EFFECT OF CHANGING JAW CRUSHER PARAMETERS ON GRANULOMETRY AND STATIC ANGLE OF REPOSE OF CRUSHED AGGREGATE

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ABSTRACT

Crushing is one of the important technological operations in the reduction of oversized pieces of utility material. It is of great importance in mineral processing, where the excavated material is processed into a final product or for the purpose of further treatment. There are several different types of industrial crushers. In practice, it is usually not possible to process the raw material into the desired product using only one machine; it is usually necessary to use several crushers, often in combination of two or more construction types. When the material is crushed, its grain composition and flow properties change. The change in these properties affects the way the material is handled, in particular its transport and storage. A systematic approach to the influence of crusher parameter settings on the flowability and granulometry of the resulting product has not yet been published. In this study, the effect of laboratory jaw crusher parameter settings on the granulometry and static angle of repose of different types of crushed aggregates was investigated. It was observed that changing the setting of the crusher gap width changes the ratio of dust and coarser particles of the crushed material, and this ratio has a significant effect on the changes in the static angle of repose of this material.

Keywords: Angle of repose; Comminution; Crushing; Granulometry; Jaw crusher.

1 INTRODUCTION

There is a large amount of minerals in nature that can be used by man in many industries. However, most minerals are found in nature in a state that does not meet the requirements of the industry and therefore must first be processed. Mineral processing means that the physical properties of these raw materials, or even their chemical composition, are changed by various technological operations [1,2].

One of the most important technological processes in mineral processing is comminution (crushing and grinding). The purpose of this process is to reduce the grain size of the raw material to a size that is suitable for the technological procedures for further use of the raw material [3,4].

During the comminution process, the individual particles (grains) of the material are reduced by external mechanical forces. Depending on the type of mechanical stress, there are several methods of comminution – compression, impaction, shearing, bending and grinding [4]. This paper focuses on compression crushing (crushing by pressure). For this type of crushing, jaw crushers are used. In a jaw crusher, the grains are stressed by mechanical pressure between two solid surfaces, called jaws [5,6]. The compressive strength of a grain is significantly higher than its tensile strength, which is only about 4 to 10 % of its compressive strength. The grain

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shortens in the direction of the applied force as a result of its elasticity. Inside the grain, tensile stresses are generated in a plane perpendicular to the direction of the applied force. Subsequently, the grain breaks because of its low tensile strength. After the breakage, the stress is transferred to the edges of the grain where bending stresses are generated. The bending stress will cause the grain to break in its peripheral parts, while further breakdown of the grain into very small parts will occur in the areas that continue to be stressed by compression [1,4].

In practice, it is usually a polydisperse mixture of grains that enters the crushing machines. The size of the largest grain must not be larger than the dimensions of the crusher gape. However, even the most efficient crushing machines do not guarantee that the size of all grains passing through the crusher will be reduced [1]. The efficiency of the crusher is affected by the input fragmentation, the disintegration of the material, the granulometry and shape of the grains and also by the reduction ratio, which can be defined as the ratio of the size of the sieves through which 80 % of the feed and product passes or as the ratio of the maximum grain size before and after comminution [4,7].

Granulometry (particle size distribution) of bulk materials can be measured using a variety of devices and methods. For materials that have a common grain size (e.g. sand or gravel), a sieve analysis is performed in which the percentage of material that passes through a sieve of a given mesh size is determined [7,8]. For very fine powders and suspensions, methods based on light or laser scattering or changes in electrical conductivity are now mainly used. The state-of-the-art method is dynamic image analysis, which, using CCD cameras, provides accurate information about the particle size distribution in a short time [9].

