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Solid atomization technology and process of molten metal and alloy^①

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[Abstract] A novel solid atomization technology, which using high velocity gas jet-stream rich in solid salt particles as atomization medium, was developed. The results show that using this novel atomization process can produce various metal and alloy powders with finer particle size, finer microstructures and higher cooling rate than those powders produced by the conventional gas atomization technology.

[Key words] powder processing; rapid solidification; powder metallurgy

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1 INTRODUCTION

Two-fluid atomization technology of molten metal is an effective metal and alloy powder production method in which a high velocity jet-stream of gas or high-pressure jet-stream of water is used to disintegrate a molten metal stream into fine droplets to form powders. It has been reported that the yield of the powders produced by two-fluid atomization technology ranges from 30% to 50% of the total output of the metal and alloy powders in the world^[1,2]. The origin of two-fluid atomization technology dates back to 1870s when several patents using air atomization technology to produce nonferrous metal powders were authorized^[3]. During the Second World War, the Mannesmann Powder Production Method was developed in German, it was used for making ferrous metal powders to substitute materials used into guiding hoops of artillery shells due to a shortage of copper^[4]. Over the last eighty years numerous investigations have been conducted to improve two-fluid atomization technology, these include: changing the structure of atomization nozzle, increasing the pressure of atomization medium and improving the atomization state of molten metal. With the help of these achievements, two-fluid atomization has gradually grown into a perfected technology^[5-10], but there has been no any report on the study of the process with changed atomization medium.

In the present work, a novel metal and alloy powder production technology has been developed in which a high velocity jet-stream of gas rich in solid salt particles is used to disintegrate molten metal and alloy stream into droplets to obtain powders. The technology has been termed as solid atomization technology. The preliminary results of these experiments are reported.

2 EXPERIMENTAL

The experimental device used to atomize molten metal or alloy stream by solid salt particles involved in gas stream is illustrated in Fig. 1. The atomization experiments were conducted according to the following procedure. NaCl particles were used as atomization medium and stored in a feeding tank. During the atomization procedure, salt particles were transmitted to the nozzle by pressurized gas at high velocity from an air compressor or nitrogen gas supply. The molten metal or alloy was disintegrated by the jet-stream of the mixture of NaCl particles and gas into fine droplets and allowed to fall into water to form powders. After cleaning, filtering and drying treatment, the powders were collected and ready for utilization. The NaCl left in water was recycled.

In this study, the particle size of NaCl powders ranged from 175 μm to 350 μm . The pressure of the

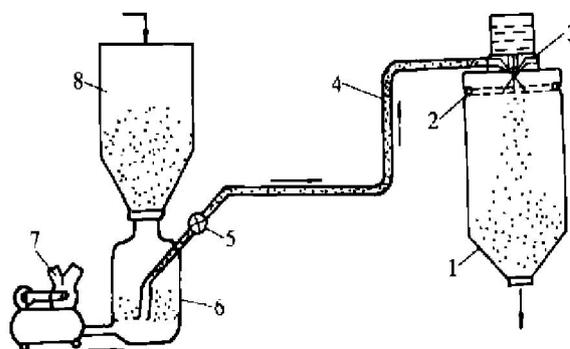


Fig. 1 Schematic diagram of experimental device using salt particles as atomization medium

- 1—Atomization chamber; 2—Water loop; 3—Atomizer;
- 4—Feeding pipe of salt particles;
- 5—Unloading valve of salt particles;
- 6—Feeding tank of salt particles; 7—Air compressor;
- 8—Storage tank of salt particles

high velocity jet-stream of air or nitrogen gas was 0.9 ± 0.1 MPa. The volume flow rates of the air or nitrogen gas were $6 \text{ m}^3/\text{min}$ and $3.3 \text{ m}^3/\text{min}$ respectively. Induction heating was adopted. The superheat of the molten metal or alloy was between 150 K and 200 K. The diameter of the melt stream was 3.5~3.8 mm. The flow rate of NaCl particles was 1.5~4.0 kg/min.

A laser diffraction particle size-measuring meter made by Malvern Instruments Cooperation in Britain and a Fisher Particle Size Measuring Meter were used to test particle size of the powders. Standard metallography techniques were used to examine the microstructure of the particles. Chemical analyzing was used to measure the residual NaCl content in the as-prepared powders.

3 RESULTS AND DISCUSSION

3.1 Mean particle size and particle size distribution of solid atomized powders

A series of comparative experiments were conducted to examine the atomization effect of molten metal using solid salt particles. The mean particle size of the produced powders and their particle size distribution were measured. The results are given in Table 1 and Table 2.

The mean particle size of NaCl atomized powders is about 50% smaller than that of the powders produced with gas atomized process. The particle size distribution of the former is much narrower than that of the later. In contrast to the conventional high velocity gas jet-stream atomization process, the finer powders with narrower particle size distribution can be obtained by this new developed technology under otherwise equal process parameter conditions, such as super-heat temperature, diameter of molten metal or alloy stream and its fluid rate and structure of the jet nozzle.

