Cutting capacity and strength of single grinding grains

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Abstract. The results received at research of the cutting ability and durability of single grinding grains are presented in article. In particular influence of such parameters as a form and a corner of orientation of grinding grain was considered.

Grinding process due to its particular nature is accompanied by removal of a large number of extra-fine cutting chips; significant amount of grinding grains are involved in running of the grinding belt. Removal of cutting chips of very small size occurs in time period measured by split seconds; therefore it makes it difficult to directly observe the ongoing processes.

For this reason characteristic properties of cutting by grains process, cutting capacity of grains and strength are commonly evaluated by indirect methods.

Research of cutting capacity of single grains.

Considering existing methods to define cutting capacity of grinding grains the most wide spread among them are:

– method of the special disc abrasion by the studied abrasive material [1];
– cutting by the single abrasive grain fixed in the rotating disc [2];
– scratching by the single grain of the processed material at low velocities of relatively linear motion [3];
– wearing of materials inside abrasive bulk [4];
– method of defining cutting capacity of grinding grains fixed by centrifugal forces [5];
– wearing in gas flow of abrasive [6].

Abrasive materials are intended for grinding, and therefore, in order to define their cutting properties it is reasonable to simulate the real grinding conditions. Grinding conditions are marked by the following attributes [7]:

1. Velocity of relative interaction of abrasive and the processed material reaches dozens of meters per second;
2. Processing is carried out by fixed abrasive (grains are connected by bunch);
3. Working surface of grinding layer is pressed to the processed material with certain forcing;
4. Multiple micro-cutting occurs by means of large amount of separate abrasive units.

Analyzing the existing methods for defining cutting capacity of grinding grains from the point of their accordance to the above listed attributes it can be concluded that method based on cutting by single grinding grain fixed in the rotating disc simulates adequately well the real grinding conditions.

For this reason this method has been taken as a basis to evaluate cutting capacity of grinding grains.

Experimental studies to define cutting capacity of single grinding grains were conducted at surface grinding machine, model 3G71 by the following cutting modes: velocity of disc with fixed grinding grain V_d=30 m/s; velocity of traverse motion V_{trav}=0.19 m/min; cutting depth t=0.04 mm; cut counts N=20, cutting scheme – plain two-axis vector grinding.

During experimental testing the grinding grain under study was fixed by bunch in a hoop under certain angle γ. The hoop was then fixed on the disc, and disc was set on the work spindle. Weight of the processed sample was preliminary measured on weight scales and it was fixed on magnetic holding plate afterwards. Cutting depth and supply were set by means of cutter control devices. Cutting depth was controlled by dial indicator. The sample was taken out and weighed after twenty runs. Then the experiment was repeated.

The samples selected for the experimental testing included: grains of aluminum-oxide abrasive, grade 13A125, isometric (K_f≈1.14), transient (K_f≈1.56) and plate-like form (K_f≈2.27).

The form of grinding grain was evaluated quantitatively by means of form coefficient K_f [15-17]. This parameter was defined as ratio of surface around grain projection circle ($S_{a.c.}$) to the square of grain projection ($S_{g.p.}$):

$$K_f = \frac{S_{a.c.}}{S_{g.p.}}. \tag{1}$$

Orientation angle of grinding grain (γ) was changed both in cutting direction from 0° to +90°, and in the opposite side from 90° to 180° through each 15°.

Rectangular bars LxBxH = 30x20x10 mm from material St3 (HB111) were used as the processed samples.

Before experiment each sample underwent grinding and finish-grinding of the processed surface. Weight of removed material was measured by weight scale ADV-200 with weighing accuracy 0.0005 g.

Cutting capacity of single grinding grains (ΔM) was defined as difference between weight of processed material sample before and after the experiment.

Experimental results are given in Figure 1.

According to the graphs it can be stated that:

1. form and angle of grains orientation affect their cutting capacity;
2. grains of plate-like form (K_f≈2.27) have better cutting capacity, while grains of isometric form (K_f≈1.14) – have less effective cutting capacity;
3. orientation angle of abrasive grains, providing better cutting capacity is:
   – for plate-like form (K_f≈2.27) – from 60° to 90°;
   – for transient form (K_f≈1.56) – from 60° to 90°;
   – for isometric form (K_f≈1.14) – from 75° to 90°.

Thus the given results enable to conclude that it is reasonable to use grinding grains of plate-like form with orientation angle of γ=75° in order to increase cutting capacity of grinding discs and belts.

