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THE TENSILE STRENGTH PROPERTIES OF LITHOLOGICAL VARIETY OF POLISH COPPER ORES[***]

1. Inroduction

Polish copper ores are exploited from the Legnicko-Glowacki copper district and this raw material is the feed for mineral plants. Polish copper ores are the mixtures of three lithological types: carbonate, sandstone and shale. The carbonate type of copper ore is represented by dolomite mineral and shale type — by slate mineral. Each of them features by different values of physic-mechanical and chemicals, what influences on the enrichment process [2].

TABLE 1

Mean lithological composition of output delivered to O/ZWR

Rejon		**Piaskowiec, [%]**	**Węglany, [%]**	**Łupek, [%]**
Lubin	I ciąg	39,3	52,90	7,8
	II ciąg	72,0	22,0	6,0
Rudna	strona A	70,9	21,5	7,6
	strona B	42,9	44,7	12,4
Polkowice		13,5	72,6	13,9

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Table 1 shows that most amount of raw output is sandstone ore, the second place there is a carbonate ore and the least is the ore shale.

2. Theoretical part

The process of size reduction of raw materials depends of many factors, such as the type of crusher, method of crushing, strength properties of the raw material as well as the type and properties of the medium in which the process of crushing take place. Mechanical destruction of the particle size is the process of destruction the internal structure of the grain regardless on the way of crushing. Considering the structure of the crystal lattice, its destruction leads to the rupture of atomic bonds in the crystal, whose strength dependents on the type of bonds. Therefore, the theoretical tensile strength of the particle should be conditioned by its crystal structure and the nature of atomic bonds in the crystal and is expressed as an approximate model [2]:

$$\sigma_t = \sqrt{\frac{\gamma E}{c}} \tag{1}$$

where:

γ — surface energy,
E — Young modulus,
c — translational lattice constant.

But the practical experience shows that the actual strength of solids in the stretching is 10^2–10^4 times smaller than the theoretical strength resulting from the rupture of atomic bonds in a perfect crystal. The actual mechanical properties of solids are determined by the presence of congenital defects in the structure and microscopic flaws in the bulk material around which concentrate the stress under the applied load crushing. In the presence of mechanical stress, due to local slip, next microcracks may be formed. The presence of these microcracks makes that material is several times less resistant for destruction than theoretically. The hypothesis of the existence of innate cracks was proposed by Griffith (1921) [6], who gave the formula for the strength of a solid, weakened by the presence of lenticular micro cracks of length $2l$:

$$\sigma_t = \sqrt{\frac{2\gamma E}{\pi l}} \tag{2}$$

Both number of cracks in the particle and their length are random variables. Since the strength of the particle depends on the number and size of microcracks is also a random variable.

Cumulative probability distribution function of the strength distribution is given by Weibull's distribution function [7, 11]:

$$P(\sigma) = 1 - \exp\left[-r\left(\frac{\sigma}{\sigma_{sr}}\right)^m\right] \tag{3}$$

where:

m — Weibull's module,

σ_{sr} — average value of strength,

r — constant, which associated with the Weibull's module from the function of gamma:

$$r = \Gamma^m\left(1 + \frac{1}{m}\right) \tag{4}$$

The parameters m and σ_{sr} depends on the distribution of the size of cracks. It is determined experimentally from the results of individual particles crushing each time registering the destructive force at which rupture of the particle occurs.

The average tensile strength of particle is related to the Weibull's module. The experience shows [5] that character of this relationships dependents on the type of microcracks.

The theory of strength says that the uniaxial compression is accompanied by particle tensile stresses arising in a parallel surface to the direction of load application. Furthermore it is accompanied by particle shear stresses in surface inclined at certain angles to the direction of load application [9]. Numerous observations of the process of disintegration of irregular particles during compression [3, 4] led to the conclusion that the formation of large particles is caused by tensile stress, while small particles with flattened shapes are formed by shear stress in the neighborhood of the point where load is applied.

According to Clark, the compressive fragmentation process is initiated on the surface of particles by the compressive stresses arising in a neighborhood of the point where load is applied and propagated into the sample. In the middle of the particle it is done by the tensile stress arising and radiating from the center to the point of load application [1].

When the shear stress in cross is inclined by an angle ϑ from the direction of compressive applied load for the particle of regular shape (cube) it can be calculated by equation [9]:

$$\tau = \frac{\sigma(1+\nu)}{2}\sin 2\vartheta \tag{5}$$

where:

ν — Poisson's ratio,

σ — tensile stress.

The size of the resulting spatter cubic particles therefore depends on the angle ϑ and the distribution of shear strength in the volume of particle. By compression of the sample containing particles of the cubic shapes affects the distribution of tensile strength in the sample.

