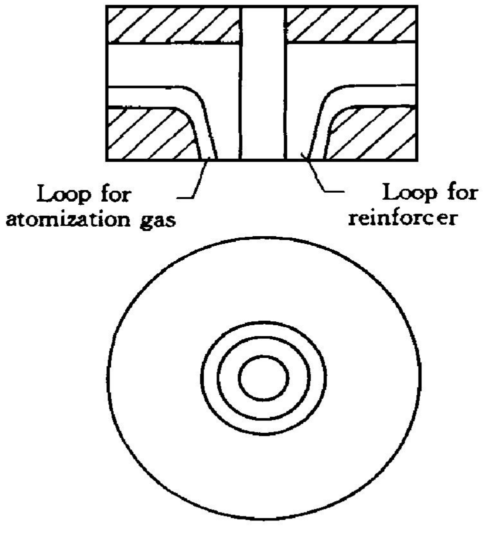

Fig. 3 Schematic diagram of structure of dual-looped atomizer

ture, gas pressure as well. Under the condition that the other parameters are fixed, as the diameter of the fluid increases, the metal flow rate increases, but the capture ratio of the SiC particulate decreases. Table 2 shows the decrease of the measured SiC content in deposit as the flux of melt and SiC particulate increased, when a d300 mm disk shape preform is prepared. The possible reason may be that SiC particulates can not be effectively captured by metal melt before atomization when the flux of particulates and melt increase, because of small collide and interaction region between particulates and melt before atomization. And the mass flux of SiC particles and metal droplets has different distribution in the spray cone. Under the condition of proper deposition parameters, when the spray cone of metal droplets covers almost all the atomized SiC particles, SiC can be well captured by liquid metal droplets. Large metal flow rate makes metal droplets trend to concentrate in the center of the spray cone, while small SiC particles mainly distribute in the rim, which may lead to poor capture. Further investigation on the atomization feature of the dual-looped atomizer and capture law of the reinforcers is in progress.

When the deposition distance increases, there are more pores existing in the preform, and capture ratio of SiC decreases. This may due to the increase of solid metal droplets that impact on the surface of the preform, so less SiC particulates bouncing back from the deposit are captured. Too low atomization temperature has the similar effect on the capture of SiC. Therefore, when large composite preforms are produced, it is necessary to form an arch on the top of the preform in order to gain similar deposition distance from the center to the edge of the billet.

Atomization gas pressure and atomization angle are not investigated in detail yet, but they must have some effects on the atomizing state, which may influence the capture of SiC particles.

4 PRODUCTS

The main purposes of multi-layer spray deposition are to gain higher cooling rate and prepare large-sized preforms[5~7]. By the application of this technology in the preparation of 6066/SiC_p composites, much rapid solidification rate can be achieved due to import of reinforcing SiC particles, and also large diameter preforms and thick tubes can be produced due to the reciprocally scanning movement of spray system. After extrusion, high performance composite products can be obtained. 6066/SiC_p composite billets of d300~540 mm and tubes of up to d650/d300 mm × 1 000 mm have been prepared. A d540 mm × 700 mm composite billet is shown in Fig. 4(a). Fig. 4(b) is the photograph of extruded composite tubes of size d350/d250 mm × 800 mm (with extrusion ratio of 5.5∶1).