<u>Research of strength of single grinding grains.</u>

The existing methods used to define strength of grinding grains are as follows:

1. MU2-036-057-82 – method of determination of grinding grain destruction [7];
2. MU2-036-105-85 – method of defining strength of single grain of grinding materials [7];
3. Method of defining brittleness of grinding grains in ball mill [8];
4. Method of cutting by single grain of V-shaped processed sample during flat grinding [9, 10];
5. Method of destruction by uniaxial compression on the facilities of roll crusher-type [8];
6. Method of strength tests of grinding grains by impact of special hammer head [11];

7. Method of strength tests of grinding grains by falling weight from different height [12];
8. Method of strength tests of grinding grains by oscillating weight [13].

Taking into account the real stress state of grains during operation in grinding tool, the indicated methods to different extent have a number of disadvantages.

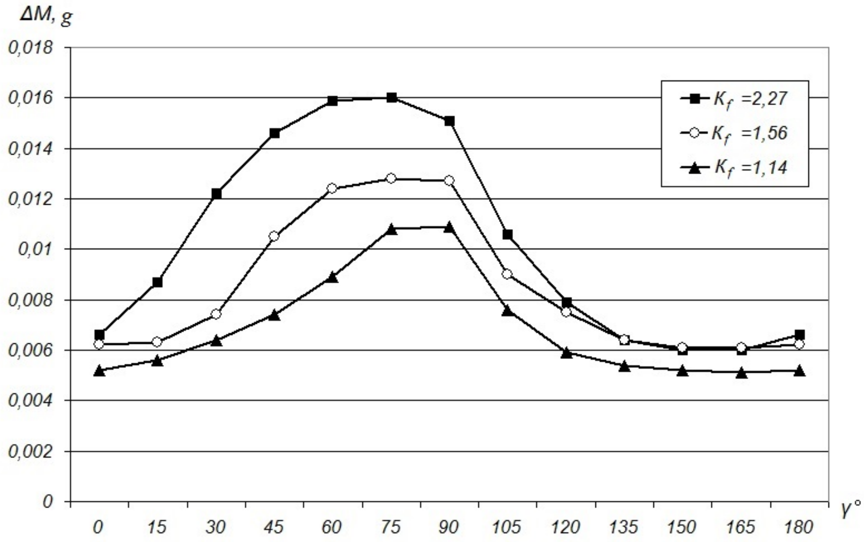

Figure 1. Influence of form and orientation angle of grinding grains on their cutting capacity.

Knowing that grinding grain operates under periodic short-term loads, methods based on dynamic loading will better simulate the real loading conditions. Method of strength tests of grinding grains by oscillating weight refers to one of such methods. However it is rather problematic to define influence of slope angle of grinding grain on its impact strength by the instruments used within this method. Keeping that in mind the present work implies using the instrument including apart from standard knots structural elements dealing with slope of grinding grain and controlling its height [14].

To perform strength tests grains of aluminum-oxide abrasives were used, grade 13A with grain number 125, 100, 80, and aluminum-oxide abrasives of grade NK F24 (Germany) with grain number 80. Grains were of isometric (K_f ≈1.14), transient (K_f ≈1.56) and plate-like form (K_f ≈2.27).

Slope angle of grain (γ) in regards to horizontal plane was accepted as 90°, 75° and 60° (within the impact direction).Thus it enabled to evaluate the tendency of grain strength alteration depending on its orientation relative to the basis.

Impact strength of grinding grain (a) was defined according to the following formula [13]:

$$a = \frac{U}{S}, \tag{2}$$

where U – impulse force;
S – area of fracture surface of grinding grain.

Impulse force equals:

$$U = m \cdot (V_{xx} - V_{px}), \tag{3}$$

where V_{xx} and V_{px} – velocity of non-load and operating run;
m – hammer head weight.

Velocities of non-load and operating run were calculated according to the following formulas:

$$V_{xx} = 2 \cdot \sqrt{g \cdot l} \cdot \frac{\sin \alpha_{xx}}{2}, \tag{4}$$

$$V_{px} = 2 \cdot \sqrt{g \cdot l} \cdot \frac{\sin \alpha_{px}}{2}, \tag{5}$$

where g – free fall acceleration;

α_{xx} and α_{px} – angle of deviation of balance from the equilibrium position during non-load and operating run.

Experimental results are given in Figures 2-5.

