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Disintegrator as Device for Milling of Mineral Ores

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One of the predominant technologies in mining, in the production of minerals, and in materials treatment is grinding and the ball mills mainly used. Grinding by collision is more effective method for refining of brittle material an on of the few machines for material grinding by collision is disintegrator. This type of grinding implemented in twin-rotored machines is characterized with high productivity but at the same time with the heightened demands to the grinding media – to the materials of grinding elements and linings. The aims of this investigation were (1) to study the grindability of different mineral materials using milling by collision in disintegrator and (2) evaluate the erosion wear resistance of steels as grinding media for mineral materials milling. Grindability of different mineral materials (limestone, sandstone, basalt, gold ores, chromite etc) was studied. The abrasivity of materials was found and relative erosion wear resistance of steel Hardox 600 in the stream of above mentioned materials as abrasives was determined.

Keywords: mineral ores, grindability, disintegrator milling, abrasive erosion, wear resistance of steels.

1. INTRODUCTION

One of the predominant technologies in mining, in the production of minerals, and in materials treatment is grinding. Due to the increasing scales of mining operations the large diameter ball mills are introduced. Much of the research was directed towards modifying existing materials and selected variations of high manganese steel [1]. Because of its ability to withstand the severe impact conditions such as those experienced in the large ball mills, the high manganese steel became the focus of many of the early investigations [2]. In such kind of comminution machines as ball mills, a particle remains between the two grinding bodies (balls) and is broken by shifting. The maximum generated stresses σ that occur in particle are locally equal or exceed the strength of the material [3].

Grinding by collision is a more effective method for refining of brittle material. One of the few machines for material grinding by collision is a disintegrator [4]. The value of the stresses generated in a material to be ground exceeds the strength of the material about ten times and the particles fall into pieces [3].

This type of grinding implemented in twin-rotored machines is characterized by high productivity, but at the same time with the heightened demands to the grinding media – to the materials of grinding elements and linings due to the high impact velocities and abrasivity of materials to be treated [5]. As it was shown in [6, 7], by treatment of very hard composite material as tungsten carbide based hardmetal contamination of ground product – ultrafine hardmetal powder with iron from grinding media was surprisingly high (up to 15 %). From this point of view, both the grindability of the materials in a disintegrator and the wear performance of grinding media are very important.

To predict the suitability of concrete materials and to find relative erosion resistance of them erosion theory has also been developed [8]. It is needed when the lifespan of some part is to be increased by replacing the material not used yet in similar conditions. So-called S-curves law and a diagram for evaluation of the “hardness value” were produced, depending on material type and the hardening method. To construct the curves in the axes $\varepsilon - H_m$ the data needed are wear rates of standard and studied materials against abrasive that is softer or equal than standard or studied materials and against abrasive that is those’s 1.6 times harder than it [8].

The aims of this investigation were (1) to study the grindability of different mineral materials using milling by collision in a disintegrator and (2) to predict the relative erosion wear resistance of steels as grinding media for mineral materials milling under conditions similar those to industry.

2. EXPERIMENTAL MATERIALS AND METHODS

To study the grindability of materials, different mineral materials (limestone, sandstone, basalt etc) were under study.

Milling experiments to assess the grindability of different mineral materials (Table 1) were conducted in semi-industrial disintegrator DSL-137 with rotor diameter 600 mm and rotation velocity 1500 rpm. The parameter of grinding – specific treatment energy E_S was used to estimate grindability [9].

For the abrasivity study of above mentioned mineral materials and different gold ores, the centrifugal accelerator CAK-4 was used. The velocity of abrasive particles was 80 m/s and impact angles – 30°, 60° and 90°. Milled mineral materials with particle size less 1 mm were used as abrasives. The types of mineral materials, gold ores and chromites as abrasives are given in Table 1 and Table 2.