In terms of flowability of bulk materials, the following mechanical-physical properties are of main importance: angle of repose, the internal friction angle and the wall (external) friction angle. Angle of repose is the angle of inclination of a heap of a free-poured material, with respect to the horizontal. A distinction is made between static angle of repose (the material is poured onto a stationary surface) and dynamic angle of repose (the material is poured onto a moving surface, e.g. a conveyor belt) [9,10]. The internal friction angle characterizes the stress state inside the bulk solid. It can be interpreted as a measure of the internal work loss when particles and layers of the bulk mass move relative to each other. The angle of internal friction is measured by means of shear testers. Two basic types of shear testers are distinguished – the linear shear tester (Jenike type) and the rotary shear tester (Schulze type) [11,12]. The wall friction angle characterizes the friction between the bulk material and the solid surface. It is usually measured, like the internal friction angle, by shear testers [13].

The study deals with the crushing of natural aggregates from different localities in the Czech Republic. A systematic approach to the influence of the setting of the crusher parameters on the changes in the flow properties and granulometry of the resulting product has not been published so far. This paper focuses on the changes in grain composition and static angle of repose of different types of natural aggregates after crushing in a jaw crusher at different settings of the crushing gap width. The samples were first crushed in a laboratory jaw crusher and then characterized and analyzed for granulometry and static angle of repose.

2 MATERIALS AND METHODS

For the study, three samples of natural aggregate fraction 16–32 mm originating from three different localities in the Czech Republic were selected: a sample of shale from the Lhotka mine (sample 1), a sample of greywacke from the Jakubčovice quarry (sample 2) and a sample of gneiss from the Bystřec quarry (sample 3), see Table 1.

Table 1. *Samples used in this study and their places of origin*

Sample no.	Locality name	GPS of the locality	Rock type
1	Lhotka	49.8092078N, 17.7368656E	shale
2	Jakubčovice	49.7011503N, 17.7796356E	greywacke
3	Bystřec	50.0058364N, 16.6006164E	gneiss

To carry out the experimental work, the following technologies and devices were used: a BCD-mini jaw crusher (BRIO Hranice spol. s r.o., Czech Republic), a Retsch CAMSIZER optical granulometer (Retsch Technology GmbH, Germany) and a static angle of repose measuring device consisting of a LABORETTE24 vibratory feeder (Fritsch GmbH, Germany) and a circular measuring bowl. Images for the evaluation of static angle of repose and grain geometry were captured using a 1.3Mpx USB microscope camera (Conrad Electronic SE, Germany) and stored on a computer via eScope software (Conrad Electronic SE, Germany).

The BCD-mini is a Blake type jaw crusher designed for laboratory purposes. The crushing mechanism of the BCD-mini consists of an adjustable jaw mounted on a pin and a movable jaw with an eccentric shaft. The movement of the movable jaw is provided by an electric motor and belt transmission. The surface of both jaws is smooth. The whole device is mounted on a solid welded frame, in the upper part of which a feed hopper is located. The crushed material falls into a collecting drawer at the bottom of the frame. The width of the gap between the jaws at the discharge outlet is adjusted manually using a lever located on the front of the frame. The setting of the gap width ranges from 0 to 9 mm.

Retsch CAMSIZER (see Figure 1) is an opto-electronic device used to measure grain size and shape of bulk materials in the size range of 30 um to 30 mm. The device is equipped with a vibrating feeder, a planar light source, two CCD cameras for particle measurement and a computer. The evaluation of the measurements is carried out by the CAMSIZER analysis software.

The device on which the static angle of repose was measured consists of a vibratory feeder that feeds material onto a circular measuring bowl. The resulting pile of material is captured by the USB microscope camera and the images are stored in a computer by means of eScope software. Each pile is photographed from eight positions and the angle of inclination of the pile with respect to the horizontal surface of the bowl is then read from these images, see Figure 1. The resulting static angle of repose is determined as the average of these readings.