Table 1 Comparison of particle size between gas atomized powders and powders atomized by solid salt particles

Alloy or metal	Sample number	Mean particle size/ μm	Particle size/ μm	Atomization technology
Al12% Si	1-1	88.22	29.19	Gas atomization
Al12% Si	1-2	42.73	13.27	Solid atomization
Pb	2-1	79.44	8.65	Gas atomization
Pb	2-2	45.41	4.06	Solid atomization
Sn	3-1	78.18	15.39	Gas atomization
Sn	3-2	36.69	7.26	Solid atomization
Zn	4-1	76.42	8.64	Gas atomization
Zn	4-2	44.30	3.89	Solid atomization
Cu	5-1	84.22	28.67	Gas atomization
Cu	5-2	40.28	14.26	Solid atomization

3.2 Effect of atomization process parameters on particle size of metal powders

In this technology, the state of salt particles is a key parameter. Its effect on particle size of the atomized powders was systematically investigated. The result shows that the higher the mass fluid rate and velocity of salt particles and the finer the salt particles, the finer the atomized powders are. Generally speaking, the mass fluid rate and velocity of salt particles depend on the volume fluid rate and velocity of the carrier gas. In the present experiments, the pressure of air and nitrogen are both controlled at 0.8 MPa, the volume fluid rate of them are kept at $6 \text{ m}^3/\text{min}$ and $3.3 \text{ m}^3/\text{min}$ respectively, the variables are the feeding rate of salt particles with same particle size. The mean particle sizes of the as-prepared Al12% Si alloy powders are 42.73 μm and 60.42 μm respectively when the feeding rate of salt particles are 4 kg/min and 2.1 kg/min respectively.

Table 2 Comparison of particle size distribution between gas atomized powders and powders atomized by solid salt particles

Alloy or metal	Sample number	Particle size distribution/ μm						
		0~ 10	10~ 30	30~ 50	50~ 70	70~ 100	100~ 150	> 150
Al12% Si(g)	1-1	1.78	8.73	16.20	14.50	17.56	18.04	23.19
Al12% Si(s)	1-2	8.84	25.16	25.60	16.64	13.00	8.10	2.66
Pb(g)	2-1	2.80	12.86	16.65	13.91	15.70	17.80	20.28
Pb(s)	2-2	10.51	23.79	20.19	12.51	12.13	8.87	12.00
Sn(g)	3-1	1.18	12.07	16.80	15.85	16.49	13.61	24.00
Sn(s)	3-2	12.92	29.37	22.03	11.43	10.00	6.65	7.60
Zn(g)	4-1	2.19	9.89	19.76	15.83	19.07	15.86	17.40
Zn(s)	4-2	9.68	23.89	24.82	13.45	13.18	8.14	6.84
Cu(g)	5-1	1.50	8.91	15.32	14.65	17.37	19.05	23.20
Cu(s)	5-2	9.05	24.66	26.70	17.34	15.22	6.10	0.93

* g—Gas atomization, s—Solid atomization: mass flow of salt particles is 4 kg/min

It is obvious that the particle size of the as-prepared powders were greatly affected by the feeding rate of salt particles. According to theory analysis, it can be concluded that if the fluid rate of carrier gas is given, then the higher the pressure of the carrier gas and the higher the fluid rate of salt particles and the higher the dynamic energy of the salt particles, the better the atomization effect of the molten metal or alloy. Because of the limitation of the experimental device, it is hard to quantitatively examine the effect of atomization parameters on particle size of the as-prepared powder that requires further research.

3.3 Cooling rate of atomized metal and alloy powder particles

The thermal conductivity of air and nitrogen gas is range in $0.015 \sim 0.06 \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$, for water it is ranges in $0.65 \sim 0.70 \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$, for NaCl and KCl they are $1.15 \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$ and $6.53 \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$ at 272 K. The specific heat of NaCl and KCl are $854 \text{ J} \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$ and $690 \text{ J} \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$ respectively, their density are 2.17 g/cm^3 and 1.99 g/cm^3 respectively. According to Jones's viewpoint^[12], the cooling method of molten droplets during atomization is by heat convection on the interface of the droplet and gas, the heat conductivity h can be calculated by the following equation:

$$h = \frac{2k}{d} + 0.6 \left(\frac{k^4 \rho^2 C^2}{\mu} \right)^{1/6} \left(\frac{v}{d} \right)^{1/2} \quad (1)$$

where k , ρ , C and μ are the heat conductivity, density, specific heat and viscosity of the atomization medium respectively; v stands for relative velocity of the droplet and the cooling medium, and d the diameter size of the particle. The higher the calculated h , the higher the cooling rate of the droplet.