The large particles resulting from crushing, stemming from tensile stress at the time of the destruction of the original particles usually two fragments of unequal sizes are formed. This is due to the local distribution of strength in the volume of particle, which, according to the concept of the weakest link determines the tensile strength of the particle. The size of particles generated from a sample of primary particles is therefore a function of the spatial distribution of local strength distribution in the sample with the minimum strength of the sample.

As it can be, the problem of finding the distribution of particle size and form of this distribution as well, the dependence between mechanical properties is a very complex problem.

3. Laboratory tests

The experiments were performed on particles of dolomite, sandstone and slate. The authors prepared 5 size fraction for every lithological type of copper ore. The range of each fraction was 16–18 mm, 18–20 mm, 20–25 mm, 25–31.5 mm and 31–45 mm. In each fraction of particle size a weighted average particle size Dmax was calculated.

Single–particle breakage test for each fraction performed using compression-testing machine. Individual particles were loaded at a constant rate until the first fracture across the particle occurred. The value of the destruction force of each particle was recorded.

Previously, the flat and elongated particles were rejected from the population.

After compression of each fraction particles, the distribution of strength of crushed particles was calculate. Strength distribution curves was plotted in the system (σ/σ_{sr}, P), where P — distribution function decomposition, σ_{sr} — average strength of the crushed particles in each fraction of particles.

The whole range of destructive stress value for each sample was divided into several narrow fractions (partitions) separately. For each fraction of particles the yield in the strength was calculated. The results of these measurements were used to calculate the average strength and determine the distribution of strength.

4. Treatment of results

The purpose of crushing the five fractions of particles in the three lithological varieties of copper ore was to investigate changes in mechanical properties of grains (evaluation of value σ_{sr} and the Weibull's module m).

The tensile strength of particles was calculated according to the following formulas:

$$\sigma = \frac{P}{D^2} \tag{6}$$

where:

P — value of the destroying force,

D — value of average screen diameter of the crushed particle.

The cumulative yield of particles in the next fraction of destroying forces, calculated on the total weight of the sample, is represented by the distribution function of particles strength or the probability of the crushing process. Empirical data were fitted to a model distribution function expressed by the formula (3). Calculations performed according to the method of least squares method are as follows:

— the particles of dolomite

$$P(\sigma) = 1 - \exp\left[-0.917\left(\frac{\sigma}{\sigma_{sr}}\right)^{3.057}\right] \tag{7}$$

— the particles of sandstone

$$P(\sigma) = 1 - \exp\left[-0.809\left(\frac{\sigma}{\sigma_{sr}}\right)^{2.995}\right] \tag{8}$$

— the particles of slate

$$P(\sigma) = 1 - \exp\left[-1.018\left(\frac{\sigma}{\sigma_{sr}}\right)^{2.486}\right] \tag{9}$$

Figures 1–3 presents plots of distribution model and which were applied to the experimental points. These curves show that model values agree well with experimental ones. It can be said that the Weibull's distribution approximates well the distribution of strength of irregular mineral particles.

In addition to these observations, the observed increase of average particle strength with decreasing average particle size led to fragmentation in all three lithological varieties of copper ore (Fig. 4). This is consistent with a statistical strength theory according to which the increase in particle volume caused increase of the probability of the crushing numbers of microcracks that cause damage to the particle.

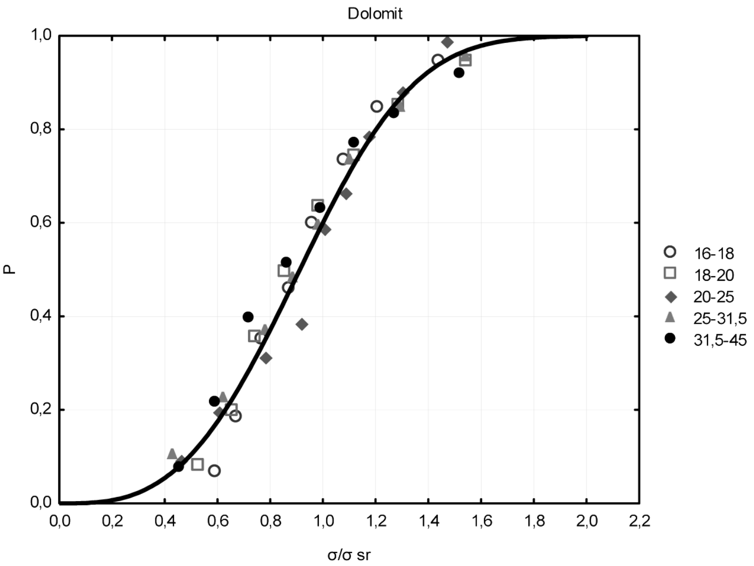

Fig. 1. Cumulative distribution function of tensile strength of dolomite particles