Figure 1. *The Retsch CAMSIZER optical granulometer (left) and an example of static angle of repose evaluation (right)*

Eight subsamples were taken from each of the three aggregate samples. Each subsample consisted of about 2,5 kg of the aggregate sample. Each of these subsamples was subjected to crushing in a laboratory BCD-mini jaw crusher at different settings of the width of the gap between the jaws at the crusher outlet, ranging from 1 to 8 mm. The crushed material was then analyzed for particle size distribution and static angle of repose. Before the measurement each subsample was mixed so that all fractions of the subsample were equally represented, then the amount needed for the measure was taken with a scoop. To evaluate the measured data, statistical evaluation methods were used. For each material, the following values were investigated: dust particle content <200 um (%), dust and fine particle content <500 um (%), particle content of a size corresponding to the gap width setting of the crusher (a kind of theoretical maximum grain size after crushing, d_{thmax}) within a range of $d_{thmax} \pm 10$ % and coarse particle content $>1.5d_{thmax}$ (%). The resulting static angle of repose of the crushed materials was determined as the arithmetic mean of the values read from the images of the free-poured material piles.

3 RESULTS AND DISCUSSION

The individual results of the granulometric analysis have been evaluated graphically, see Figures 2 and 3. For all three materials it can be noted that the highest amount of dust and fine particles was achieved when crushing to the finest fraction, i.e. at a 1 mm crusher gap width. Furthermore, it can be observed that in all cases the proportion of dust and fines decreases with increasing width of the gap and reaches a minimum when crushed to the coarsest fraction. This is probably due to the fact that in fine crushing the smaller particles are ground between the coarser grains and as the gap widens this effect disappears. In doing so, noticeable differences between the different materials can be observed.

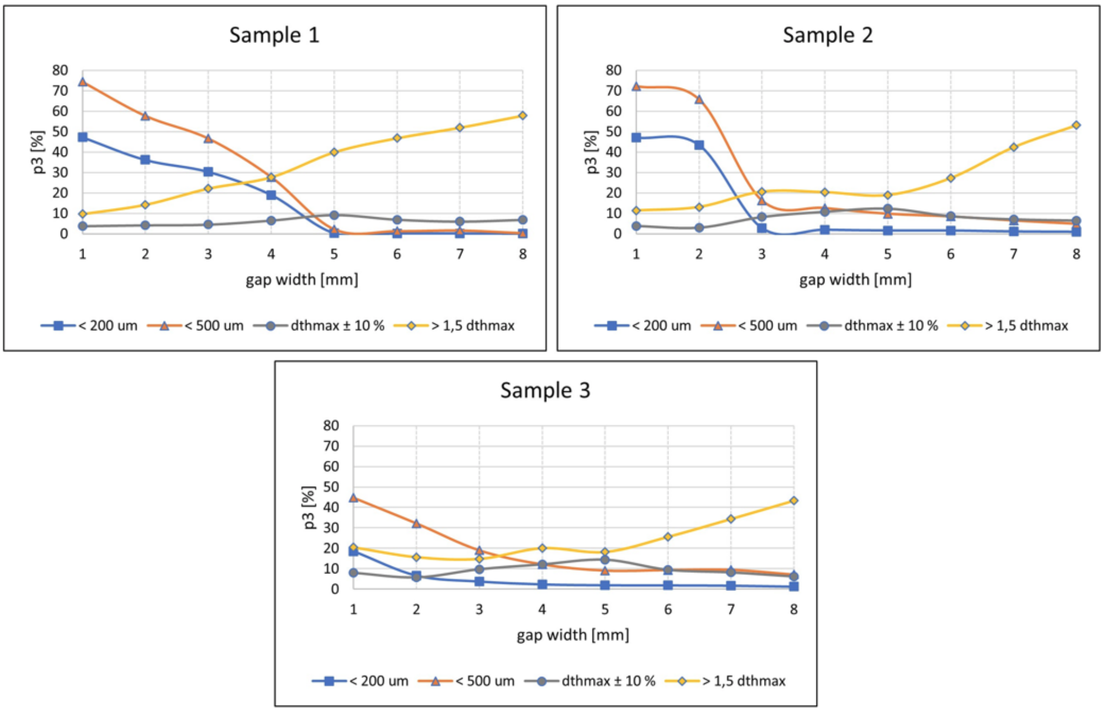

Figure 2. *Results of granulometric analysis of individual samples depending on the crusher gap width (sample 1 – Lhotka; sample 2 – Jakubčovice; sample 3 – Bystřec)*