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Table 1. Characterization of mineral materials to be milled

No and type of mineral materials	Initial particle size, mm	Hardness HV0.2
1. Limestone (Engis)	+6.3-10 and +10-14	135 – 205
2. Sandstone (Trooz)	+6.3-10 and +10-14	140 – 205/250 – 280*
3. Polphyry (Voutre)	+6.3-10	560 – 880
4. Basalt (Cerf)	+6.3-10 and +10-14	560 – 840

*Dark phase in sandstone.

Table 2. Composition of selected mineral ores, wt%

No and type of ore	Quartz 2000 HV	Pyrite 1530 HV	Feldpars 1290 HV	Others
Gold ores				
5. Crown Mine (South Africa)	80	2.5	1.5	16
6. Waihi (Australia)	63	2.5	27	7.5
7. South Pipeline (USA)	51	–	8	41
8. KBGM (Australia)	30	1	35	24
9. Plutonic (Australia)	15	–	25	30 – Amphibole (946 HV) 30
Chromite				
10. CMI (South Africa)	1.1	–	4	82 – Chromite (1530 HV)
				5.5 – Amphibole (946 HV)
				7.4
11. Wonderkop (South Africa)	0.5	–	3	95 – Spinelle (725 HV) 1.5

Table 3. Chemical composition and hardness of the studied steels

Type of steel	Chemical composition, wt%	Hardness
St37	0.21 – 0.25 C; ≤0.055 P, S	140 – 150 HV30
Hardox 600	0.48 C; 0.70 Si; 1.00 Mn; 1.20 Cr; 2.50 Ni; 0.80 Mo	560 – 640 HBW*
Reference material C45	0.42 – 0.50 C; 0.50 – 0.80 Mn; ≤0.045 P and S	580 – 635 HV30
(normalized)		230 – 260 HV30

*by specification.

Wear tests to assess the erosion behaviour of the grinding media – steels St 37 and Hardox 600 were conducted in wear tester CAK-4 at the impact velocity $v = 80$ m/s and impact angles 30° and 90°. The selected abrasives (sandstone, glass and quartz) with particle size 0.1 – 0.3 mm were used. The chemical composition and hardness of steels is given in Table 3. Microhardness by Micromet 2001 of mineral materials and abrasives (Table 1) and Vickers hardness of studied steels (Table 3) were determined. Steel of 45 % C was adapted as a reference material.

The coefficient of abrasivity A of materials used in abrasive wear tests was determined by steel St37 (normalized, 140 – 150 HV).

$$A = I_g^{\text{mineral ore}} / I_g^{\text{quartz sand}}, \quad (1)$$

where I_g is the wear rate by weight, mg/kg

The wear resistance of the grinding media mostly influenced by the hardest components in the mixture and calculated/reduced hardness H' values of mineral materials (gold ores and chromites) were used in estimation of wear resistance.

$$H' = H_1 \cdot V_1 + H_2 \cdot V_2 + H_3 \cdot V_3 + \ldots H_n \cdot V_n = \sum_{i=1}^{n} H_i \cdot V_i\,, \quad (2)$$

where $H_1 \ldots H_n$ are the hardness of the components of abrasive, $V_1 \ldots V_n$ are the relative weight amounts of components in the mixture.

To construct curves $\varepsilon = f(H_a)$ for steels (soft and hard) used as the grinding media (mild steel St37 and hardened steel Hardox 600) sandstone as softer abrasive (140 – 205 HV), glass grit as medium abrasive (550 – 600 HV) and quartz sand as harder abrasive (1100 – 1200 HV) with similar particle size (0.1 – 0.3 mm) but different shape (Fig. 1) were used for tests.

3. RESULTS AND DISCUSSIONS

3.1. Grindability and abrasivity of mineral materials and ores

The results of grindability studies of mineral materials are given in Fig. 2.

As shown in Fig. 2, a sandstone and porphyry showed better grindability, the materials with higher hardness showed a decrease in the mean particle size after one step milling about 20 %, after twin milling about 50 % and more. The size reduction of limestone and basalt after first millings was less.

