GAS-JET ATOMIZATION OF LIQUID METALS AND ALLOYS

I. P. Goldaev, A. P. Motornenko,
A. P. Shevchenko, and Yu. A. Lastivnyak

UDC 621.762.224

Atomization of a jet of molten material is one of the most effective methods of preparation of metal and alloy powders [1, 2]. To improve the thermodynamic gas parameters, the present authors have developed a technique for producing such powders with the aid of a supersonic, high-temperature gas jet. A novel feature of the new technique is that the energy carrier for the atomization of a molten metal jet is produced within the apparatus itself, in a special gas generator [3] operating on compressed air and a hydrocarbon fuel (gasoline, kerosene, gas, etc.). Thus, the function of the gas generator is to produce gaseous combustion products of any chemical composition and accelerate their discharge from a special nozzle unit to a supersonic velocity.

The gas generator (Fig. 1) is a combustion chamber of the air-breathing jet engine type. It consists of the shell 1, the window 2, the injector holder 3, the air swirling device 4, the injector 5, the fire tube 6, the spark plug 7, the gas duct 8, and the nozzle unit 9. The gas stream issuing at a supersonic velocity is directed onto a jet of molten metal and disintegrates it. The gas composition may vary depending on the ratio of the components and the chemical composition of the fuel. The gas generator enables the parameters of the gas jet issuing from the nozzle unit to be continuously regulated within the following ranges: temperature from 500 to 1500°K and velocity from 700 to 1250 m/sec.

In the first phase, to minimize experimental costs, it was decided to employ the new gas generators in conjunction with an industrial compressed-air atomization installation. For the supply of liquid fuel, a pump or a high-pressure system may be used. Thus, such an installation for the gas-jet atomization of metals and alloys consists of the units shown diagrammatically in Fig. 2.

At the Zaporozhe Ferroalloy Plant, in addition to the industrial installation, an experimental installation based on the same principle was constructed for conducting comparative tests. Bearing in mind that, other things being equal, the powder particle size depends on the type and design of the nozzle unit, comparative tests were carried out also on nozzle units of two – annular and multijet, with separate Laval nozzles – types (Fig. 3). The metal jet diameter was kept constant at 9 mm.

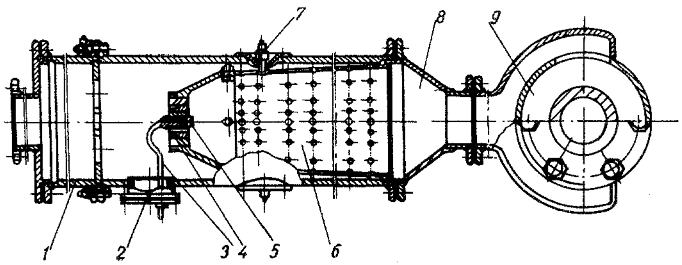

Fig. 1. Gas generator. For description see text.

Kharkov Aviation Institute. Translated from Poroshkovaya Metallurgiya, No. 2 (98), pp. 9-13, February, 1971. Original article submitted December 10, 1969.

TABLE 1. Results of Comparative Studies of Compressed-Air and Gas-Jet Atomization of Ferrosilicon

No.	Energy carrier	Type of nozzle unit	Percentage yields of powder fractions (in μ)				
			+160	−160 +100	−100 +63	−63 +40	−40
1	Compressed air	Unit with six Laval nozzles, $F_{cr.tot}$=238 mm²	22.3	19.2	23.7	17.2	17.6
2	The same	The same	18.71	19.56	29.36	18.81	13.5
3	The same	The same	12.45	22.35	32.00	18.80	14.50
4	The same	Annular nozzle, F_{cr}=340 mm²	6.52	16.27	33.42	25.12	18.67
5*	Supersonic, high-temperature gas jet	Unit with six Laval nozzles, $F_{cr.tot}$=238 mm²	13.8	15.48	25.08	22.58	23.68
6*			9.7	12.6	20.3	23.5	33.9
7*			6.66	9.21	20.31	25.16	38.66
		Average	10.05	12.43	21.79	23.74	32.08
8	The same	Annular nozzle, F_{cr}=340 mm²	2.7	12.3	25.3	31.1	28.6
9*	The same	The same	15.00	17.80	26.00	19.00	22.20
10*	The same	The same	8.35	12.25	24.20	24.9	30.40
11*	The same	The same	12.70	15.05	25.80	22.5	23.95
		Average	12.00	15.03	25.33	22.13	25.51

*Samples were collected periodically during 16 min of gas generator operation.

