Application of particle-size analysis in various industries

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Abstract For various materials, rapid generation of results is always critical. Particle-size analysis of processing products using a laser-based particle-size analyzer is a valid alternative to the traditional sizing test. The article presents the results of studies conducted using Microsizer 201C equipment by the example of layered aluminosilicates and metal powders for additive manufacturing. The size analysis for these products is generally complicated by their ability to stick and agglomerate. Ultrasonic mixing does not harm the material analyzed and promotes uniform distribution of the sample during analysis. The results of granulometric analysis of kaolin ores obtained after different heat treatment are presented. The results of air-electric classification of metal powders obtained after vibration disintegration of metal chips are presented. The variety of raw materials shows a wide range of applications of this method in industry.

1. Introduction

Approximately 90% of all ores mined is currently pre-processed, since, in their initial state, many ores are not directly suitable for chemical and metallurgical operations, primarily due to the high content of impurity components. Therefore, successful manufacturing operations require proper processing.

Mineral raw materials and the resulting processing products represent a mixture of particles of irregular shapes and sizes, which require classification. Their distribution by various size classes characterizes the particle size composition of the material. Particle-size analysis is an important component of laboratory research in the preparation of raw materials for subsequent chemical and metallurgical operations, since, in the process of disintegration of the original ore, valuable components are classified into the respective particle sizes according to their physical and mechanical characteristics. The fineness characteristic is also important in a variety of manufacturing operations.

The properties of powder materials, suspensions, and emulsions largely depend on the sizes of their component particles. Therefore, particle-size analysis (i.e. measurements of the size distribution of particles in dispersed media) is one of the critical elements at various advanced production and scientific facilities [1-3].

The requirement for the production of metal powders has recently increased due to the growing demand for additive manufacturing. This technology has the advantage of producing items of various shapes, which reduces both the number of process stages and the consumption of the source materials. Particle-size composition is a key requirement for powders. Depending on the fusion method, particle size classes of 20 to 200 μm may be used. The content of particles below 20 μm must not exceed 7%, since finer powders impair fluidity and contribute to the formation of suspensions, which leads to equipment clogging [4].
Sizing tests are generally used to establish the particle-size distribution. These imply material screening into various size classes using sieves with certain mesh sizes. This method allows estimating particle sizes of up to 45 μm; however, when analyzing certain types of materials, for example, fine powders or clay minerals, a number of difficulties prevent further estimations for the finer classes. Therefore, sizing tests are mainly used for coarse powders.

A laser-based particle analyzer is recommended for the finer fractions, which allows establishing the grain sizes for objects of 0.2 to 600 μm. In laboratory studies, a fine-class particle-size analysis was carried out using a Microsizer 201C instrument, designed for establishing particle-size distribution in liquid media.

Its principle of operation is based on recording the scattering intensity of a beam of rays emitted by a He-Ne laser and passing through a plane-parallel measuring cell with a sample. The scattered radiation is registered using a specialized photodiode array. The versatility of this device allows analyzing a wide range of objects, including materials directly studied by Mekhanobr-Tekhnika, such as aluminosilicates, alumina, and metal powders.

Since the particles studied are prone to agglomeration and quick settlement, reliable results may be obtained with the suspension of particles dispersed using ultrasonic radiation and continuously pumped through the measuring cell. During the experiment, all particles of the suspension repeatedly pass through the light beam, which ensures a high degree of averaging for the results. The analysis results represent the dependence of the weight fraction of particles P on their diameter D and are displayed in the form of histograms and tables.

This article presents the results of experimental studies conducted using a laser-based particle-size analyzer. Examples of the use of this analysis method in the processing of aluminum-containing ores and for removing dust from metal powders for additive manufacturing are also presented. The heterogeneity of the source materials indicates a wide range of applications for this method in the industry.

### 2. Particle-size analysis in the study of layered silicates

When processing clay minerals, such as kaolin, into alumina, the fine class of -0.2 mm is of special interest, where the Al₂O₃ content in individual classes (for example, 0.075 mm) may reach 35% after ore disintegration [5]. However, mineral particles of this fraction are highly dispersed and they adversely affect the rheological properties of suspensions used in concentration and metallurgical processes [6]. Thermal modification is a promising solution, enabling lower negative impacts of clay minerals on the main processing operations in ore preparation and concentration and increasing their chemical activity in metallurgical operations. It changes the physical and chemical properties of the clay component in the material [7].

| Fraction | Weight, g | Yield, % |
|----------|-----------|----------|
| +1       | 159.80    | 16.55    |
| -1+0.63  | 152.12    | 15.75    |
| -0.630+0.315 | 238.94 | 24.74    |
| -0.315+0.2 | 120.08   | 12.43    |
| -0.2+0   | 294.85    | 30.53    |
| Total    | 965.79    | 100.00   |

| Table 1. Particle-Size Composition of Kaolin Studied |

Related experimental studies and particle-size analysis for the samples have demonstrated that the yield of the required fraction after the first crushing stage of -0.2 mm is 30% of the total material...
weight. In the fine class, the fraction of -0.01 mm prevails. During the heat treatment, changes begin to occur in the material of the fine class: with longer exposure times and higher temperatures, the number of particles of the given size decreases due to the formation of loose-packed aggregates caused by a reduction in the interplanar spacing with the removal of crystallization water. The results are presented in Figure 1 and in Tables 1 and 2.

