THEORY, PRODUCTION TECHNOLOGY, AND PROPERTIES
OF POWDERS AND FIBERS

EFFECT OF BLAST PARAMETERS ON THE MECHANISM
OF DISINTEGRATION OF A MOLTEN METAL JET
AND ON THE PROPERTIES OF ATOMIZED POWDERS

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Our knowledge of the mechanism of disintegration of a high-temperature molten metal jet under the action of a gas stream is largely hypothetical in character and has not been confirmed by direct experimental data. In [1], the atomization process of molten metals is linked with a two-stage mechanism of disintegration of the jet and its elements. Yet the actual mechanism involved in the disintegration of the jet and the subsequent breaking up of the primary drops is not yet fully understood, in spite of the application of such direct methods of investigation as photography and high-speed filming. At the same time, it has been shown [2] that many properties of atomized powders depend to a large extent on blast parameters and are therefore directly associated with the processes occurring during the disintegration of the molten metal jet. Consequently, the character of changes in some physicotechnological properties of powders may supply indirect evidence suggesting which particular mechanism of jet disintegration is operative or dominant under any given process conditions.

To determine the effect of blast parameters on the formation of metal and alloy particles and on the characteristics of the resultant powders, experiments were conducted on the air and nitrogen atomization of jets of molten iron and 50 N iron−nickel alloy.* Atomization was performed in a gas-stream atomizing unit with a convergent annular nozzle, as described in [3]. At blast pressures in the nozzle of more than 200 kN/m^2, the metal jet was disintegrated by a gas stream issuing from the nozzle with a velocity of not more than 320 m/sec. The gas pressure at the mouth of the nozzle exceeded the pressure of the atmosphere into which the gas emerged, and consequently atomization was effected by a concentrated and elastic gas stream. The pressure in such a stream, at the mouth of the nozzle, can be found from the relationship

$$P_2 = \beta \cdot P_1 ,$$

where P_2 is the pressure in the stream at the mouth of the nozzle, in kN/m^2, P_1 the gas pressure before emergence from the nozzle, in kN/m^2, and β a coefficient, equal to 0.528 for diatomic gases.

Raising the gas pressure increased both the gas outlet velocity, to the velocity of sound, and the rate of flow of the gas, thereby causing the total kinetic energy of the blast to grow. With increase in blast parameters, gas eddy currents near the lower end of the nozzle become intensified. Impingement on these currents disturbs the molten metal jet, which loses its continuity and breaks up into primary droplets (or ligaments) well above the atomization focus (Fig. 1). In the focal atomization zone, the primary elements of the jet are disintegrated by the main, concentrated gas stream into fine droplets, which cool down and solidify in the gas stream below the atomization focus.

Since the velocity and density of the gas stream appreciably fall with increasing distance from the nozzle mouth and the principal axes of the stream [4, 5], the effectiveness of the disintegration of the primary jet elements in the focal atomization zone (zone III in Fig. 1a) varies, which is one of the main reasons why atomized powders exhibit substantial variations in particle size. An atomized powder may contain particles of few microns and 1-2 mm in size, the proportion of fine particles increasing with rise in blast pressure [6, 7].
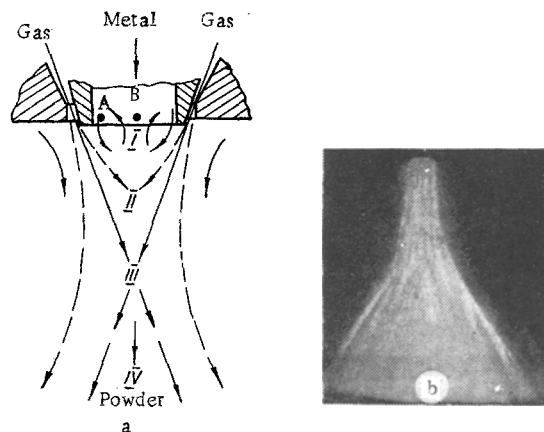
*50% Fe − 50% Ni alloy − Translator.

