Application of a vision systems for assessment of particle size and shape for mineral crushing products

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Abstract. Morphological properties of mineral particles, in particular their size and shape, play a fundamental role in the course of mineral raw materials processing. They affect the efficiency of grain classification and downstream beneficiation operations. The article presents the results of the size and shape distribution for the particles after the comminution process. The measurements were made with using a vision system with dynamic image analysis. The aim of investigations was to evaluate the applicability of this technique for control of the particle size of raw material products crushed in various laboratory crushing devices.

1. Introduction
The size and shape of particles are the basic geometric parameters used in description of mineral resources. The sieve analysis and the qualitative description of the shape of particles along with the determination of their shape made on the slotted screen, are the most commonly used methods for determination the particle size and shape of mineral raw materials. In recent years, however, there has been observed a rapid development of vision methods based on computerized image analysis of particles. The first particle analyzers using simple image processing algorithms were developed in 1985 [1], and the first advanced methods of quantitative analysis applied in basic research based on image analysis were proposed by Brawman and Sukumaran [2,3].

Currently, there are many measurement technologies that combine high quality imaging equipment with artificial intelligence software for determination the size and shape of particles with using the vision technology in laboratory and industrial conditions, i.e. QICPIC, Analysette 28 ImageSizer, CAMSIZER, Split-Online, VisioRock, Plant Vision, WipFrag Momentum. In mineral processing operational practice it is essential the knowledge concerning the properties of material, especially particle size, shape, useful mineral content, particle size composition, mineralogical composition etc., because on the basis of this information it is possible to adjust and optimize both crushing and grinding operations [4,5,6], as well as downstream beneficiation processes [7], in terms of their more effective course. The problem is significant for both for mineral aggregates production and ore beneficiation.

2. Materials and methods
The main aim of investigations presented in the paper was to verify the possibility of application a dynamic image analysis for control the particle size distribution of dolomite after crushing process and to determine the impact of the crushing device on geometric properties of the particle. The research programme included the stage of raw material preparation through crushing and screen classification as well as morphological analysis of individual particles in crushing products by means of the vision analysis system for particle size and shape. The scheme of investigations was presented in figure 1.
The samples of the feed material were crushed below 2 mm in various laboratory crushers in a closed circuit with classification. Fine particles below 0.2 mm were removed and the particle size class from 0.2 to 2 mm was obtained for further geometrical tests of particles.

The vision dynamic image analysis technique was used for evaluation of the shape of particles. The shape factor Aspect Ratio, defined as the ratio of the minimum to the maximum particle diameter according to Feret (k = d_{Fmin}/d_{Fmax}), was determined, as well as the particle size distribution of the crushing products according to the minimum Feret diameter. The crushing process was carried out in laboratory crushers utilizing following forces affecting the feed material:

- an impact force caused by movable working elements of the crusher mounted on the shaft,
- an impact force caused by vibration of the working elements of crusher. The reduction in size of feed takes part in several stages by gradually detaching the outer layers of the particle,
- centrifugal force generated by the vertically rotating rotor. This force gives the particle a high speed, and thus the kinetic energy, which is spent on the destruction of its structure during a collision with a stationary plate,
- compression force derived from the pressure of the working elements of the device.

The structure, principle of operation and the distribution of forces acting on particles determine the main classifications of the crushing devices. This is an issue widely described in literature [8,9,10].

The Analysette 28 ImageSizer vision analyzer was used for measurement of geometric properties of particles [11]. The measurement in this device is carried out with the dry technique in the particle size range from 0.02 mm to 20 mm. The analyzer consists of a vibratory feeder, a camera that records an image of particle and a source of strobe light (figure 2). The principle of measurement is based on the dynamic image analysis (DIA) method. The camera intercepts the image of particles moving in a measuring cell, and then the computer software analyzes the shape and size of each particle separately. Ten thousand of images per minute, approximately, is analyzed. An exemplary report is presented in figure 3.
Figure 2. Construction and principle of operation of a dynamic particle size and shape analyzer: 1) camera 2) measurement volume, 3) light source, 4) feeder [11].

Figure 3. Exemplary report obtained from the Analysette 28 ImageSizer.

3. Analysis of results

In order to compare the operation of individual crushing devices in terms of generation of elongated (irregular) particles, the results were grouped and averaged. Figure 4 presents the average values of elongation coefficients in the tested samples obtained for different crushers, while in table 1 the distribution of the coefficient k is shown for the distribution values 10, 50 and 90%, respectively. The analysis of the following results indicates that the more elongated particles have been generated in centrifugal crusher (lower value of k index), while more the centric ones – in impact crusher (figure 4). The differences in both cases, however, are not very significant. Generally, the particles after the crushing process show a more circular shape.

Analyzing the particle size distribution of crushing products expressed by the diameters of characteristic particles d_{10}, d_{50} and d_{90}, as well as an average diameter (d_{mean}) of the particle (arithmetic average) according to Feret, it can be seen that for fine particles (d_{10}) the most efficient operation was achieved for the crusher that utilizes the pressure as the destructive force. For coarse particles (d_{90}), in turn, an impact crusher appeared to be more effective (table 2). It confirms operational practice, because crushing of fines by impact forces is of a lower efficiency due to the small inertia forces acting on these particles.
Figure 4. Average values of shape index for crushed particles determined by means of dynamic image analysis (DIA) method.

Table 1. Distribution of shape index values in crushing products for individual crushing devices.

| Crusher     | Aspect ratio |
|-------------|--------------|
|             | $k_{10}$ | $k_{50}$ | $k_{99}$ |
| impact      | 0.648     | 0.818   | 0.925   |
| vibrating   | 0.642     | 0.813   | 0.920   |
| centrifugal | 0.639     | 0.813   | 0.926   |
| pressure    | 0.641     | 0.813   | 0.923   |

Table 2. Distribution of particle size in crushing products for individual crushing devices.

| Crusher     | Population | $d_{10}$ (µm) | $d_{50}$ (µm) | $d_{90}$ (µm) | $d_{\text{mean}}$ (µm) |
|-------------|------------|---------------|---------------|---------------|-------------------------|
| impact      | 9680       | 352           | 845           | 1593          | 658                     |
| vibrating   | 11195      | 355           | 989           | 1861          | 707                     |
| centrifugal | 6118       | 409           | 1068          | 2148          | 819                     |
| pressure    | 13388      | 317           | 823           | 1695          | 617                     |

4. Conclusions

Results of investigations over geometrical properties of particles for the given type of mineral raw material with using of a video system utilizing the dynamic image analysis technique confirm the usefulness of this measurement method in evaluation of the crushing devices operation and control of the size and shape of mineral particles.

Analysis of the particle shape expressed by the elongation ratio $k$ (Aspect Ratio) showed no significant differences in the shape of the product particles obtained in the tested crushing devices. The most regular shapes were obtained in an impact crusher, while the more elongated particles were
produced in a centrifugal crusher. Particles of the dolomite (tested material) after the crushing process are rather of a centric shape ($k>0.5$) than the elongated one ($k<0.5$).

Analysis of the particle size distribution of crushing products expressed by the average minimum diameter according to Feret indicates that the finest product was obtained in a crusher that utilizes pressure force coming from the working elements, while the coarsest one was produced in impact crusher, where centrifugal crushing forces predominate.

The research topic is important and interesting, and definitely worth continuing with application to other rocks or minerals.

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