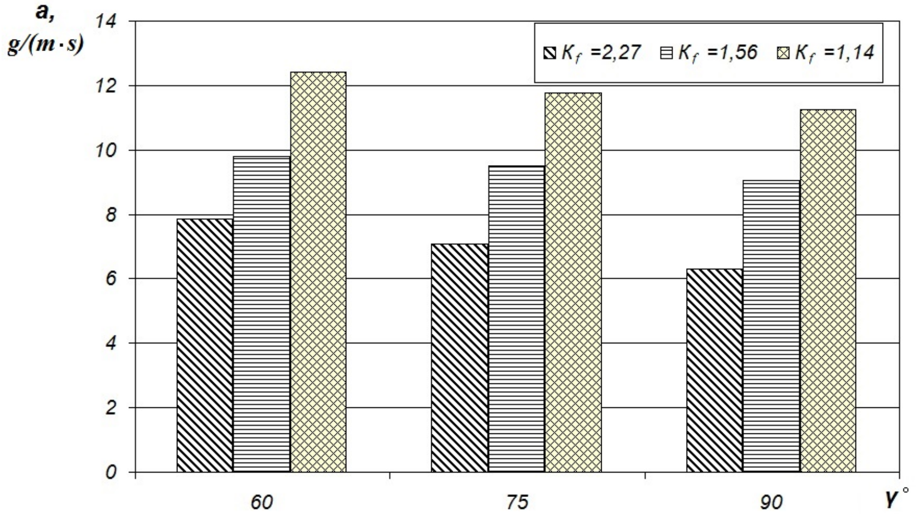

Figure 2. Influence of form and orientation of single grinding grains 13A125 on their impact strength.

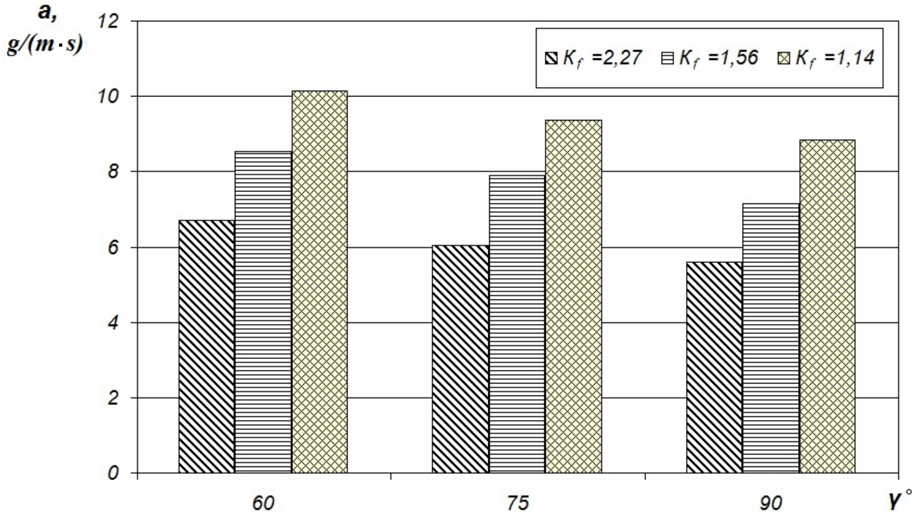

Figure 3. Influence of form and orientation of single grinding grains 13A100 on their impact strength.

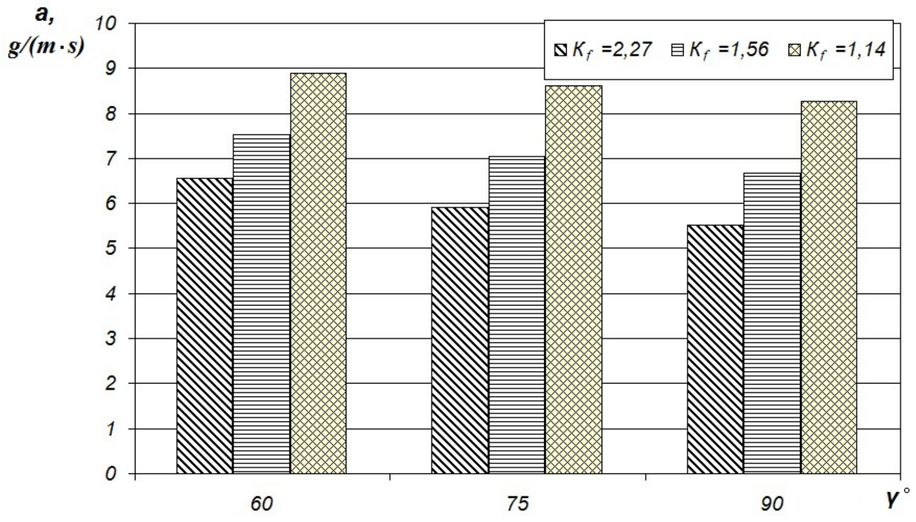

Figure 4. Influence of form and orientation of single grinding grains 13A80 on their impact strength.

