PREPARATION OF NICKEL POWDER BY ATOMIZATION

O. S. Nichiporenko, Yu. I. Naida, and A. V. Kochergin

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Atomization, consisting in breaking up a stream of liquid metal by a jet of gas, is a process which should prove very effective in the manufacture of nickel powder. It is characterized by very high productivity and relatively low cost, and enables powders to be produced having a wide range of particle sizes and various particle shapes.

The technological factors affecting the formation of powder particles were described previously [1, 2]. Particles of spherical shape are obtained when the particle spheroidization time is less than the particle cooling time, i.e., \( \tau_s < \tau_c \). Particles of nonspherical shape are produced when the inequality \( \tau_s > \tau_c \) is satisfied. The spheroidization and cooling times are determined from the expressions:

\[
\tau_s = \frac{3\pi^2}{4} \frac{\mu}{\sigma \cdot V} (R^4 - r^4),
\]

\[
\tau_c = r \frac{c \gamma_m}{3\alpha} \ln \frac{t_m - t_g}{t_{melt} - t_g}.
\]

Here \( \mu \) is the coefficient of dynamic viscosity of the metal, kg/sec/m²; \( \sigma \) the surface tension of the metal, N/m; \( R \) the radius of a spherical particle, m; \( r \) the radius of an original cylindrical particle, m; \( c \) the heat capacity of the metal, J/kg°C; \( \gamma_m \) the specific gravity of the metal, kg/m³; \( t_m \), \( t_{melt} \), and \( t_g \) are the temperature of the superheated metal, the melting point of the metal, and the temperature of the atomizing gas, respectively, °C; \( \alpha \) is the coefficient of heat transfer from the metal to the gas; \( V \) the volume of a metal drop, m³.

Substituting the parameters \( \tau_s \) and \( \tau_c \) into this inequality gives a relationship determining the feasibility of obtaining a desired powder particle shape. For example, for obtaining round particles, the equation may be rewritten in the following form:

\[
\frac{\mu}{\sigma} < \frac{4c \gamma_m V}{9\alpha \pi^2 (R^4 - r^4)} \ln \frac{t_m - t_g}{t_{melt} - t_g}.
\]

The required mean particle size was taken as 300 \( \mu \), the temperature of the metal before atomization as 1600°C, and the temperature of the gas before atomization as 30°C. (The remaining gas and metal parameters were obtained from Kishkin and Shirkovich's textbook [3], while the coefficient \( \alpha \) was determined from the results of an earlier study [4].) The condition, calculated from Eq. (3), ensuring that spherical powder particles are produced is \( \mu / \sigma < 0.013 \). Since the surface tension of nickel is 1.350 N/m and its viscosity is 0.0013 kg/m/sec, the inequality \( \tau_s < \tau_c \) is easily satisfied, indicating that spherical powders will be produced. The sign of the inequality can be changed by increasing the melt viscosity by two orders. To achieve this, it is necessary to add a component forming refractory oxides when exposed to atmospheric oxygen. Aluminum may be employed as such a component; the viscosity of a melt at the instant of formation of the oxide \( \text{Al}_2\text{O}_3 \) rises by several orders [2]. As a result, no particle spheroidization will take place and a powder with irregular-shaped particles will be obtained.

The intensity of breaking up of the metal stream is determined by the force of the dynamic impact exerted by the gas jet, particularly the jet velocity. Volynskii [5] has derived the following formula for determining the gas jet velocity ensuring that powder of predominant particle size $d$ is produced:

$$W_g = \sqrt{\frac{14\sigma}{\rho_g \cdot d}},$$

where $\rho_g$ is the density of the atomizing gas.

From Eq. (4) it follows that, to obtain powder of $\sim 300 \mu$ particle size, a blast velocity of 250 m/sec is necessary. This velocity was achieved by employing a pressure of 2.5 atm gauge and a nozzle with an annular slit 0.8 mm wide. The metal stream diameter was 6 mm. The resulting nickel powder was spherical when atomization was performed without any additions and nonspherical when about 0.05 wt.% of aluminum was added to the melt (Fig. 1). Atomization was carried out in batches weighing 4-7 kg each. The powder was completely homogeneous, silvery-gray in color. An experimental batch was subjected to tests to determine the technological and physical properties of the powder. The results of these tests are presented in Figs. 2-5. The particle size distribution curves of the spherical and nonspherical powders produced, illustrated in Fig. 2, have peaks in the range 250-350 $\mu$, which is in accord with calculated data. Figure 3 shows the effect of particle size on the apparent specific gravity of the powders. The apparent specific gravity of the spherical powder is about 5 g/cm$^3$ and, compared with the nonspherical powder, is less affected by particle size; with decrease in particle size, the apparent specific gravity of the nonspherical powder falls from 3.5 to 2.5 g/cm$^3$.

Figure 4 shows the flowability curves of the two powders. As would be expected, the flowability of the spherical powder is higher and ranges from 8 to 14 g/sec depending on the particle size; the flowability of the nonspherical powder is much less, 2.5-10 g/sec, the coarsest fractions (500 and 700 $\mu$) exhibiting no free flow whatever. Of considerable interest are pyknometric measurements of powder density, since they provide information on the internal porosity of particles. For the powders under investigation, such data are presented in Fig. 5. The density of the spherical powder, which is uniform and virtually independent...