Analysis of the Particle Size Distribution of Products Crushing Shale and Dolomite Crushing by Compression of Single Irregular Particles

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Abstract

The paper presents the results of compression crushing tests of single particles for two lithological types of copper ore: dolomite and shale. The breakage test for single irregular particles were performed with using a hydraulic press device. The authors prepared five particle size fractions of each material, within ranges: 16–18 mm, 18–20 mm, 20–25 mm, 25–31,5 mm and 31–45 mm. The particle size distribution function of single-particle breakage test was calculated separately for each size fraction of dolomite and shale. In addition, the cumulative particle size distribution function for five size fractions for both materials was presented. The curves of the particle size distribution were approximated by the three-parameter function, which parameters depend on the particle strength and material type. The three-parameter function approximating agrees well with the particle size distribution of irregular dolomite and shale particles.

Keywords: particle size distribution, three-parameter function, dolomite, shale

Introduction

There is no uniform basic function characterizing the results of crushing and grinding processes and the well-known particle size distribution functions are limited in application. This limitation is caused by the process of a material formation, a mining technology or a crushing method and others. These functions have usually two parameters having constant values and being determined empirically. In these investigations, curves of the particle size distribution were approximated by using of a three-parameter function, which parameters depend on the particle strength and material type. The function was proposed by the scientists of AGH University of Science and Technology and the first time the function was applied for approximation of particle size distribution of crushing product for single particles of limestone and porphyry, comminuted by slow compression (Brożek, 1993; 1994; 1995; 1996; 1996; 2003a,b,c; Nad and other 2012). The three-parameters distribution function can be expressed by formula:

$$\Phi(x)=ax^{b}\,e^{kx} \qquad (1)$$

where: x is parameter: x=d/D, while d is the particle size of crushing product and D is the particle size of feed (the particle size measured by means of its screen diameter, i.e. the linear dimension of particle obtained from the sieve analysis); a,b,k empirical distribution parameters depending on the strength of material and material type.

The same distribution function was used for approximation the particle size distribution of crushing product of single irregular particles of dolomite (Nad and Brozek, 2015). The model fit well with empirical data.

Experimental

Tests were carried out on samples of copper ore from the Rudna copper mine. Polish copper ores are the mixtures of three lithological types: dolomite, sandstone and shale. The experiments were performed on particles of dolomite and shale. The sample was taken from the ore crushed in hammer crusher. Next the sieve analysis, for sieve meshes: 16 mm, 18 mm, 20 mm, 25 mm, 31.5 mm and 45 mm, was performed. After the screening, there were prepared five size fractions for two lithological type of copper ore. The range of each size fraction was: 16–18 mm, 18–20 mm, 20–25 mm, 25–31,5 mm and 31–45 mm. In each fraction the weighted average particle size Dmax was calculated. The flat and elongated particles were rejected from the population. In each fraction of particle size were randomly selected about 100 particles.

Individual particles, of all the above-mentioned size fractions, were slowly compressed at a constant rate, until the first fracture across the particle occurred. The value of the destruction force of each particle was recorded. Single–particle breakage tests were performed with using the compression-testing machine Toni Technik (universal testing strength machine with hydraulic drive). The load range was adjustable; 600; 300 and 120 kN. For the testing programme, the load force was 120 kN, with the accuracy of destructive force registration up to 0.1 kN. The particles obtained from each single-breakage tests were collected separately. The entire range of destructive stress value (0, Fmax) for each sample was divided into several narrow fractions (partitions). In each narrow destructive force fraction, a sieve analysis was made. To get the general form of the equation of the particle size distribution function, the cumulative yield from the each narrow destructive force fractions for particular size fraction was calculated.