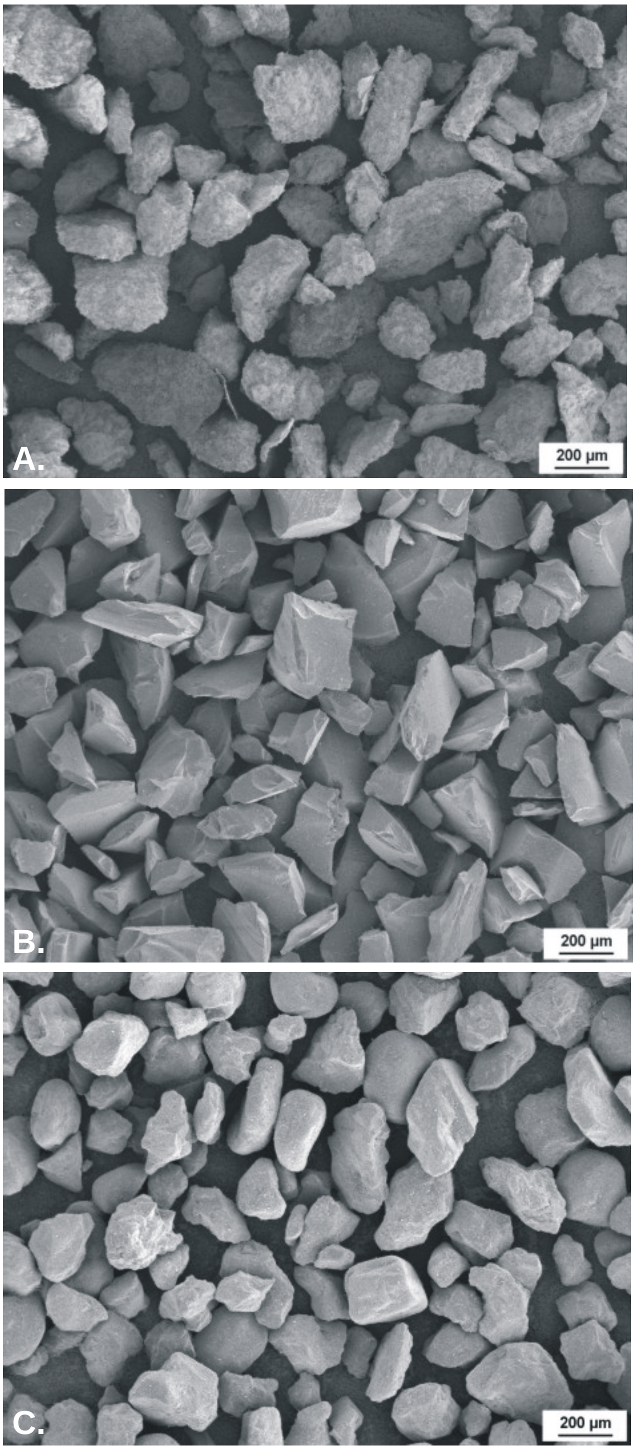


Fig. 1. SEM images of abrasives: A – sandstone; B – glass grit; C – quartz sand

At the same time results after multiple milling did not differ (limestone and porphyry after fifth milling).

Based on the abrasive wear studies the abrasivity of materials was found. It was demonstrated that no direct correlation between the hardness and abrasivity of materials to be tested exists (Table 4).

3.2. Wear resistance of the grinding media in mineral abrasives

The results of erosion tests of steel St37 with abrasives – ground mineral materials particles at impact velocity 80 m/s and impact angles 30°, 60° and 90° similar to industrial conditions are given in Fig. 3 and Fig. 4.

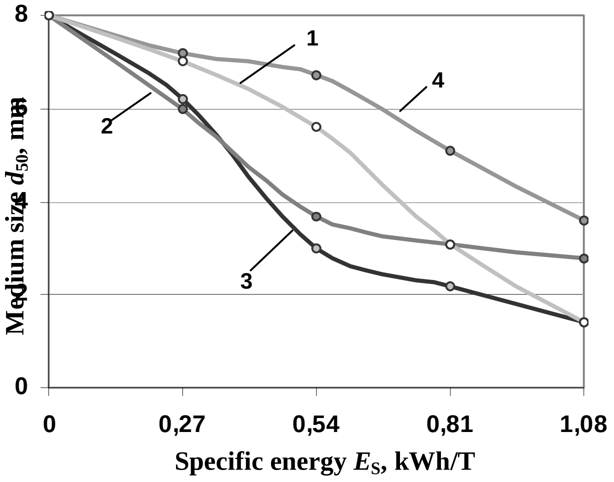


Fig. 2. Grindability curves of minerals: 1 – limestone; 2 – sandstone; 3 – porphyry; 4 – basalt