Fig. 1. Diagrammatic representation (a) and photograph
(b) of atomization of molten metal jet. Zones: I) of eddy
currents and jet disturbance; II) of initial disruption of
molten jet; III) of intense disruption (atomization focus);
IV) solidification and assumption of final particle size
and shape.

In our experiments, the blast pressure was varied from 150 to 600 kN/m². The diameter of the pouring channel of the metal container (a quartz tube) was 6.5 ± 0.1 mm. The resultant particles were finally cooled in water, after which they were drained, dried in a vacuum desiccator at 70-100° C, and reduced in a dried hydrogen atmosphere at 600-800° C.

A study of the physical and fabrication properties of powders produced by atomizing low-carbon (0.02% max C) molten metals demonstrated that, in both air and nitrogen atomization processes, raising the blast pressure increases the apparent and pyknometric densities of powder fractions, lowers the oxygen content of the finest fractions, and increases the proportion of fine particles in the powder (Fig. 2). In the air atomization of 50 N alloy, the nickel content of the fine powder fractions was found to fall slightly, presumably due to an enrichment of the surface layers of the jet and the primary droplets (from which fine particles are most likely to form) in iron oxides. Such a redistribution of iron between the main volume of a drop and its surface layer can indeed be expected to take place, because iron oxidation predominates in the oxidation process of molten iron — nickel alloys [8].

To gain a better insight into the phenomena observed in the investigation into the air atomization of iron — nickel melts, experiments were carried out on a 50 N alloy which had been carburized during production to 0.8% C. The carbon protected the metallic basis of liquid droplets against oxidation and virtually prevented nickel oxides from forming on the particle surfaces. This was confirmed by an electron diffraction analysis of the surface particle layer, which revealed the presence of iron oxides, only mainly Fe_3O_4. Samples of 50 N alloy powder intended for nickel determination had been annealed for 4 h in hydrogen at 800° C. The residual carbon and oxygen contents of the powder did not exceed 0.01 and 0.02%, respectively.

A comparison of particle size and chemical composition distribution curves for the 50 N alloy powder (Fig. 3) shows that the greatest nickel content deviations were observed for < 0.25-0.3 mm fractions. The chemical composition of coarser particles at all blast parameters remained practically constant. These experimental data suggest that the formation of fine and coarse particles at different blast parameters may be due to different mechanisms. It would appear that coarse particles are formed through the division of large primary molten metal drops into a relatively small number of finer droplets, in which twinning is the operative mechanism. The formation of particles by this mechanism is illustrated in Fig. 4, which shows a particle solidified at the instant of division. It is conceivable also that some primary drops break up by a complex twinning mechanism, resulting in the formation of three, four, or more particles from a single elongated drop. As the twinning mechanism operates mainly at low blast parameters, fine particles are unlikely to be produced from the whole volume of molten metal.
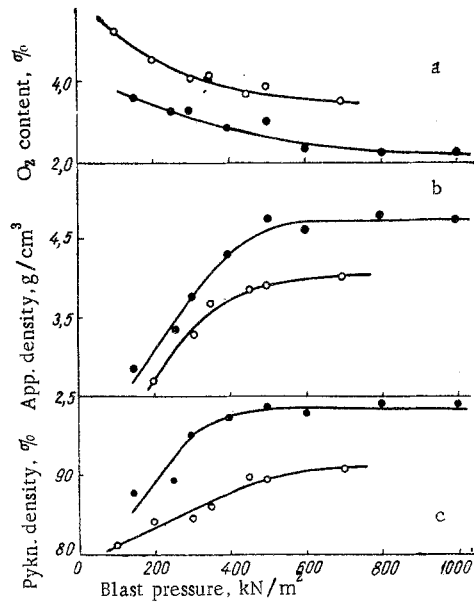
Fig. 2. Effect of blast pressure on oxygen content (a), apparent density (b), and pyknometric density (c) of iron powder. Atomization with: ○) air; ●) nitrogen.
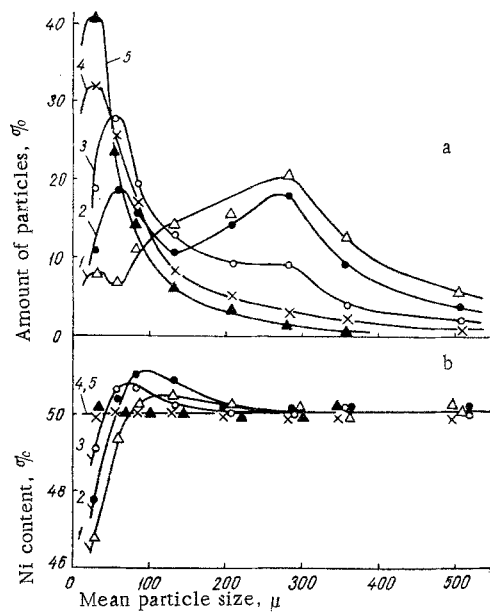