The particle size distribution of dolomite and shale

Detailed analysis of particle size distribution for dolomite, was presented in paper (Nad and Brozek, 2015). In this article, the results of granulometric characteristics of crushing product obtained by slow compression of single shale particle, were focused. For each equation the residual deviation S_r and the coefficient non-linear correlation r_k, were determined. Below, the equations of particle size distribution curves, approximated by function (1) for five particle size fractions, were presented:

a) size fraction of shale: 31,5–45 mm, D = 38,25 mm

$$\Phi(x) = 1{,}916x^{0{,}186}\, e^{5{,}140\,x} \tag{2}$$

$S_r = 1{,}599$

$r_k = 0{,}997$

b) size fraction of shale: 25–31,5 mm, D = 28,25 mm

$$\Phi(x)=1{,}423x^{0{,}309}\, e^{5{,}254\,x} \tag{3}$$

$S_r = 3{,}938$

$r_k = 0{,}989$

c) size fraction of shale: 20–25 mm, D = 22,5 mm

$$\Phi(x)=4{,}100x^{0{,}430}\, e^{3{,}774\,x} \tag{4}$$

$S_r = 5{,}195$

$r_k = 0{,}986$

d) size fraction of shale: 18–20 mm, D = 19 mm

$$\Phi(x)=2{,}461x^{0{,}360}\, e^{3{,}976\,x} \tag{5}$$

$S_r = 2{,}373$

$r_k = 0{,}997$

e) size fraction of shale: 16–18 mm, D = 17 mm

$$\Phi(x)=6{,}001x^{0{,}368}\, e^{3{,}222\,x} \tag{6}$$

$S_r = 5{,}684$

$r_k = 0{,}986$

The non-linear correlation coefficient was calculated according to:

$$r_k = \sqrt{(1-\varphi^2)} \tag{7}$$

where

$$\phi = \frac{\sum_{i=1}^{n}\left(y_i - \hat{y}_i\right)^2}{\sum_{i=1}^{n}\left(y_i - y_{sr}\right)^2} \tag{8}$$

y_{sr} – average value $\Phi(x_i)$.

The residual deviation is:

$$S_r = \sqrt{\frac{\sum_{i=1}^{p_s}\left(\hat{O}_e(d_i) - \hat{O}_t(d_i)\right)^2}{p_s - 2}} \tag{9}$$

where:

p_s – the number of used sieves with mesh sizes d_i,

Φ_e – value of the empirical distribution,

Φ_t – the value of the distribution calculated with using the approximating equation for particle size d_i.

Figure 1 illustrates the combined curve of particle size distribution for five size fractions of shale. The theoretical function, calculated by the equation (10), is marked by continuous line. Empirical data for five size fraction of shale were fitted to theoretical distribution function, expressed by the formula (1). Calculations were performed with using the least squares method:

$$\Phi(x) = 3{,}556x^{0{,}438}\, e^{3{,}907\,x} \tag{10}$$

$S_r = 7{,}003$

$r_k = 0{,}962$

Comparing with dolomite, indices S_r and r_k have higher deviations for shale. It is caused through variability in the properties of material (concise dolomitic shale and poorly concise shale). In addition, the material has two lines of breakability – cleavage and grain – which make it possible to split the stone into thin sheets. Taken into account, that the investigation was performed for irregular particles, it can be concluded, that the calculated value of the indices S_r and r_k indicate that the three-parameters function approximates well the particle size distribution of shale.

Figure 2 presents the cumulative curve of particle size distribution for five size fractions of dolomite. Theoretical function, calculated by the equation (11), is a continuous line on the figure. The same calculations, carried out for the empirical data for five size fraction of dolomite particles, are shown below:

$$\Phi(x)=3{,}479x^{0{,}392}\, e^{3{,}788\,x} \tag{11}$$

$S_r = 4\,{,}287$

$r_k = 0{,}984$

Figure 3 shows the cumulative particle size distribution function of dolomite and shale together. It can be noticed, that empirical data obtained in sieve anal-

