Express Method for Estimating Particle Isometricity for Quality Control Ferrosilicium

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Abstract. Currently, in connection with the expansion of the volume of implementation of the dense medium separation (DMS) process at the processing plants, it becomes necessary to solve the problem of quality control of the ferrosilicon used, the relevance of which is due to an increase in the instability of the initial technological properties of ferrosilicon supplied by various manufacturers. This paper presents an express method for controlling the quality of ferrosilicon, the use of which allows, using data on the bulk and true density of ferrosilicon, to evaluate the isometricity of its particles.

1. Introduction

At present, in connection with the spread of the process of dense medium separation in the enrichment plants of the Russian Federation, there is a need to solve the problem of reducing the losses of an expensive weighting agent - ferrosilicon. Losses of ferrosilicon that occur in the process can be up to 40% of the total operating costs of the DMS installation, which leads to an increase in the cost of extracting the useful component [1-8].

As the studies of many experts on this issue have shown, in order to reduce the operating costs of the DMS installation, it is necessary to use ferrosilicon with the most isometric rounded shape of particles that do not have cracks on the surface and inside. Isometric ferrosilicon is more efficiently regenerated in the magnetic separation cycle, more resistant to abrasion and corrosion, easier to extract in a medium compaction cycle, provides cleaner products and lower heavy media losses. [1, 5, 8].

In accordance with the foregoing in this work, an effective way to solve the problem of reducing losses of ferrosilicon is to create an express method for assessing the isometricity of particles to control the quality of ferrosilicon used.
2. Main part

The shape of the particles of bulk materials is evaluated using various factors that determine the degree of deviation from the correct geometric shapes [7]. The coefficient of isometric of particles is determined as follows:

\[ K_I = \log \left( \frac{l}{b} \right), \]

where, \( l \) - is the particle length; \( b \) - is the particle width.

It is known from the theory of densest ball packings that, in addition to the packing method, the particle shape also affects the maximum packing density of monodisperse systems. Table 1 shows the values of the maximum packing density for different ratios of particles of the same size [2].

**Table 1.** The maximum packing density of particles of the same size depending on the ratio of length (l) to width (b).

| The ratio of length to width of the particle \((l/b)\) | 2   | 4   | 6   | 10  |
|--------------------------------------------------|-----|-----|-----|-----|
| Maximum packing density \((\varphi_{max})\)       | 0.68| 0.60| 0.53| 0.42|

In turn, the packing density (filling factor) is defined as:

\[ \varphi_{max} = \frac{V_t}{V_c} = \frac{\rho_b}{\rho_t} \]

where, \( V_t \) - total volume occupied by solid particles in the cell; \( V_c \) - cell volume; \( \rho_b \) - bulk density of solid particles in the cell; \( \rho_t \) - true density of solid particles in the cell.

Based on expression (2), we can conclude that the isometricity of the particles will depend on the bulk density and true density of ferrosilicon.

The research materials in this work were ferrosilicon samples of various manufacturers. Granulated hematite and milled wollastonite were taken as a reference sample (Figure 1).

![Figure 1](image_url)

**Figure 1.** Electronic image of the form factor of the samples: a - granular hematite; b - milled ferrosilicon; c - milled wollastonite.

The bulk density of ferrosilicon samples of various manufacturers was determined by measuring the mass of the powder, which in a loose state completely fills a cell of known volume (ISO 19440-94). A loose state is achieved when the cell is filled with a funnel located above it at a certain distance.

The true density of ferrosilicon samples of various manufacturers was determined by the pycnometric method (GOST 22662-77) [6, 9].

