PREPARATION OF 6066 Al/ SiC_P(+ Gr) COMPOSITES BY MULTI-LAYER SPRAY DEPOSITION ①

Chen Zhenhua, Zhang Hao, Chen Gang, Liu Qiulin, Sun Zhangming, Yang Fuliang
Research Institute of Nonequilibrium Materials Science and Technology, Central South University of Technology, Changsha 410083

ABSTRACT A novel multi-layer spray deposition technology was developed, by which 6066Al/ SiC_p(+ Gr) composites were manufactured. The matrix is of rapid cooling rate and large excess solid solubility. SiC particles distribute uniformly in the matrix with clear interface. Extrusion was conducted to improve the microstructure and mechanical properties. SiC particles can be broken up and rearranged. After T6 heat treatment, the final material shows low porosity and good mechanical properties. The introduction of small amount of graphite particles into the preform can improve the damping property.

Key words spray deposition metal matrix composites SiC particles

1 SEVERAL TECHNOLOGIES FOR MANUFACTURING PARTICLE STRENGTHENED METAL MATRIX COMPOSITES

Metal matrix composites can be generally classified as dispersion-reinforced composites, particle-reinforced composites and fiber-reinforced composites according to the various geometrical features of the reinforcing phases and the various strengthening mechanisms. In the particle reinforcing composites, the matrix is reinforced by fine particles or short whiskers, and the strengthening mechanism is the hard particles bearing loads and restricting the deformation of the matrix. The strengthening effect of these composites mainly depends on the distance between the particles, the diameter and the volume fraction of the particles. Powder metallurgy, mixing casting and pressure infiltration casting are frequently adopted for the yielding of particle-enhanced composites.

In powder metallurgy, composites are produced by heat processing such as heat extrusion or forging after pre-mixing matrix metal powders with ceramic particles or short fibres. Although composites with fine microstructures can be obtained, the process, including mixing, cold pressing, potting, degassing in vacuum and hot isostatic pressing, heat extrusion, is too long. So, the production cost of this method is very expensive, and it is very difficult to achieve large-dimensional composites because of the limitation of pressing ability. Meanwhile, the powders can be easily contaminated and oxidized due to the long production procedures, which may result in a bad interface adhesion. Moreover, it is very difficult to achieve a homogeneous distribution of the reinforcing particles among the matrix powders.

In mixing casting, the composite is fabricated through co-solidification after adding the reinforcing particles or whiskers into the molten metal directly and stirring fast. This method can manufacture parts in large scale at low cost. At the same time, the microstructure of the as-cast material is severely coarse because of slow solidification rate. The distribution of particles is not uniform, which results from the bad wetability between particles and matrix metal. Large porosity arises from gas wrapped during stirring. The long stay of molten metal probably leads to serious interface reaction. Therefore the proper-

① Supported by the National Doctorate Program Fund of the State Education Committee of China and the Natural Science Foundation of Hunan Province Received Jun. 18, 1996; accepted Jul. 31, 1996

ties of as-cast material are low and even fall below unreinforced ones.

In pressure infiltration, composites preforms and parts are fabricated by pressing molten metal into a preform made of reinforcing particles or fibres. This method is expensive, complex, and difficult to prepare large blanks.

Rheocasting is an alternative to produce composites, in which reinforcing particles are added into partially solidified matrix, then the composites are shaped by pressing after stirring. In semi-solid state, although high shear stress arising from stirring does help to homogeneous distribution of reinforcing particles, the large amount of impurities and gases, and low density microstructure will have bad influence on the properties of the material.

In recent years, spray co-deposition technology(SD) has caught much interest of many composites-manufacturers with its excellent performance[1, 2]. This process involves adding reinforcing particles via gas jet into the atomizing spray, consequently both the spraying metal droplets and the reinforcing particles are co-deposited onto a relatively cold substrate. The second phase particles are uniform in matrix. This method of fabricating composites have many technological advantages. The cooling rate of the metal matrix can be improved greatly because the inert gas and the reinforcing particles can adsorb large amount of heat in this method, thus the matrix has characteristic microstructure of rapid solidification. Especially in spray deposition, a homogeneous distribution of the reinforcing particles in the metal matrix can be obtained and bad interface reaction can be eliminated effectively. So this method is promising for fabricating metal matrix composites of rapid solidification. Up to now, much attention and further research are directed to this technology[3, 4].