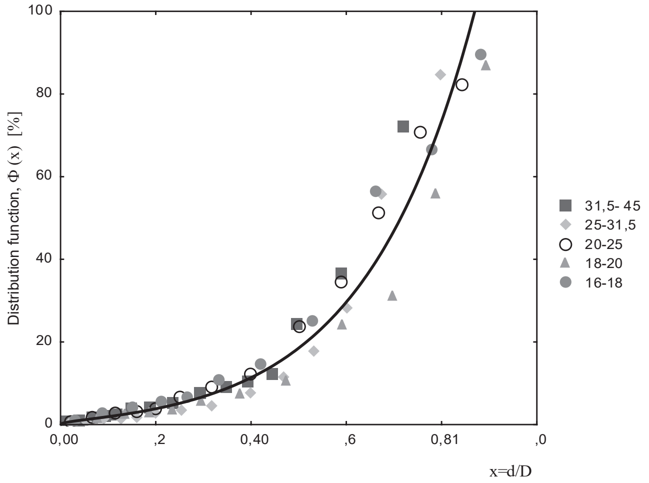

Fig. 1. Particle size distribution function of shale for five size fractions
Rys. 1. Zbiorowa krzywa składu ziarnowego produktu rozdrabniania ziaren łupka

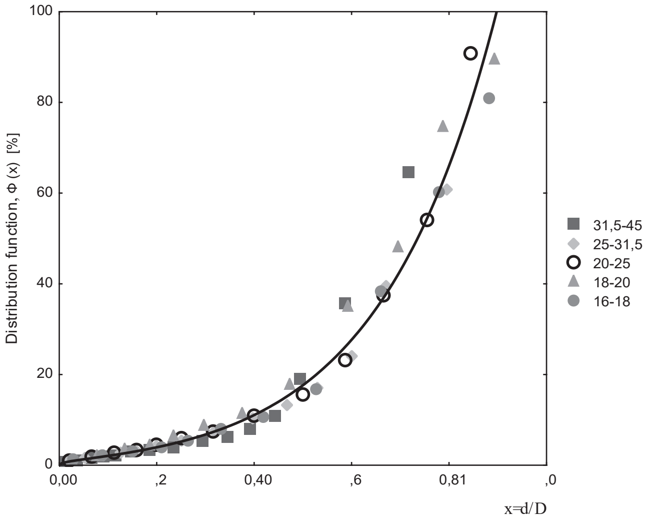

Fig. 2. The cumulative particle size distribution function of dolomite for five particle size fraction
Rys. 2. Zbiorowa krzywa składu ziarnowego produktu rozdrabniania ziaren dolomitu

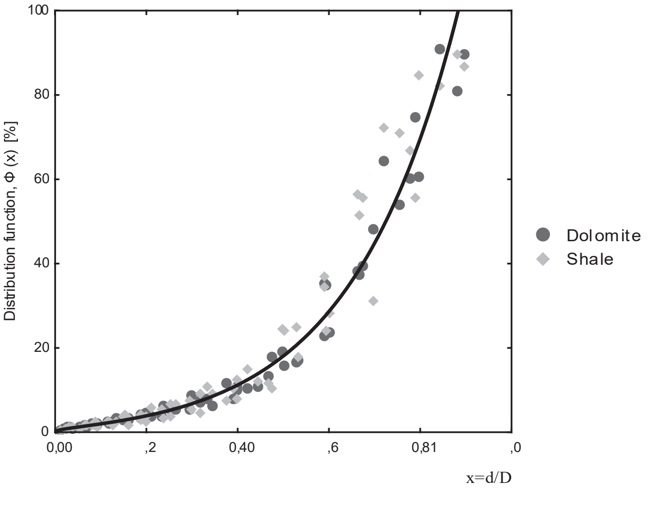

Fig. 3. The cumulative particle size distribution function of dolomite and shale
Rys. 3. Zbiorowa krzywa składu ziarnowego produktów rozdrabniania ziaren dolomitu i łupka