Referring to the data of every parameter for different medium, it is obvious that the cooling efficiency of NaCl and KCl powders is much higher than that of water and gas, the cooling rate of the powder atomized by solid salt particles is also higher. Fig. 2 shows the microstructures of eutectic AlSi alloy powder, the primary silicon phase in the salt atomized particles is much finer than that obtained by air atomization method. The cooling rate of a certain particle can be calculated with the following equation:

$$T = c \lambda^k \quad (2)$$

where T is cooling rate, c and k are constants, λ is the space between the two secondary dendrite crystal arms. In present study, λ is about only $1 \mu\text{m}$ according to Fig. 2, so the cooling rate is in the range of $10^4 \sim 10^5 \text{ K/s}$ according to Eqn. (2). It is higher by one to two orders of magnitude than that of the conventional gas atomization process, $10^2 \sim 10^3 \text{ K/s}$ ^[7].

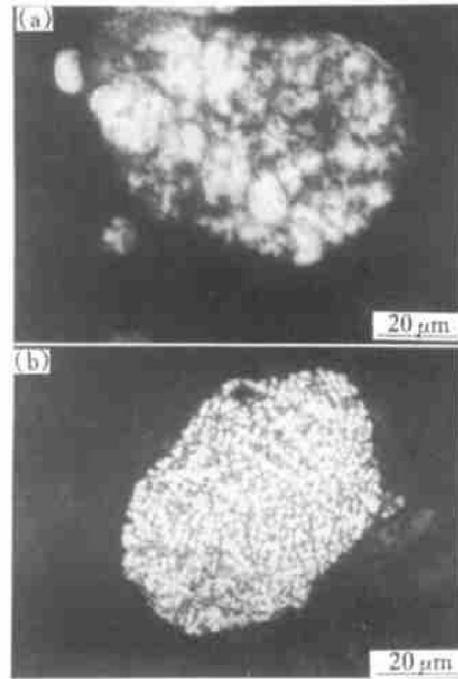


Fig. 2 Microstructures of atomized AlSi alloy particles prepared by two processes
(a) —Atomized with air;
(b) —Atomized with solid salt particles

3.4 Explosion problem of salt particles during atomization process

The expansion coefficients of NaCl and KCl crystal are $44 \times 10^{-6} / \text{K}$ and $36 \times 10^{-6} / \text{K}$ at 300 K which are much higher than that of common metals and alloy, so it is very easy for them to explode during quick heating. Obvious explosion phenomenon of the salt particles occurred during the present atomization procedure which is beneficent for atomization of molten metal stream and make the phenomenon of melt wrapping up salt particles hard to take place.

3.5 Corrosion effect of salt on metal powder

The residual salt in the as-prepared powders atomized by solid salt particles is very easy to be cleaned out by water washing treatment. The residual Na^+ ion concentration can be reduced to a considerable low level after water washing, filtering and drying treatment. Table 3 shows that water

Table 3 Na ion concentration in powders atomized by solid salt particles after water washing treatment

Metal or alloy	Sample number	Na ions concentration after water washing treatment
Al 12% Si (g)	1-1	0.016%
Al 12% Si (s)	1-2	0.012%
Sn (g)	3-1	0.005%
Sn (s)	3-2	0.006%

washing treatment can lower the concentration of Na ions in the powders atomized by solid salt particles to that of air atomized powders. This kind of powder has not been corroded by salt after several months' storage.

3.6 Application prospects of this new atomization technology

The essence of present new atomization technology is to use high velocity jet-stream of air carrying high concentration of solid powder as a main medium of atomization to atomize molten stream of metal or alloy. It is a simple and applicable production technology for fine metal powder comparing with other conventional powder technology. To fabricate high quality of metal powders proper solid salt particles as atomization medium must be chosen carefully. The salt particles must meet such requirements as easy and simple to be cleaned away from the metal powder without residual ions and having higher heat capacity and thermal coefficient. So NaCl, KCl and any other organic and inorganic solid powders, which are dissolvable in water, can be used as the atomization medium. The transfer method of solid powder belongs to high pressure gas transfer system for density materials, it is necessary to develop special devices for various solid atomization process to increase the rate of solid powder to gas and the velocity of the solid powder in high pressure carrier gas. With such kind of devices, commercial production of metal and alloy powders with various particle sizes can be realized easily.

This novel atomization technology is fit for production of various kinds of nonferrous powders, powders for injection formation process and rapid solidified powders and has the hope of fabricating finer powders on the basis of systematical and intensive investigation on the atomization process.

4 CONCLUSIONS

1) In contrast to the conventional high velocity gas jet-stream atomization process, the finer powders

with narrower particle size distribution can be obtained by the newly developed technology under otherwise equal process parameters conditions, the cooling rate of the particles obtained by this technology is higher.

2) Particle size of the as-prepared powders is obviously affected by the state of salt particles in the carrier gas stream. The higher the relative amount of the salt particles in the gas jet-stream, the higher the velocity of the salt particles, the finer the size of the salt particle and the finer the size of the as-atomized powder particles.

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