2 FABRICATION OF 6066Al/SiC_p COMPOSITES BY MULTI-LAYER SPRAY CODEPOSITION TECHNOLOGY

6066Al/SiC_p composites are prepared by the multi-layer spray deposition equipment developed by the authors[5]. The chemical composition of 6066Al is Al-1.4%Si-1.1%Mg-1.0%Cu-0.8%Mn. SiC particles are α-type and in the range of 5~10μm. The mode of adding SiC particles into the spray is shown in Fig. 1. The process procedure is: 6066Al alloy is heated to 1 123~1 213 K, and the melt is atomized by nitrogen at a pressure of 1~1.4 MPa, while SiC particles are transmitted into the spray by nitrogen at a pressure of 0.3~0.5 MPa. The particles are uniformly dispersed and co-deposited onto a moving substrate which is cooled by inner water, thus a composite preform is formed. Unlike the coventional process in which the heating crucible and the spray nozzle are often static and the deposition blank is formed through single-direction movement, in multi-layer spray deposition, the heating crucible and the spray nozzle are motive and the deposits are formed through duplicate movement. The as-deposited preform is subsequently extruded at 680K. The extrusion ratio is 14∶1. After extrusion, T6 treatment was conducted. The final properties and microstructure of the material were measured by WD-10A

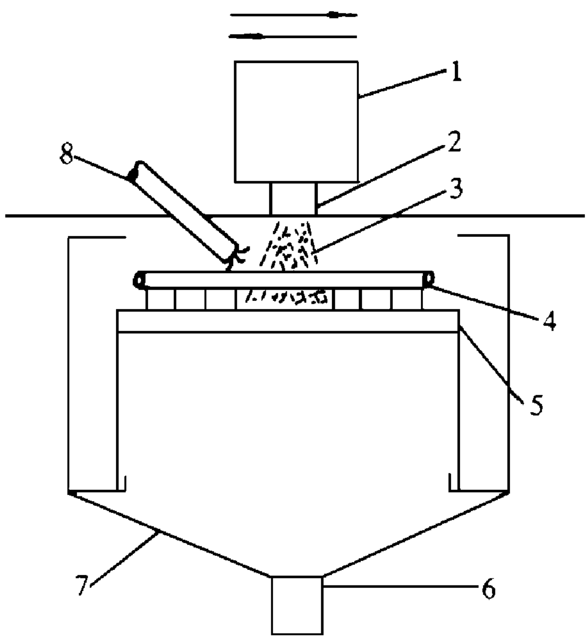

Fig. 1 Schematic diagram of equipment of multi-layer spray co-deposition

1—mobile crucible; 2—atomizer;
3—metal droplets; 4—external cooling;
5—water-cooled substrate;
6—gas outlet;
7—atomizing chamber;
8—nozzle for transmitting SiC

electron material testing appratus, X-650 SEM, optical microscopy, etc.

3 RESULTS AND DISCUSSION

3.1 Homogeneous distribution of particles

Generally, the distribution of the reinforcing particles in the composites produced by spray co-deposition technology is more homogeneous than that in the composites produced by powder metallurgy, mixing casting, pressure infiltration, and rheocasting process. However, in traditional spray deposition technology as shown in Fig. 2(a), the concentration of the reinforcing particles in the rim of the spray zone is higher than that in the centre of the spray zone due to the influence of the atomizing gas sprayed by the spray nozzle. In the multi-layer spray co-deposition as shown in Fig. 2(b), the concentration of the reinforcing particles in the matrix is more homogeneous because of the mutual movement between the spray nozzle and the substrate. Fig. 3 shows the microphotograph of the 6066Al/ 15% SiC_p composite prepared by multi-layer spray deposition. It exhibits a very uniform distribution of SiC particles in the matrix. It has been demonstrated that in the multi-layer spray deposition the soaking time of the liquid is very short, from which the microstructure of rapid solidification results. Therefore particles' gathering caused by thermodynamic driving force is difficult to happen. Commonly, the capture mechanism of SiC particles in matrix includes mechanical force, hindering by dendritic fragments or solidified liquid droplets[6, 7].