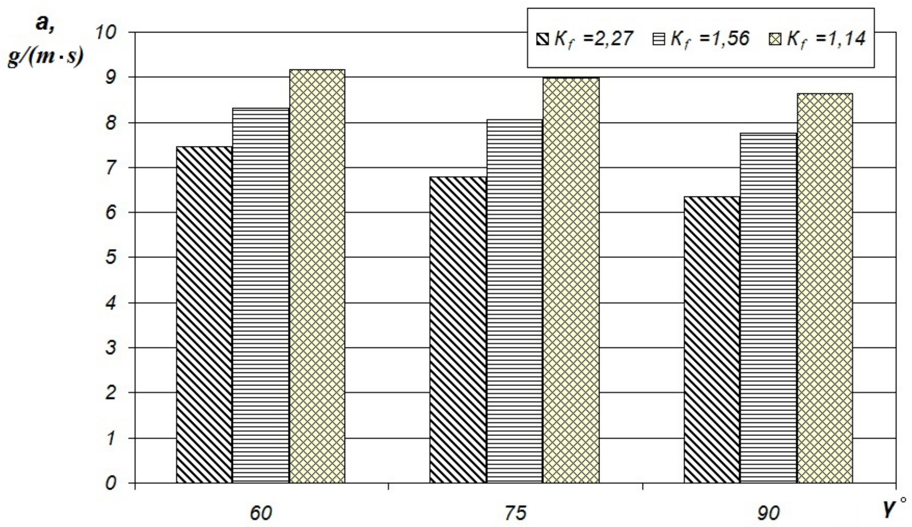

Figure 5. Influence of form and orientation of single grinding grains NK F24 on their impact strength.

The obtained results demonstrate as follows:

1. Form and orientation of grains influence significantly the value of impact strength;
2. All other conditions being equal, isometric grains are characterized by larger strength. Their strength is 1.2 times higher than of transient grains and 1.35 times higher than of plate-like grains;
3. In case of angle of slope alteration from 90° to 60° (within impact direction) grain strength increases:
   - for grains 13A125 – by 7÷18%;
   - for grains 13A100 – by 10÷16%;
   - for grains 13A80 – by 7÷18%;
   - for grains NK F24 – by 5÷17%.
4. Apart from form and orientation parameters grain strength is also affected by size and grade of abrasive.

The obtained data was analyzed by the program software "STATISTICA 6.0". On the basis of this software connection between impact strength (*a*) and parameters of single grinding grain (K_f, γ) given as:

$$\ln a = a_0 + a_1 \cdot \ln K_f + a_2 \cdot \ln \gamma . \quad (6)$$

Calculation of regression coefficients was carried out by least square method. Fisher's ratio test was used to validate the accuracy of the obtained models.

Parameters of statistical model reflecting the influence of abrasive grade (13A or NK), forms of grinding grain, orientation angle and size of grinding grain on impact strength are given in Table.

In Table a_0 – free term of model;

K_f – form coefficient of grinding grain;

γ – angle of slope of grinding grain.

Table. Parameters of statistical models.

Abrasive material grade	Model terms	Coefficients of statistical model
13A125	a_0	3,802989
	$\ln K_f$	-0,752999
	$\ln\gamma$	- 0,290076
13A100	a_0	4,235779
	$\ln K_f$	-0,713419
	$\ln\gamma$	- 0,299496
13A80	a_0	3,463996
	$\ln K_f$	-0,517542
	$\ln\gamma$	- 0,296567
NK F24	a_0	3,225691
	$\ln K_f$	-0,382461
	$\ln\gamma$	- 0,232846

It can be seen from the models that with decrease of the grain size degree of influence of form on its impact strength decreases. The given result is explained by the fact that with decrease of grain size its cross-section area with form alteration will be changed to the less extent. Influence of grinding grain orientation on strength almost does not depend on grain size. Analysis of model for grain NK F24 shows that influence of form and orientation angle of this grinding grain on impact strength is significantly lower than of grain 13A80.

Conclusions

1. Form and orientation angle affect the cutting capacity of grinding grains;
2. Grains of plate-like form (K_f≈2.27) intentionally-oriented on the surface of basis have better cutting capacity, while grains of isometric form (K_f≈1,14) have less capacity;
3. Orientation angle of grinding grains when cutting capacity is the most efficient is:
   – for plate-like form (K_f≈2.27) – from 60° to 90°;
   – for transient form (K_f≈1.56) – from 60° to 90°;
   – for isometric form (K_f≈1.14) – from 75° to 90°.
4. Form and orientation of grains significantly affect the value of impact strength;

5. All other conditions being equal, isometric grains are characterized by larger strength. Their strength is 1.2 times larger than of transient grains and 1.35 times larger than of plate-like grains;
6. In case of angle of slope alteration from 90° to 60° (within impact direction) grain strength increases:
   – for grains 13A125 – by 7÷18%;
   – for grains 13A100 – by 10÷16%;
   – for grains 13A80 – by 7÷18%;
   – for grains NK F24 – by 5÷17%.

Results of statistical analysis correlate with and prove conducted model experiment. It is particularly noted that together with increasing K_f and γ (from 60° to 90°) impact strength of single grinding grains decreases.

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