Table 4. Hardness and abrasivity of the studied mineral ores

Used abrasives and their No	Hardness	Coefficient of abrasivity *A*
Limestone (No. 1)	135 – 205*	0.30 – 0.36
Sandstone (No. 2)	140 – 205*	0.71 – 0.64
Porphyry (No. 3)	560 – 880*	0.59 – 0.48
Basalt (No. 4)	560 – 840*	0.43 – 0.33
Cold ore		
Crown Mine (No. 5)	1658**	1.00 – 0.94
Waihi (No. 6)	1647**	0.64 – 0.56
South Pipeline (No. 7)	1123**	0.51 – 0.41
KBGM (No. 8)	1067**	0.59 – 0.52
Plutonic (No. 9)	906**	0.46 – 0.32
Chromite		
CMI (No. 10)	1380	1.20 – 1.15
Wonderkop (No. 11)	775	0.85 – 0.75

*Vickers hardness measured with Micromet 2001 at the load 2 N (HV0.2).

**Calculated by Eq (2). The components with hardness ≥700 HV in the mixture were taken into consideration.

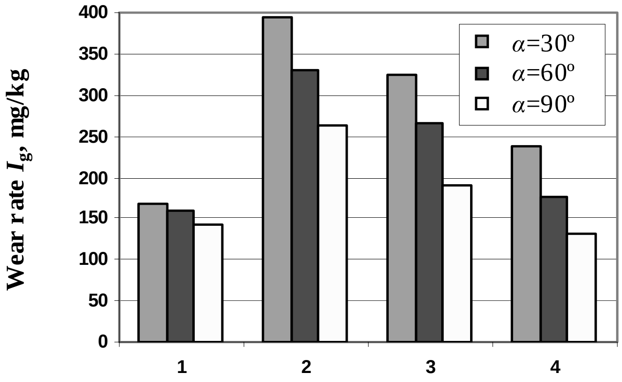


Fig. 3. Wear rate of steel St37 at different impact angles and in abrasives: 1 – limestone; 2 – sandstone; 3 – porphyry; 4 – basalt

As shown in Fig. 3, the wear rate by the studied four abrasives is not in correlation with the hardness of materials to be tested.

Higher wear rate by relatively soft sandstone can be explained by the existence of a harder component in the material and by the shape of abrasives particles – the particles of sandstone were more angular as compared with polphyry or basalt.

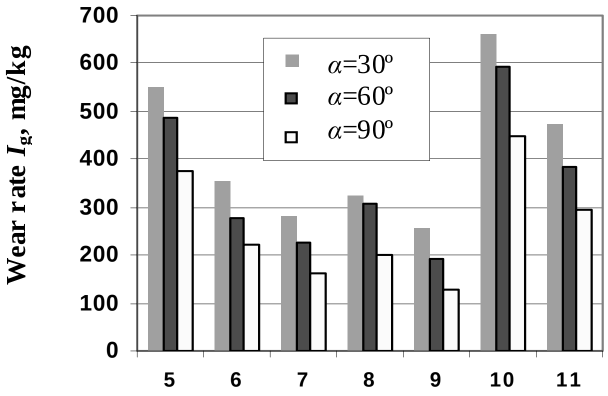


Fig. 4. Wear rate of steel St37 at different impact angles and in gold ore abrasives: 5 – Crown Mine; 6 – Waihi; 7 –South Pipeline; 8 – KBGM; 9 – Plutonic; 10 – CMI; 11 – Wonderkop

As shown in Fig. 4, the wear rate of steel St 37 in the stream of different abrasives is in good correlation with their hardness. With the increase of hardness, the wear rate is decreasing.