3.2 Microstructure of as-deposited preform

The preform by multi-layer spray deposition is overlapped for many times by every layer of deposits. The cooling rate of the preform is higher than that of the preform prepared by traditional spray deposition process[3]. When the atomized melt flux co-deposits with reinforcing particles, the cooling rate of the preform becomes higher and reaches 10^3 K/s or so. Fig. 4 shows the microstructure of 6066Al/ 15% SiC_p material by multi-layer spray deposition process. From this photo, it can be found that partial matrix is "optical featureless zone". This optical featureless zone indicates partitionless solidification resulting from high cooling rate of the matrix. This matrix with optical featureless zone

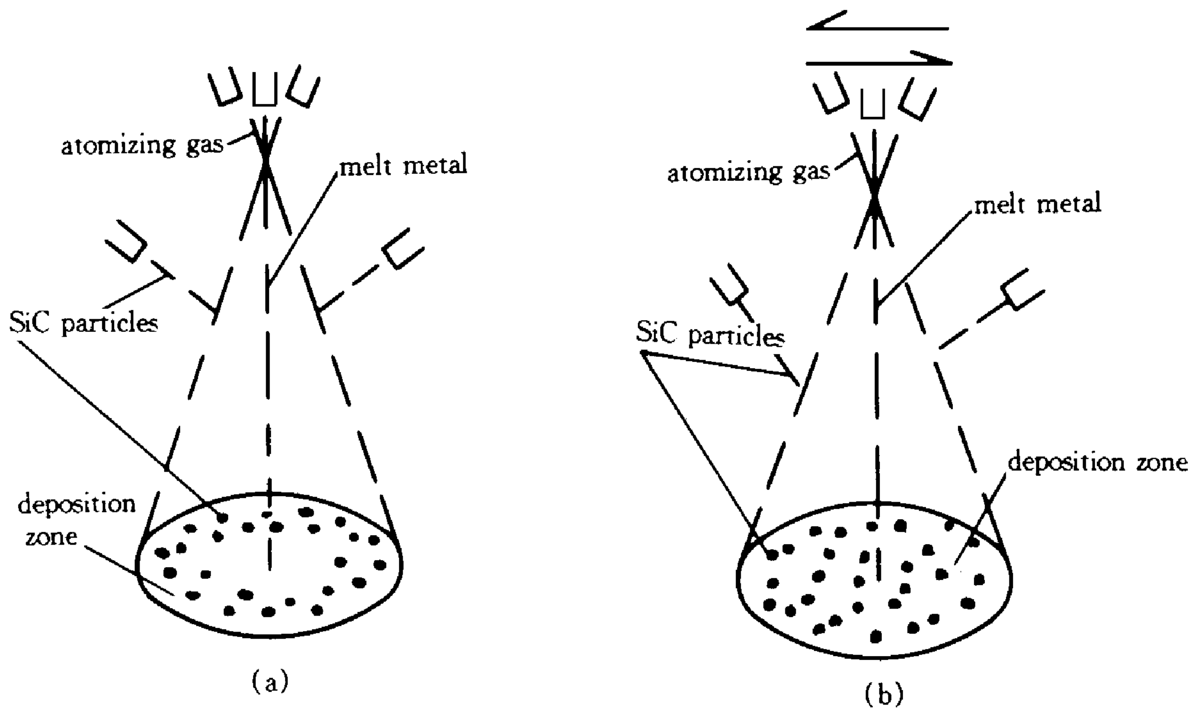

Fig. 2 Comparision of multi-layer spray deposition and traditional spray deposition