Sample 1 (Lhotka) shows a relatively high dust content even when crushed to 4 mm. When crushed to 5 mm or more, the dust and fine content is already minimal. The dustiness of sample 2 (Jakubčovice) is roughly comparable to sample 1 when crushed to 1 and 2 mm, but drops steeply at a gap width of 3 mm and does not vary significantly further, while the content of particles up to 200 um is negligible. The dust content of sample 3 (Bystřec) is significantly lower than that of the previous two samples. The content of fines and dust particles decreases significantly until crushing to 4 mm, at which point the content is minimal and does not vary significantly further. As in the case of sample 2, particles of 200–500 um prevail. The absolute highest dust content (74.42 % <200 um) was observed for sample 1 when crushed to 1 mm. For all samples, dustiness was very low (<2% of particles below 200 um) when crushed to 5 mm or more. The differences observed for each sample are apparently due to the different types of material, its petrographic composition and different geological evolution [14].

Furthermore, the content of grains with a size corresponding to the width of the crushing gap (i.e. a kind of theoretical maximum grain size of the crushing product, d_{thmax}) was investigated within a range of $d_{thmax} \pm 10$ %. For all samples it can be observed that the content of these grains increases gradually with increasing coarseness of crushing until crushing to 5 mm, where it reaches a maximum, and then gently decreases. It may be assumed that, when crushing to 5 mm, the gap is wide enough to prevent grinding of the finer particles between the coarser grains, and at the same time narrow enough to prevent excessive dropping of significantly coarser grains without being crushed.

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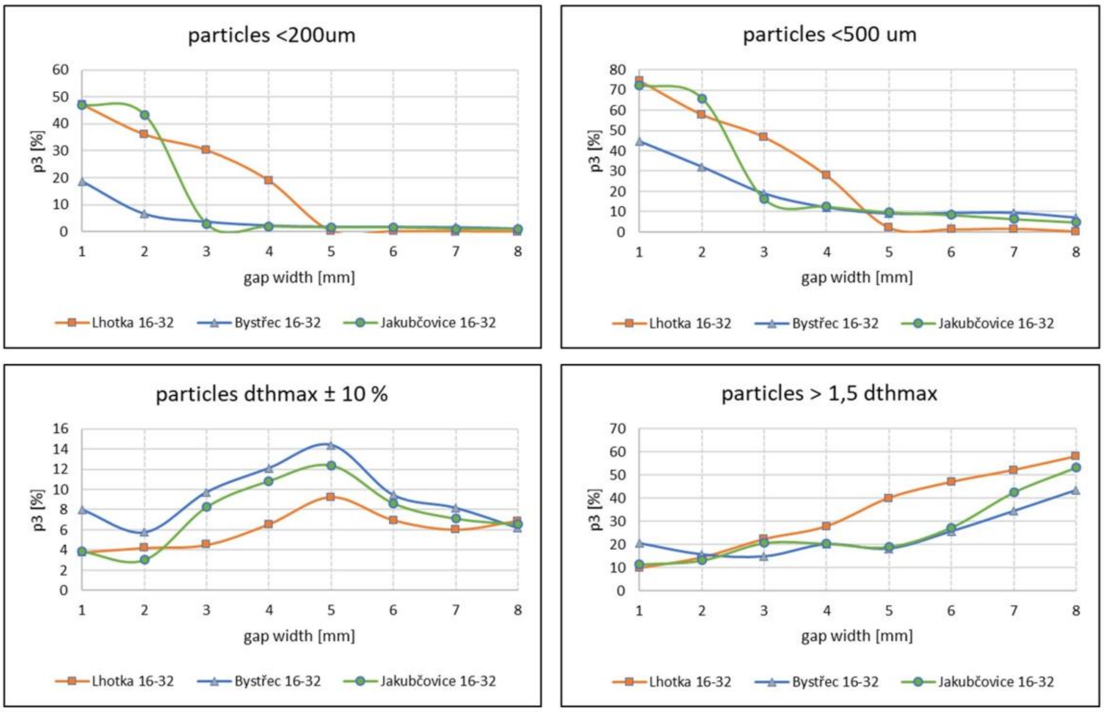