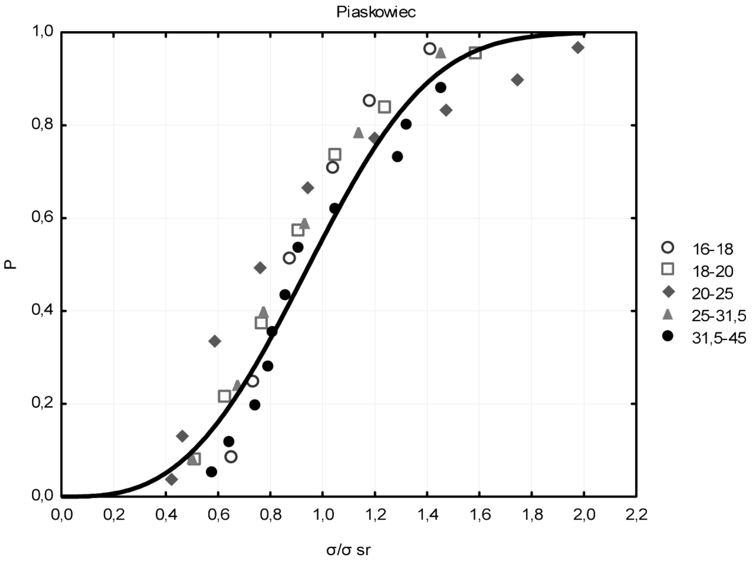

Fig. 2. Cumulative distribution function of tensile strength of sandstone particles

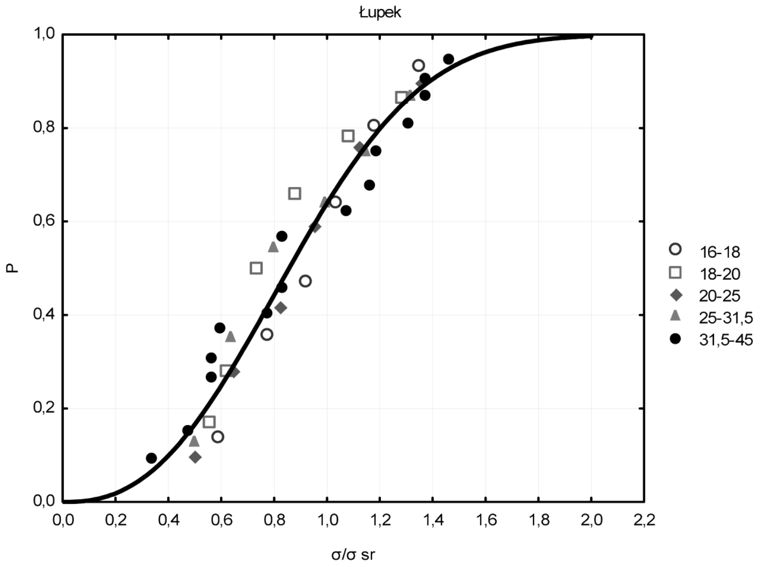

Fig. 3. Cumulative distribution function of tensile strength of slate particles

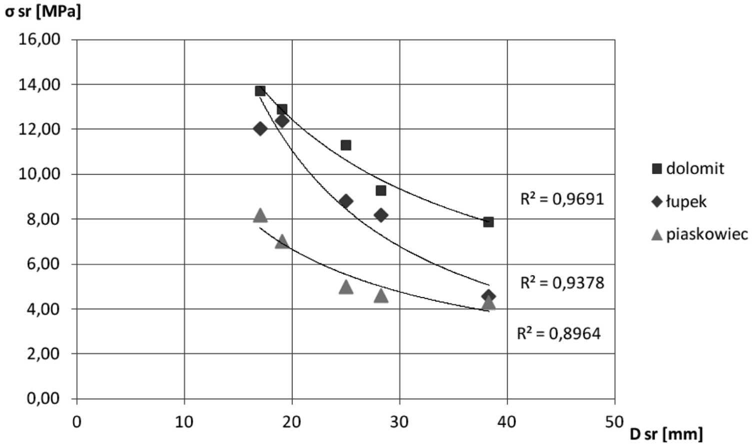

Fig. 4. The dependence of average tensile strength of dolomite, slate and sandstone particles on size particles

5. Conclusions

The results in this paper indicate that the distribution model agree well with experimental values. It can be said then the Weibull's distribution approximating agrees well with the distribution of strength of irregular mineral particles.

All of three lithological types of copper ore indicated the observation that decreasing average particle size led to increase of average crushing strength of particles. The greatest strength has dolomite (approximately 14 MPa), nearly two times smaller has sandstone (up to 8 MPa). The difference in tensile strength of slate and dolomite particles with a particle size of about 40 mm is due to the fact that the particles of shale usually are flat, while the further process of grinding such particles destroys them and their form influences less on the strength. Tensile curves for slate and dolomite are similar to each other, what can cause in difficulties selection of grinding method of such raw materials.

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