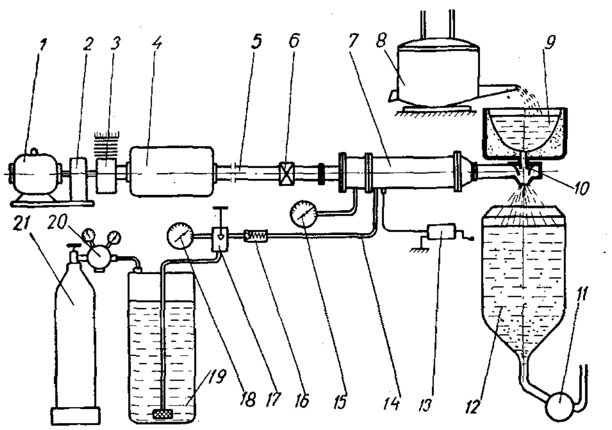

Fig. 2. Diagram of installation for gas-jet atomization of liquid metals and alloys: 1) electric motor; 2) reduction gear; 3) air compressor; 4) receiver; 5) air duct; 6) valve; 7) gas generator; 8) electric furnace; 9) metal container; 10) nozzle unit; 11) pumps; 12) powder tank; 13) magnets; 14) fuel supply tube; 15) air manometer; 16) reverse valve; 17) fuel control cock; 18) fuel pressure manometer; 19) fuel tank; 20) air cylinder; 21) fuel discharge reduction valve.

In view of production requirements and the classification employed at the plant, the powder yield was divided into five groups, as shown in Table 1. The whole powder with particles less than 40 μ in size was classified as belonging to a single group.

Tests carried out with this installation demonstrated that a supersonic, high-temperature gas stream atomizes liquid ferrosilicon more effectively than does compressed air. Raising the mean gas temperature in the gas generator and at the outlet from the nozzle unit has a strong effect and alters the particle size distribution of the powder by significantly increasing the amount of the fine fraction. This is clearly shown by the atomization data cited in Table 1: The yield of <40 μ particles rises on the average from 16.4 to 24.5% with the annular nozzle unit and from 15.22 to 32.08% with the unit incorporating six separate Laval nozzles. Data relating to some samples of the powders produced and a general analysis of the operation of the installation permit the conclusion that, with appropriate metal preparation and suitable setting of the gas generator and the nozzle unit, the yield of the fine fraction can be at least doubled.

TABLE 2. Results of Compressed Air Atomization Tests on Nozzle Units

No.	Type of nozzle unit	Dimensions: n, No.	Dimensions: d_{cr}, mm	Dimensions: a, mm	Dimensions: b, mm	Dimensions: α, deg	Dimensions: $F_{cr.tot}$, mm²	Inlet air pressure, kg/cm²	Energy carrier flow rate, m³/h · 10³	Percentage yields of powder fractions (in μ): +100	−100 +90	−90 +70	−70 +46	−46
1	A	8	10	—	—	52	628	20,0—10,0	6,8 —6,0	31,42	9,72	1,62	25,12	32,12
2								19,6— 9,0	6,95 —5,3	20,92	10,82	8,92	22,22	37,12
												Average		34,62
3	A	16	6	—	—	52	451	19,3—13,8	6,9 —5,0	24,92	11,32	9,62	19,62	34,52
4								19,4—13,3		8,22	8,32	15,72	18,92	48,82
5		16	7	—	—	52	614		7,0 —5,0	25,74	2,04	6,94	28,44	36,84
6	A							19,6— 9,3	7,0 —4,75	21,06	3,76	7,86	32,76	34,56
												Average		40,07
7	B	19	—	3	8	52	456	19,5—10,0	6,05 —4,0	33,58	11,48	12,78	17,08	25,08
8								19,3—10,3	6,0 —4,375	20,24	10,84	3,04	28,54	37,34
												Average		31,21
9	B	20	—	2	8	52	480	19,0— 9,2	4,875—3,75	28,84	19,54	1,24	20,34	30,04
10								19,5—11,4		23,32	9,32	10,72	21,42	35,22
												Average		32,63
11	C						306	19,5—11,0	4,125—3,375	21,76	6,46	1,56	25,86	44,36
12							280	19,4—12,8	3,75 —3,0	24,18	8,48	1,18	28,78	37,38
												Average		40,87

Designations: n = number of channels or nozzles, d_{cr} = diameter of critical cross section, a = slit height, b = slit width, α = angle between axes of two diametrically opposed nozzles or slits, $F_{cr.tot}$ = total surface area of critical cross section in nozzle unit.