(a) —traditional technology; (b) —multi-layer technology

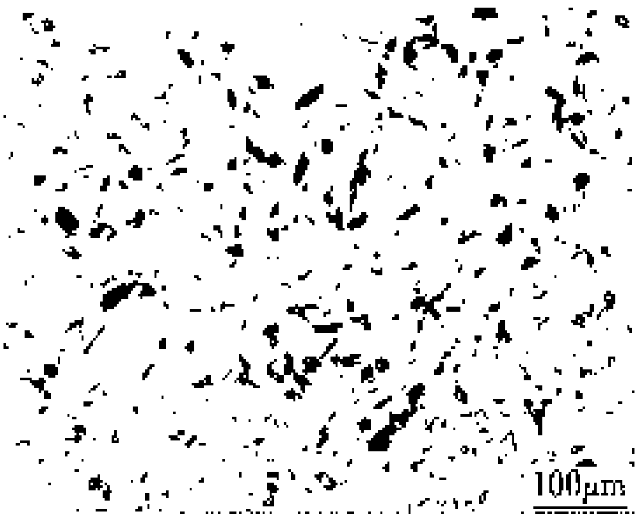

Fig. 3 Metallograph of 6066Al/ 15% SiC_p preform by multi-layer SD

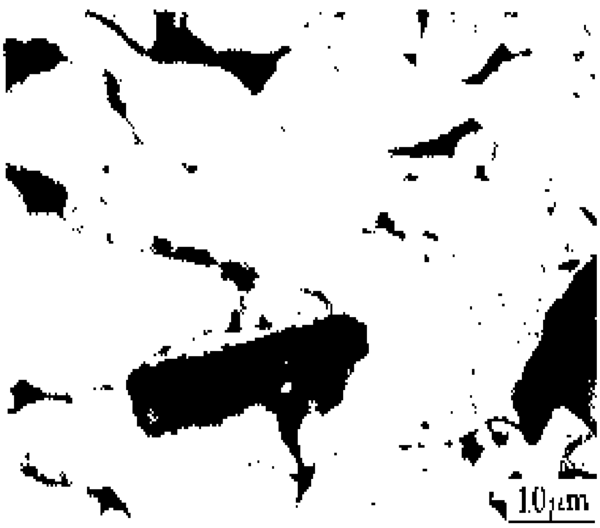

Fig. 4 Microscopic diagram of as-deposited 6066Al/ 15% SiC_p composite

has excellent manufacturing ability and mechanical properties. Moreover, the microstructure of the matrix without optical featureless zone is shown in Fig. 5. The microstructure is of dendrites with the distance between secondary dendrite arms(DAS) being 2 μm. According to the correlation between the cooling rate and the DAS: $D = a\varepsilon^{n}$[8], it is estimated that the cooling rate of the deposit is about $10^3 \sim 10^4$ K/s.

3.3 Interface bonding

Harmful interface reaction between the matrix and reinforcing particles can be avoided effectively due to high cooling rate for multi-layer spray deposition. Fig. 6 shows the microstructure of 6066Al/ SiC_p composite. It is found from this photo that the interface between the matrix and the reinforcing particles is clean, and the interface bonding is mainly mechanical mode.

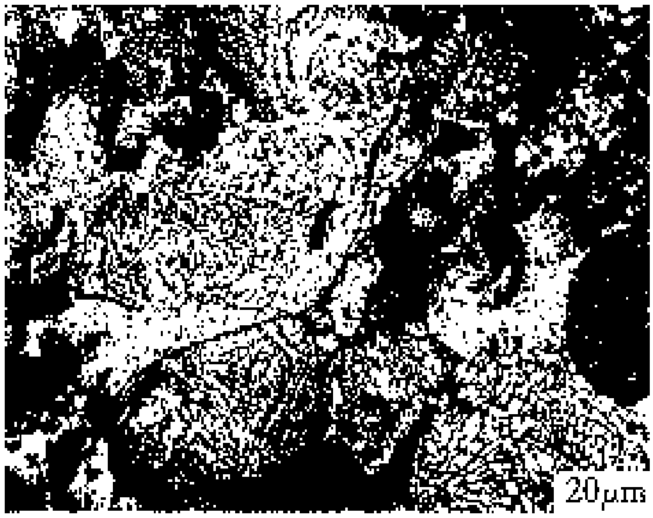

Fig. 5 Microscopic diagram of 6066Al/ 15% SiC_p composite

Fig. 6 Interface state of 6066Al/ SiC_p composite

3.4 Effects of extrusion on distribution and morphologies of SiC particles

Figs. 7(a) and (b) show the distribution and the morphology of SiC particles respectively in the spray deposition preform and the extrusion preform. It can be seen from these photos that in Fig. 7(a), there are large particles in the matrix, and the interface bonding is worse than that of small particles. Many particles are not spherical.

However, after extrusion, the particles become finer and more spherical obviously. And also, the interface porosity is greatly eliminated, and the total porosity decreases significantly. The plastic deformation in the extrusion has changed the relative position of all parts of the composite, and SiC particles are fractured due to shear stress in the plastic flow and dislocated, rearranged in the plastic deformation. Figs. 8(a) and(b) show the morphology of the SiC particles before and after extrusion respectively. It is indicated that there are cracks in SiC particles after ball grinding, as shown in Fig. 8(a) . This kind of particles will be broken up and the relative movement between the particles and the matrix occurs in extrusion. Fig. 8(b) shows some fragments of SiC particles smaller than 10 μm and the realative slide of the fragments.