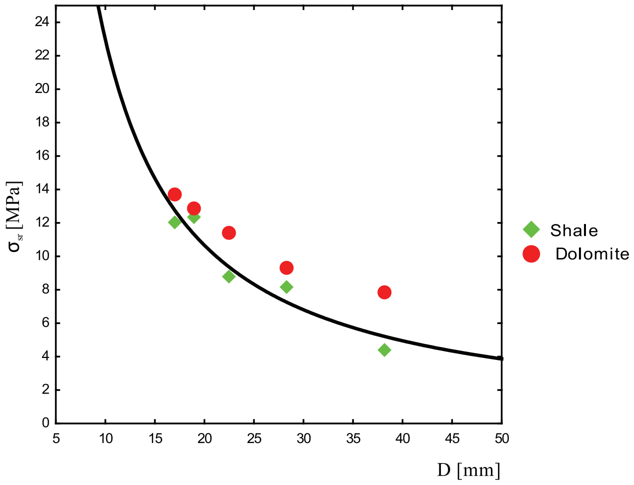

Fig 4. The relationship between an average tensile strength of dolomite and shale and the size of particles
Rys. 4. Zależność średniej wytrzymałości ziaren dolomitu i łupka od wielkości ziarna

yses for broken single irregular particles of shale and dolomite, are similar to each other. This is reflected in similar ratios in equations of particle size distribution functions for five size fractions of dolomite and shale:

$\Phi(x)=3{,}479x^{0{,}392}\, e^{3{,}788\,x}$ dolomite

$\Phi(x)=3{,}556x^{0{,}438}\, e^{3{,}907\,x}$ shale

The general equation for the two materials is:

$$\Phi(x)=3{,}517x^{0{,}414}\, e^{3{,}847\,x} \qquad (12)$$

$S_r = 5{,}732$

$r_k = 0{,}973$

The theoretical function, calculated by the equation (12), is presented with using the continuous line in Fig. 3.

Influence of the particle size to the mechanical properties of material were shown in figure 4. Decreasing in average particle size for both materials results in increasing an average strength of single particle. This is consistent with a statistical strength theory, according to which an increase in particle volume causes an increased probability of micro-cracks generation, providing the particle breakage.

Conclusions

The conducted research indicates that the distribution model fits well with experimental data. The three-parameters function fits to empirical data obtained by sieve analysis of broken single irregular particles of shale and dolomite, regardless the size fraction of these materials. This proves the identity of single particle grinding mechanism by slow compression for shale and dolomite, regardless of the initial particle size. Comparing with the dolomite, particle size distribution indices S_r and r_k for shale have higher deviations. The reason can be explained by variability in material properties (concise dolomitic shale and poorly concise shale).

On the basis of high values of model fitting indices and after analysis of Fig. 8, it can be accepted a hypothesis that the materials with similar distribution strength will have a similar particle size distribution for crushing products, which can be described by equation (1) with quite high accuracy.

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Analiza rozkładu produktów rozdrabniania łupka i dolomitu w próbach jednoosiowego ściskania ziaren nieregularnych

Artykuł przedstawia wyniki badań rozdrabniania pojedynczych ziaren dwóch typów litologicznych rud miedzi: łupka i dolomitu. Materiał został rozdrobniony w prasie hydraulicznej poprzez powolne jednoosiowe ściskanie pojedynczych nieregularnych ziaren. Do testów zostały przygotowane pięć klas ziarnowych każdego surowca: 16–18 mm, 18–20 mm, 20–25 mm, 25–31,5 mm, 31,5–40 mm. Wyliczono równania krzywych składu ziarnowego oddzielnie dla każdej klasy ziarnowej dolomitu i łupka oraz podano jedno równanie wspólne dla pięciu klas każdego typu litologicznego rudy miedzi. Do aproksymacji krzywych składu ziarnowego został użyty rozkład trójparametrowy, parametry którego zależą od wytrzymałości ziaren na rozciąganie i rodzaju materiału. W wyniku aproksymacji uzyskano wysokie wskaźniki dopasowania modelu do rozkładu.

Słowa kluczowe: krzywe składu ziarnowego, rozkład trójparametrowy, dolomit, łupek