Fig. 3. Effect of blast pressure on particle size (a) and chemical composition (b) distribution curves for 50 N alloy powders: 1) 150; 2) 200; 3) 250; 4) 400; 5) 600 kN/m².

The mechanism of shock ("explosive," according to [1]) disintegration of primary jet elements is operative primarily at high blast parameters, when the gas stream has sufficient kinetic energy to break up primary drops into a multitude of fine particles. Even in this case, however, in the peripheral zones of the gas stream, where the gas velocity sharply falls, the twinning mechanism may be chiefly responsible for particle disintegration.

Analysis of curves characterizing the variation in chemical composition of 50 N alloy with particle size (Fig. 3) shows that fine powder fractions are formed from primary molten metal drops more than

Fig. 4. Division of molten drop, arrested by rapid cooling, × 200.

0.25-0.3 mm in size. The continuous variation in chemical composition of the alloy with particle size is evidence that we are dealing here not with a single act of "explosive" disintegration of large particles, as described in [1], but with a steady process in which first a primary drop and then the droplets produced from it break up into still finer particles. The possibility of liquid particles disintegrating in such a series of steps is demonstrated by, for example, data on the residence time of particles in the liquid state [9]. It is found that, at low blast parameters, fine particles are formed from the surface layers of larger drops. Increasing the energy parameters of the blast steadily raises the proportion of particles forming from the whole volume of primary drops, which, of course, ensures that the particles have a more uniform chemical composition.

Conditions resulting in the production of powders with particles having the greatest nonuniformity of chemical composition prevail when the maximum in their distribution curves occurs in the region of large particles. This maximum shows that the twinning mechanism plays the dominant role in the disintegration of primary molten metal drops. With increase in blast parameters, the maximum in the region of large particles gradually becomes less pronounced and finally disappears, while at the same time a maximum in the region of fine particles appears and steadily increases in size. Since increasing the blast parameters results in the production of powder having a more uniform chemical composition as a function of particle size, which is an indication that the shock mechanism plays a greater part in primary drop disintegration, it is reasonable to assume that the maximum in the region of fine particles characterizes the extent to which the shock (explosive) mechanism is responsible for the disruption of the molten metal jet.

In actual processes for the manufacture of steel and alloy powders, blast parameters at which the shock (explosive) mechanism of particle formation plays the dominant role should be regarded as critical.

On the basis of data yielded by this investigation, practical recommendations have been made which should enable alloy powders to be produced with particles having the same composition irrespective of their size.

CONCLUSIONS

1. It has been confirmed that, under the action of a gas stream, a molten metal jet breaks up in two stages, resulting in the formation of primary drops (ligaments) above the disintegration focus and fine particles in the focal atomization zone.

2. It has been established that the shock (explosive) mechanism of particle formation and the twinning mechanism operate simultaneously, the former predominating at higher blast parameters and the latter at low. It is shown that the shock mechanism reveals itself in a series of steps, in which first primary drops and then the droplets produced from them break up into still finer particles.

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