The influence of impact angle on wear rate by all abrasives studied was even – with the increase of the impact angle, the wear rate is decreasing. It is similar to steels as plastic materials. As compared with limestone, the wear resistance of sandstone is about 2.3 and 1.9 times higher at 30° and 90° respectively.

The wear rate and relative wear resistance in different mineral ores with hardness from 775 HV up to 1647 HV depends first on the composition of ores, on the amount of the hardest component – quartz (2000 HV) in mixture (see Table 2).

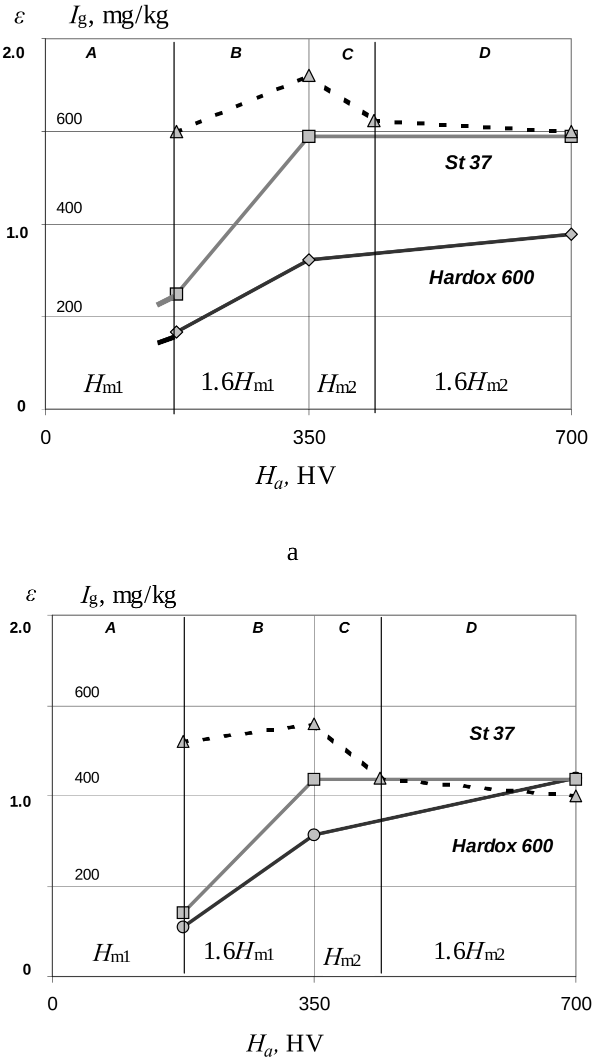
The wear rate is the highest by chromite (82 % in mixture is component with hardness 1530 HV), followed by gold ore – Crown Mine (main component – 80 % is quartz with hardness 2000 HV).

3.3. Prediction of relative erosion resistance of the grinding media

To evaluate the suitability of hardened steels as the grinding media and to have the wear curves $\varepsilon = f(H_a)$, the wear rates of standard material – soft steel St37 (140 – 150 HV30) in abrasives – in limestone (135 – 205 HV) and glass grit (550 – 600 HV) and wear rates of harder material – steel Hardox 600 (580 – 635 HV30) in abrasives – in glass grit and quartz sand (1100 – 1200 HV) were determined. The results of experiments are given in Table 5.

On the base of test results the $\varepsilon - H_a$ curves were constructed (Fig. 5).