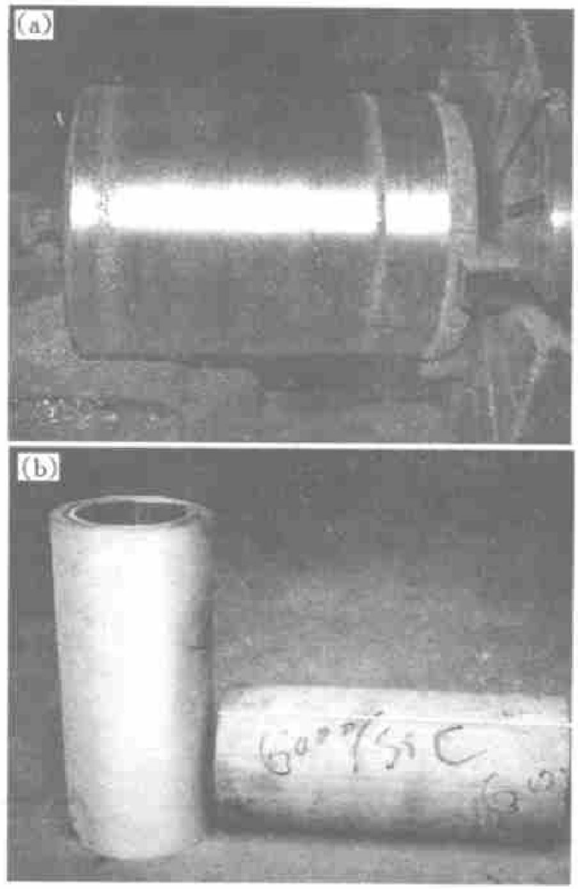

Fig. 4 Photographs of 6066/SiC_p composite
(a) —d540 mm × 700 mm 6066/SiC_p billet being machined;
(b) —d350/d250 mm × 800 mm 6066/SiC_p tubes

The mean relative density of multi-layer spray formed 6066/SiC_p composites is about 90% ±2%. Layer structure can be observed from the macro fracture of the deposit. The thickness of each layer is up to the scan range and period, usually millimeter-sized. Between layers, there are more pores than in layers. In the multi-layer deposited 6066/SiC_p composites, SiC particulates are uniformly distributed and combined well with the matrix alloy. And no harmful reaction product is found on the interface. Because of rapid solidification, once the SiC particulates are captured, they can hardly have time to move or agglomerate, and interface reaction can be avoided as well. Fig. 5 shows the homogeneous distribution of SiC in as-deposited material. The average size of SiC is 10~14 μm. And some fine pores can be observed. Typical microstructure after being etched of multi-layer deposited composite is shown in Fig. 6. Very fine microstructure of matrix due to rapid solidification can be obtained. Due to higher cooling rate of deposit compared to Osprey process, grain boundary is difficult to be observed in multi-layer spray-formed composites, because the spheroidal grains have little time to form and grow in deposit. While in Osprey process, the presence of a spheroidal grain morphology is usually rationalized in terms of the relatively slow cooling rate that is experienced by the materials following deposition.

After extrusion, layer structure in deposited preform can be eliminated and the material is fully densified. Typical microstructures of as-extruded material are shown in Fig. 7. They reveal that the spray formed and extruded composites are characteristic with very fine microstructure. The size of SiC is 5~7 μm, which seems to be passivation and spherical after extrusion. In longitudinal section, SiC particulates distribute along the extruding streamline. After extrusion and T6 treatment, the multi-layer spray deposited 6066/ SiC_p composites can achieve excellent mechanical properties as: $\sigma_b > 440$ MPa, $\sigma_{0.2} > 400$