Figure 3. *Comparison of granulometric properties of the Lhotka, Bystřec and Jakubčovice samples depending on the applied setting of the crusher gap width*

The content of grains significantly larger than the theoretical maximum grain size d_{thmax} was also evaluated. It was found that the content of particles larger than 1.5 times the d_{thmax} for all compared samples increases (with slight fluctuations) with increasing width of the crushing gap and reaches a maximum value at 8 mm crushing. For the Lhotka sample this increase is almost linear. The occurrence of oversized particles is due to the formation of chips or plates of material during crushing, the length of which is significantly greater than the width of the crushing gap. It was observed that shale of the Lhotka sample is the most susceptible to the formation of chips, while gneiss of the Bystřec sample is the least susceptible, see Figure 4.

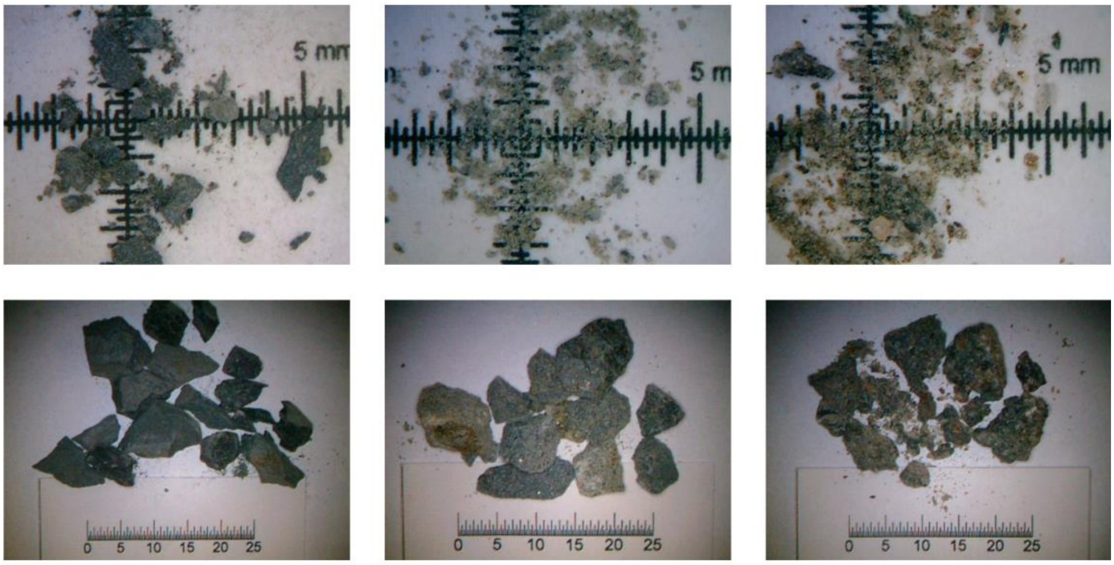

Figure 4. *Top: typical grain shapes of fine fraction (1 mm crushing); Bottom: coarse fraction (8 mm crushing); from left to right: the Lhotka, Jakubčovice and Bystřec samples*