3.5 Mechanical properties

Mechanical properties of the preform by multi-layer spray deposition after extrusion and T6 heat treatment are listed in Table 1. The results show that the extruded preform after T6 heat treatment has excellent mechanical properties.

3.6 Damping property of 6066Al/ 15% SiC_p+ 2% graphite composite

6066Al/ 15% SiC_p+ 2% Gr composite produced by the multi-layer spray deposition shows

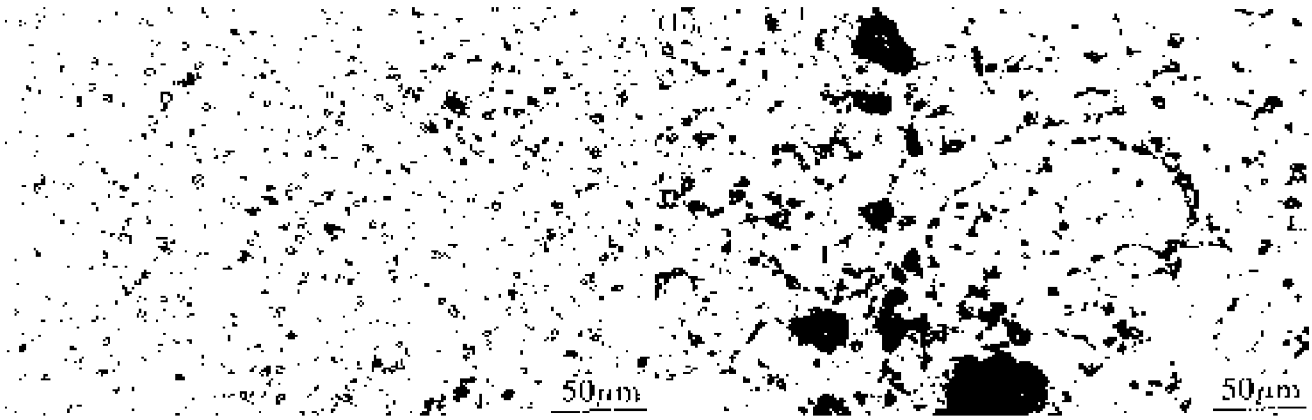

Fig. 7 Distribution of SiC particles in the matrix
(a) —before extrusion; (b) —after extrusion

Fig. 8 Morphologies of SiC particles
(a) —before extrusion; (b) —after extrusion

Table 1 Mechanical properties of 6066Al/ 15%SiC composite

Sample	σ_b/ MPa	$\sigma_{0.2}$/ MPa	E/ GPa	δ/ %
6066Al/ 15% SiC extrusion+ T6	640	510	133	9.4

a good damping property. The intrinsic damping of the composite is $9\times10^{-3}\sim5\times10^{-2}$, and mechanical properties of the composite are similar to those of the 6066Al/ 15% SiC_p composite. The data are not many, so further research is to be conducted.

4 CONCLUSIONS

(1) In the composites fabricated by multi-layer spray deposition, the distribution of the reinforcing particles is homogeneous, and the interface between the matrix and the reinforcing particles is clean. Also, the cooling rate of the matrix is high, the mechanical properties of the composites are excellent.

(2) The mechanical properties of 6066Al/ 15% SiC_p composite produced by multi-layer spray deposition technology, after extrusion and T6 heat treatment, are shown as: σ_b = 640 MPa, $\sigma_{0.2}$ = 510 MPa, δ = 9.4%.

(3) It has been shown that the reinforcing particles in the composites become finer, more spherical, and more homogeneous after extrusion.

REFERENCES

1 Ibrahim A. J of Mater Sci, 1991, 26: 1137.
2 Wu Y. Low Dimensional Material. Beijing: Chemical Industry Press, 1995: 326.
3 Gupta M. J of Mater Sci, 1991, 26: 6673.
4 Gupta M *et al*. Metall Trans, 1992, 23B, 719.
5 Chen Z H. Trans Nonferrous Met Soc China, 1995, 5(4): 66.
6 Gupta M *et al*. Mater Manufact Process, 1990, 5: 165.
7 Gupta M *et al*. In: Inter Symp on Advances in Processing Composites, Halifan, Canada, 1989: 236.
8 Cahn R *et al*. Phys Metall. North-Holland Physics Publishing, 1970: 1785.

(Edited by Peng Chaoqun)