**Table 2. Chemical Composition of Kaolin by Fractions**

| Fraction | Component content, wt. % | SiO₂ | Al₂O₃ | Na₂O | Fe₂O₃ | CaO | nnn |
|----------|--------------------------|------|-------|------|-------|-----|-----|
| +1       |                          | 61.80| 23.30 | 0.022| 1.64  | 0.35| 10.50|
| -1+0.63  |                          | 55.10| 27.20 | 0.027| 1.30  | 0.39| 13.00|
| -0.630+0.315 |                    | 52.50| 28.10 | 0.026| 3.20  | 0.42| 13.40|
| -0.315+0.2  |                         | 52.60| 30.10 | 0.033| 1.64  | 0.42| 13.50|
| -0.2+0    |                          | 51.00| 29.20 | 0.047| 1.87  | 0.46| 13.70|

**Figure 1. Particle-Size Composition of the Fine Class of Kaolin Samples**

The particle-size composition (Figure 1) of heat-treated kaolin indicates that the reduction intensity of the interplanar distance depends on the heating type and conditions. The maximum particle coagulation effect was recorded in convective heating of kaolin in a muffle electric furnace. Unlike convective heating, microwave heating did not contribute to the intensive formation of aggregates, but allowed obtaining a material with a modified microstructure and a high adsorption capacity. Based on the studies, it may be concluded that microwave treatment of materials is advisable at the metallurgical processing stage in order to increase its chemical activity and reactivity, while convective treatment of clay materials may be used at the stage of ore preparation and concentration.
3. Obtaining metal powders from metal waste

In the manufacture of metal powders for the powder metallurgy and additive manufacturing, particle-size distribution analysis is also of great practical importance. In particular, the content of fine classes (below 10 μm) of over 10% affects part of the production processes, such as the supply of material to the sintering chamber or mold. Fine dispersed powders are prone to agglomeration and sticking, which affects the processing properties of the product. Additionally, high contents of the dust fraction may lead to spontaneous combustion of the powder and must be carefully regulated at powder production facilities in order to avoid fire hazards [8-10].

A series of experiments were carried out using air-electric classification to remove particles below 10 μm from metal powders. A powder was obtained by vibrational disintegration of nickel chips to the particle size of less than 125 μm. The studies were carried out using the laboratory unit, shown in the figure 2. The principle of operation of the unit is as follows. The metal powder studied was fed using vibrating feeder 1 to the tray of vibrating feeder 2. Then it was subjected to vibrational fluidization and fed into the separation zone. In the separation zone, when exposed to an electric field from a high-voltage electrode, fine particles were detached from the surface of the feeder tray and, due to the vacuum created by the vacuum pump, removed into the dust-collecting cyclone. The rest of the material was discharged from the vibrating feeder into an appropriate container. The purpose of these experiments was to identify the influence of the main parameters of the unit on the classification efficiency.

![Figure 2. Laboratory unit of air-electric classification](image)

Figure 2. Laboratory unit of air-electric classification 1 – high voltage unit; 2 – separation unit; 3 – feeder; 4 – vibrofluidization unit; 5 – separation products containers.

In the first series of experiments, the effect of the voltage applied to the high-voltage electrode was investigated. As a result, the dependence shown in Figure 3 was obtained.

In the second series of the experiments, the effect of vacuum in the working area was investigated. The vacuum value was changed by changing the suction power of the vacuum pump. The dependence obtained (see Figure 4), indicates the power as a percentage of the rated value at 50 Hz.
The resulting graphs demonstrate that, with higher voltages at the separator, the recovery of the fine class of less than 10 μm also increases. With increasing pump power, the recovery characteristic becomes wave-like. In this case, the amount of powder of the required size class discharged with the waste fraction is also worth considering.

4. Conclusion
The results obtained allow making the following conclusions.
- The laser-based particle-size analysis method allows researching various samples prone to conglomeration and adhesion. Ultrasonic mixing does not harm the material analyzed and promotes uniform distribution of the sample during analysis.
- The rapid nature of the method allows analyzing a large number of samples in a short time.
- The use of a Microsizer 201C unit in the analysis of air-electric classification products for metal powders allowed obtaining a more complete picture of the particle-size distribution of the separation products and establishing the best parameters for the process, which in turn will facilitate implementation of this technology in the industry.
- The application of the laser-based particle-size analysis method to layered silicate samples, which are highly dispersed and prone to swelling and sticking, has greatly simplified and accelerated the process of establishing the particle size of these materials. The particle-size analysis results indicate lower contents of the fine class in thermally modified materials, which allows selecting the most preferable heating conditions for each material with the aim of reducing the negative effects of layered silicates on the main processes in ore preparation, concentration, chemical and metallurgical operations.

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