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The static angle of repose for all three samples initially decreases with increasing crushing gap width, see Figure 5. For the Lhotka and Bystřec samples it reaches a minimum when crushed to 4 mm, for the Jakubčovice sample it reaches a minimum when crushed to 5 mm. With further gap widening it increases again. The value of the angle of repose is supposed to be related to the content of dust and fine particles in proportion to coarse grains. In fine crushing, the resulting fraction is significantly dominated by particles smaller than 500 um and the coarse particle content is minimal. The resulting material has a character of a cohesive powder. Materials of this type are relatively easy to consolidate, even under lower pressures or humidity [15]. The degree of this compaction affects the flowability and the static angle of repose – as the material becomes more consolidated, its flowability decreases and the angle of repose increases. When crushing to coarser fractions, the proportion of fine particles decreases and the coarse grain content increases. The spaces between the coarser grains are filled with finer grain fractions. The content of different particle sizes reduces the ability of the material to consolidate, as the coarse particles 'slide' over the layers of finer fractions. The angle of repose decreases and the material shows better flow properties. In the case of crushing to coarse fractions (with a gap width of more than 5 mm), the resulting product consists almost exclusively of coarser grains. The content of dust and fine particles is negligible in relation to the coarse-grained fraction. It can be assumed that the particles wedge together by their sharp edges that are increasingly less 'covered' by the fine-grained fractions. Thus, there is no disintegration of the heap due to the slippage of coarser grains over layers of finer particles. This fact causes the static angle of repose to newly increase.

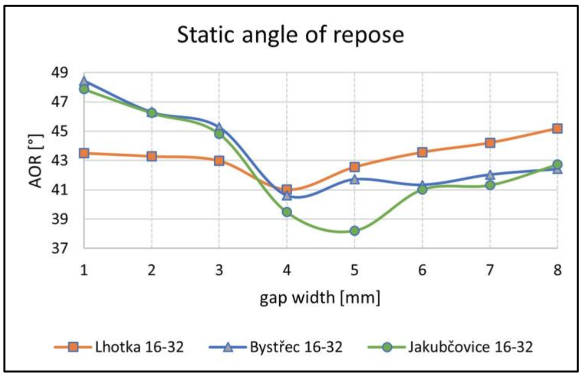

Figure 5. *Comparison of the static angle of repose (AOR [°]) of individual samples at different gap width settings*

4 CONCLUSION

The study focuses on the change in grain size distribution and static angle of repose of three different types of aggregates after crushing in a BCD-mini jaw crusher at different settings of the crusher gap width. Eight samples were taken from each aggregate type and crushed at different crusher gap width settings, ranging from 1 to 8 mm. The crushed material was then analysed using a Retsch CAMSIZER optical granulometer. The values evaluated for each aggregate sample were dust particle content (<200 um), dust and fines content (<500 um), particle content of a size corresponding to a crusher gap width setting (d_{thmax} ± 10 %) and coarse particle content (>1.5 d_{thmax}). For all samples, static angle of repose was also measured.

The results of the granulometric analysis were evaluated graphically. It can be concluded that all three materials show the highest amount of dust and fine particles when crushed at a 1 mm crusher gap width. As the crusher gap widens, the content of dust and fine particles gradually decreases. Another parameter evaluated was the theoretical maximum grain size of the crushing product d_{thmax}, which for all samples with small variations increases with increasing the gap width up to 5 mm, where it reaches a maximum, and then gradually decreases. It was also found that the content of particles larger than 1.5 times d_{thmax} for all the samples compared increases with increasing crusher gap width and reaches a maximum at 8 mm crushing. The results of the static angle of repose measurements show that for all the samples compared, the static angle of repose first decreases with decreasing dust particle content and then increases again with increasing coarse grain content when crushing to coarser fractions.

In this study, the effect of crushing parameters of different types of natural aggregates on the properties of the final product was investigated. The aim of further research will be to study changes in these properties for materials of the same type from different locations in order to optimise the crushing processes with respect to the specific properties of aggregates originating from specific locations.

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