As shown in Fig. 5, four defined zones exist:
A – wear resistance is low; *B* – wear resistance increases; *C* – wear resistance decreases rapidly; *D* – wear resistance of Hardox is low. In interval *B* – *C* the use of Hardox is most favourable.



a

b

Fig. 5. Wear rate of steel St37 (M_1) and Hardox 600 (M_2) of respective hardness H_{m1} and H_{m2} versus abrasive hardness H_a. The dash line: dependence of relative wear resistance of ε on H_a: a – impact angle 30°; b – impact angle 90°

Table 5. Wear rates of studied steels in soft and hard abrasives

Steel	HV30	Wear rate I_g, mg/kg					
		Milled sandstone		Glass grit		Quartz sand	
		$\alpha = 30°$	$\alpha = 90°$	$\alpha = 30°$	$\alpha = 90°$	$\alpha = 30°$	$\alpha = 90°$
St37	140 – 150	248.4	141.9	587.2	437.7		
Hardox 600	580 – 635			323.4	312.8	376.9	438.4

The comparative testing of soft and hardened steels as the grinding media in disintegrator type crushing devices demonstrated that hardened steels are not prospective in these application. With the material cost increasing the effect is low – the increase of life span of milling elements is minimal. It was confirmed by comparative testing of pins from different steels and different coatings [10, 11]. Relative wear resistance of steels and coatings in disintegrators by the milling of materials with hardness about 1000 HV and more is low.

4. CONCLUSIONS

1. The grindability of different mineral materials using milling by collision in disintegrator was studied and the influence of particle size reduction on specific energy of treatment was clarified.
2. The abrasivity of the milled minerals was found. It was demonstrated that there does not exist direct correlation between hardness and abrasivity of materials to be treated.
3. The experiments to evaluate the suitability of the hardened steels as the grinding media in disintegrator was carried out and it was demonstrated that hardened steels are not prospective in these application.

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REFERENCES

1. **Cherje, T. W., Simbi, D. J., Navara, E.,** Relationship between Microstructure, Hardness, Impact Toughness and Wear Performance of Selected Grinding Media for Mineral Ore Milling Operations *J. Materials and Design* 25 2004: pp. 11 – 18.
2. **Benjamine, D.,** Properties and Selection: Stainless Steels, Tool Materials and Special Purpose Metals. Metals Handbook, 9th edition, Vol. 3, ASM, p. 576.
3. **Tamm, B., Tymanok, A.** Impact Grinding and Disintegrators *Proc. Estonian Acad. Sci. Eng*. 2/2 1996: pp. 209 – 223.
4. **Tümanok, A., Kulu, P.** Treatment of Different Materials by Disintegrator Systems *Proc. Estonian Acad. Sci. Eng.* 5/3, 1999: pp. 222 – 242.
5. **Uuemõis, H., Piil, M.** Selection and Evaluation of Materials for Impact Cruchers *Proc. of Tall. Univ. of Techn*. 478 1979: pp. 31 – 36 (in Russian).
6. **Kulu, P., Käerdi, H., Mikli, V.** Retreatment of Used Hardmetals *Proc. TMS 2002 Recycling and Waste Treatment in Mineral and Metal Processing: Technical an Economic Aspects* Sweden Vol. 1 2002: pp. 139 – 146.
7. **Zimakov, S., Pihl, T., Kulu, P., Antonov, M., Mikli, V.,** Applications of Recycled Hardmetal Powder *Proc. Estonian Acad. Sci. Eng.* 9/4 2003: pp. 304 – 316.
8. **Kleis, I., Uuemõis, H.** *Undersuchung des strahlverschleissmechanismus von Metallen Zeitschrift für Werkstofftechnik* Heft 7 1974: s. 381 – 389.
9. **Goljandin, D., Kulu, P., Peetsalu, P.** Ultrafine Metal Powder Produced by Grinding from the Industrial Wastes *Proc. TMS 2002 Recycling and Waste Treatment in Mineral and Metal Processing*: Technical an Economic Aspects, Sweden Vol. 1 2002: pp. 277 – 284.
10. **Kulu, P.** Wear Resistance of Powder Materials and Coatings, Tallinn, Valgus Publishers, 1988: 119 p. (in Russian).
11. **Kulu, P.** Selection of Powder Coatings for Extreme Wear Conditions *Advanced Engineering Materials* 4/6 2002: pp. 392 – 397.
12. **Kulu, P.** The Principles of Creation of Erosion Wear Resistant Powder Materials and Coatings *Doctoral Thesis*, Tallinn, 1989 (in Russian).