The results of measurements of true and bulk density are presented in table 2.
Table 2. True and bulk density of ferrosilicon samples from various manufacturers.

| Sample name     | Bulk density, g/cm³ | True density, g/cm³ | Packing density |
|-----------------|---------------------|---------------------|-----------------|
| Granular hematite | 3,379               | 5,149               | 0,656           |
| Ferrosilicon №1  | 2,710               | 7,588               | 0,357           |
| Ferrosilicon №2  | 2,983               | 6,262               | 0,476           |
| Ferrosilicon №3  | 2,906               | 6,602               | 0,440           |
| Ferrosilicon №4  | 2,897               | 6,386               | 0,454           |
| Ferrosilicon №5  | 2,758               | 6,622               | 0,416           |
| Ferrosilicon №6  | 2,833               | 7,174               | 0,395           |
| Ferrosilicon №7  | 2,753               | 7,018               | 0,392           |
| Milled wollastonite | 0,582              | 2,742               | 0,212           |

The geometric parameters of the particles necessary for calculating the shape coefficients were measured at the Analytical Center for the Study of Natural Substances of the ICEMR RAS with a confocal laser scanning microscope (KEYENCE VK 9700). To measure the length and width of each ferrosilicon sample, the geometric parameters of 500–700 particles were measured. The results of measuring the geometric parameters of ferrosilicon particles are presented in table 3.

Table 3. The geometric parameters of the particles of ferrosilicon samples from various manufacturers.

| Sample name     | Length / Width | Coefficient of isometric |
|-----------------|----------------|--------------------------|
| Granular hematite | 1,066         | 0,027                    |
| Ferrosilicon №1  | 2,324         | 0,332                    |
| Ferrosilicon №2  | 1,619         | 0,194                    |
| Ferrosilicon №3  | 1,792         | 0,238                    |
| Ferrosilicon №4  | 1,680         | 0,209                    |
| Ferrosilicon №5  | 1,916         | 0,260                    |
| Ferrosilicon №6  | 1,724         | 0,219                    |
| Ferrosilicon №7  | 1,762         | 0,227                    |
| Milled wollastonite | 2,59        | 0,413                    |

The granulometric composition of ferrosilicon samples was determined by a laser device for measuring particle size (ANALYSETTE 22) at the ICEMR RAS Analytical Center for the Study of Natural Substances.

Since all ferrosilicon samples belong to the same brand, the samples are similar in terms of particle size distribution.

In the mathematical processing of experimental data, a correlation dependence of the fill factor on the coefficient of isometric of ferrosilicon particles and the dispersion of the particle size distribution of ferrosilicon samples of various manufacturers was revealed. The determination coefficient was 94.5%.

After that, the possibility of eliminating the dispersion of the particle size distribution from the correlation dependence was analyzed. The determination coefficient was 94.1% (Figure 3).
Figure 2. Granulometric composition of ferrosilicon samples from various manufacturers.

Figure 3. The revealed correlation dependence of the fill factor on the coefficient of isometric of ferrosilicon particles.

By a reverse recalculation, the error of the method for assessing the quality of ferrosilicon particles was estimated (Table 4).

| Sample name           | Experiment | Calculation | Error  |
|-----------------------|------------|-------------|--------|
| Granular hematite     | 0.027      | 0.032       | 0.005  |
| Ferrosilicon №1       | 0.332      | 0.292       | 0.040  |
| Ferrosilicon №2       | 0.194      | 0.188       | 0.006  |
| Ferrosilicon №3       | 0.238      | 0.220       | 0.018  |
| Ferrosilicon №4       | 0.209      | 0.208       | 0.001  |
| Ferrosilicon №5       | 0.260      | 0.240       | 0.019  |
| Ferrosilicon №6       | 0.219      | 0.259       | 0.040  |
| Ferrosilicon №7       | 0.227      | 0.261       | 0.034  |
| Milled wollastonite   | 0.413      | 0.418       | 0.005  |
The average absolute error was 0.019, and the average relative error was 7.98%.

3. Conclusions

Thus, based on an analysis of the results of experimental studies, the following results were obtained:

1. It has been established that ferrosilicon of various manufacturers differs in the shape of grains.
2. The dependence of the packing density (filling factor) on the coefficient of isometric of ferrosilicon samples of various manufacturers was revealed.
3. The express method for assessing the quality of ferrosilicon particles, proposed on the basis of the revealed dependence, makes it possible to determine coefficient of isometric with an average error of 7.98%.

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