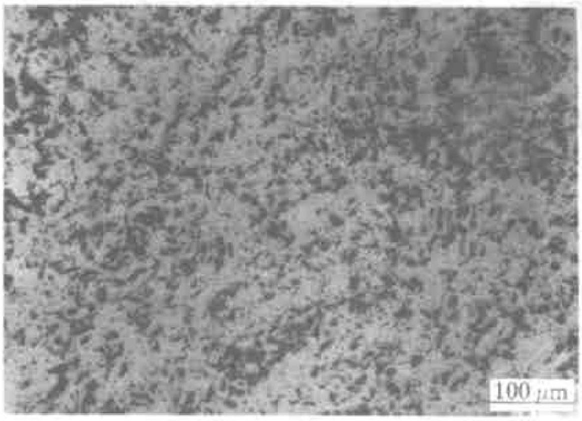

Fig. 5 Distribution of SiC particles in as-deposited 6066/ SiC_p composite

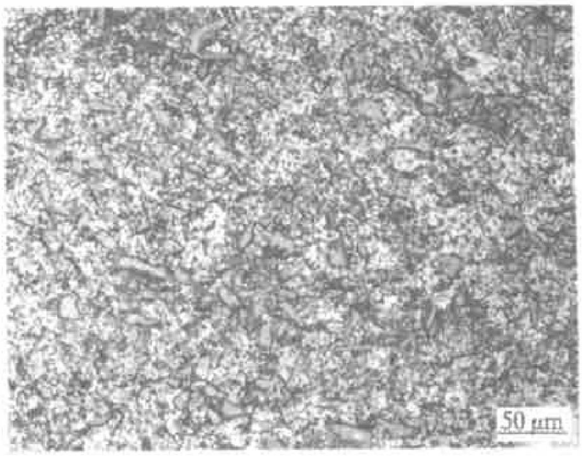

Fig. 6 Typically etched optical microstructure in as-deposited 6066/ SiC_p composite

Table 2 Change of measured SiC content with melt flow rate

Preform number	SiC flow rate / ($kg \cdot min^{-1}$)	Melt flow rate / ($kg \cdot min^{-1}$)	Designed SiC content / %	Measured SiC content / %	Measured total yield / %
1	0.45	2.61	14.7	24.6 ±0.9	57.7
2	0.82	4.26	16.1	16.9 ±0.6	57.2
3	1.01	4.41	18.6	14.0 ±1.3	57.5

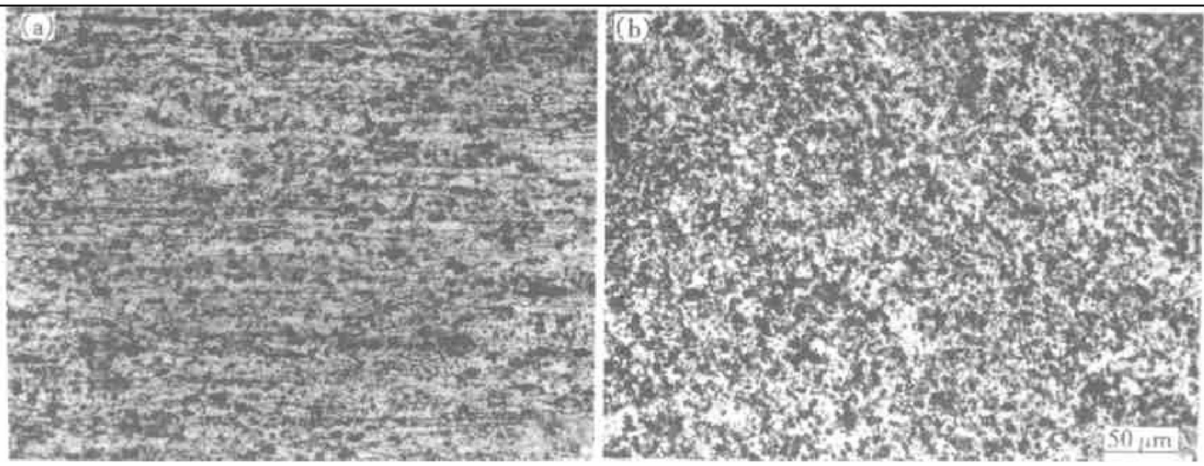

Fig. 7 Optical microstructures of multi-layer spray formed 6066/ SiC_p after extrusion

(a) —Cross section; (b) —Longitudinal section

MPa, $E > 100$ GPa and $\delta > 5\%$.

5 CONCLUSIONS

1) By multi-layer spray co-deposition, large-sized and rapidly-solidified 6066/SiC_p MMCs preforms and tubes can be prepared continuously. In this technology, a dual-looped atomizer was used, and reinforcing SiC particulate can be fed quantificationally by the feeding system. The whole preparing process is quite simple to be controlled.

2) SiC particulates distribute uniformly in the matrix both microscopically and macroscopically. The deposition parameters have effects on the capture ratio of SiC. In multi-layer spray forming, SiC particulates are mainly captured by metal droplets during the flight course or when they are bouncing back from the solid surface of the preform.

3) Because of rapid solidification, SiC particulates combined well with the matrix with no harmful reaction product found on the interface. Formation of the microcrystalline matrix is due to rapid cooling rate resulting in large excess solid solubility. After extrusion and T6 treatment, the multi-layer spray deposited 6066/SiC_p composites exhibit high properties.

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