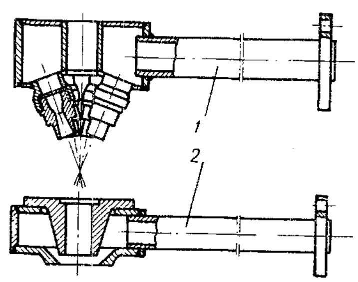

Fig. 3

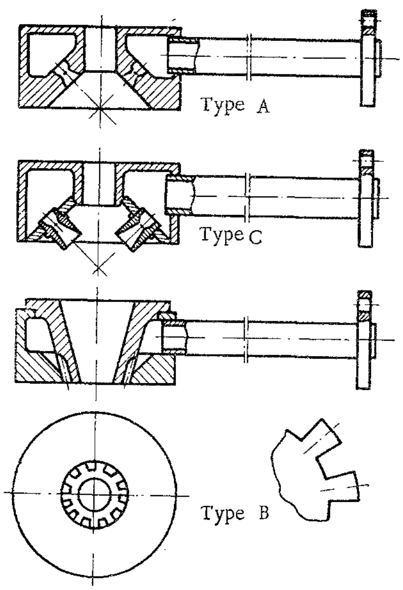

Fig. 4.

Fig. 3. Nozzle units: 1) unit with six Laval nozzles; 2) unit with slit nozzle.

Fig. 4. Experimental nozzle units.

At the same time it was noted that, at the relatively high temperature (500-1500°K) prevailing in the zone of formation of fine drops, the latter undergo less intense cooling, which markedly affects the shaping of powder particles.

During the operation of the gas generator, the pressure in the receiver drops only slightly and it is therefore possible to atomize 1.2 tons of ferrosilicon in a single run of 20-25 min duration without intermediate reheating. The resulting powder quality is more stable. In similar atomization tests using compressed air, the pressure of the latter falls more rapidly. To ensure that the pressure did not drop below a certain value, i.e., that the issuing gas jet retained its effectiveness, the atomization process was performed in five or six stages, which adversely affected powder quality, decreased the productivity of the installation, and resulted in cyclic operation.

Viscous liquids, which include liquid metals and alloys, are characterized by greater surface tension. The atomization of such liquids is strongly affected by factors including the projection range of the atomizing gas jet, the mass of the gas, the jet shape, the angle of incidence between the jet and the metal jet, etc.

To evaluate the influence of some of these factors, another few nozzle units, illustrated diagrammatically in Fig. 4, were constructed. In order to select the best among them, all these units were initially subjected to atomization quality tests using compressed air, without resorting to "hot" tests involving the use of the gas generator (relative parameters remain approximately unchanged on transition from one type of atomization to the other). The results of these tests and the geometric characteristics of the nozzle units employed are presented in Table 2. It will be seen from these data that a nozzle unit of type C is the most effective and economical in the preparation of powder of $< 46\ \mu$ size. While possessing the least overall duct surface area and requiring the least quantity of air at a given pressure, this nozzle unit ensures a fine powder fraction yield of about 40%. With gas-stream atomization, the yield of the fine fraction may be increased 1.5-2 times.

According to data obtained at the Kuznetsk Ferroalloy Plant, the 40-μ fine fraction of the usual powder contains some 15-20% of ultrafine particles 1-10 μ in size. With a suitable system of powder classification, the separation of finer fractions presents no major difficulty. The use of gas-jet atomization increases the yield of the fine fraction by improving the quality of both atomization and particle shaping, the latter being due to more favorable particle spheroidization conditions. In the light of these considerations, it can be seen that the yield of very fine powders (1-10 μ) in the existing industrial installations can be substantially raised by employing the new technique.

The investigation has revealed the following advantages of gas-jet atomization:

1) The atomization process is improved and the yield of the fine fraction is increased;

2) particle formation conditions are improved;

3) air consumption decreases;

4) the chemical composition of powder may be controlled by performing atomization in reducing, neutral, or oxidizing atmospheres.

LITERATURE CITED

1. I. M. Fedorchenko and R. A. Andrievskii, Principles of Powder Metallurgy [in Russian], Izd-vo AN USSR, Kiev (1963).
2. A. F. Silaev, in: Powder Metallurgy, Transactions of a Scientific-Technical Meeting [in Russian], Metallurgizdat (1954).
3. I. P. Goldaev, A. P. Motornenko, et al., Samoletostr. i Tekhn. Vozdushnogo Flota, No. 9 (1967).