Influence of HPGR operation on the reduction of Bond’s working index of crushing product

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Influence of HPGR operation on the reduction of Bond’s working index of crushing product

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Abstract. Article concerns the issues of ore comminution in HPGR. A series of laboratory tests were carried out for three lithologic types of sulphide ore. Four values of operating pressing force were accepted. Bond’s index value, determined with using a standard Bond method, was also determined for all HPGR products. There were also determined functional relationships between Bond index and operational pressure. Results of investigation showed, that application oh HPGR for that type of feed resulted in lowering the value of Bond index. The relationship between the pressing force and Bond index can be approximated with hyperbolic function.

1. Introduction
Comminution constitute the basic operation in technological circuit of mineral processing. It’s primary role is to reduce the particle size composition of the crushing product, but also the change in shape of individual particles, an increase of the specific surface area of the material, and the liberation of the useful components from the gangue. It can also affect the mechanical properties of the raw material, depending on the type of comminution device applied. The processes of raw materials comminution is the most energy-intensive operation in ore processing circuits. The amount of energy spent in crushing and grinding operations strictly depends on the properties of the raw material, a type of crushing devices applied and the adopted technology [7].

From the scope of assessment the crushing technology effectiveness, a key issue seems to be to determine the energetic demands in comminution operations. The most common energetic theories of comminution are the Rittinger, Kick and Bond laws. There are also some other methods of determination of theoretical energy demands for comminution [1], but standard Bond’s method is still treated in industrial practice as an universal way of determination the energy consumption in crushing and grinding operations. The theoretical energy demand index $W_i$, is determined based on the Wi Bond index, which, in turn, determines the material’s resistance to grinding. For the ball mill $W_i$ can be determined from the following formula:

$$W_i = 1.1 \cdot \frac{44.5}{P^{0.23}G^{0.82}} \left(\frac{10}{\sqrt{80}} \cdot \frac{10}{\sqrt{W_0}}\right)$$  \hspace{1cm} (1)

where:
$W_i$ - Bond’s working index, [kWh/Mg]
$P$ - control mesh size (3350), [μm]
\( G \) - the mass of the undersize product generated per one revolution of the mill, \([g/rev]\) 
\( F_{80} \) - eighty percent particle of the feed, \([\mu m]\) 
\( P_{80} \) - eighty percent particle of the product, \([\mu m]\)

Following simplified formula can be also applied in industrial practice:

\[
W_i = \left( 16 \frac{G}{G_{0.82}} \right) \cdot \sqrt{\frac{P}{100}} \cdot 1.1
\]  
(2)

Decreasing the value of Bond work index for a given type of material is possible, through application of novel comminution techniques. A high-pressure grinding technology, which is currently one of the most effective methods of ore comminution in terms of low energy consumption, can be a good example of such innovation. The HPGR crushing product has micro-cracks within the structure of individual grains, which reduces its grinding resistance in downstream grinding stages, and that contributes to lower energy consumption \([2,11]\). Results of various investigations show that application of the roller press devices in hard raw material processing circuits may result in a reduction of the grinding energy consumption up to 50% \([2]\). In general, the Bond working index value for HPGR products can be reduced from 10 to 30%, depending on the type of material. At the same time, an increase of the useful component recovery in flotation concentrates by as much as even several percent, was also noticed \([3]\). At the same time, these devices are characterized by lower investment and operating costs, high efficiency combined with a small footprint and low vibration and noise emission \([4,8]\).

The aim of the paper is to determine a relationship between operational parameters of HPGR device and the Bond work index value for the HPGR products. Determining the relationship between the value of operating pressure in the press and the Bond work index (using a standard Bond method) for the crushing product can be helpful in effective control of the grinding process in a high-pressure grinding roll device.

2. Material and methods

High-pressure comminution tests were carried out for copper ore, while three samples with different lithological compositions were under examination. Each sample contained variable contents of sandstone and carbonate fractions, while the shale contents were similar (table 1). The investigative programme included laboratory crushing tests in HPGR device, carried out in NTNU University in Trondheim (Norway).

|                      | Sample 1 | Sample 2 | Sample 3 |
|----------------------|----------|----------|----------|
| Sandstone, [%]       | 48       | 65       | 27       |
| Carbonate, [%]       | 41       | 24       | 62       |
| Shale, [%]           | 11       | 11       | 11       |

The HPGR feed, with maximum particle 10 mm, was upstream crushed in a jaw crusher. Particle size composition of three samples are presented in figure 1.
Figure 1. Particle size distribution curves for each sample.

Each sample contained variable yields of individual lithological fractions. The sandstone fraction in material 1 constituted 48%, while in samples 2 and 3: 27% and 65%, respectively. Each material sample was then split into six smaller samples, 6 kg, each. The base sample was used for determination the Bond index value for the feed, the four next samples were crushed in HPGR device under various values of operational pressing forces. The remained sixth sample was stored as a reserve. The obtained results of Bond’s values for three types of feed are presented in Table 2.

Table 2. Values of Bond’s work indices for three types of feed used in investigations.

|                  | Sample 1 | Sample 2 | Sample 3 |
|------------------|----------|----------|----------|
| Bond’s Index Wi, [kWh/Mg] | 14.1     | 11.2     | 14.9     |

As it can be seen from the table 2, the value of Bond’s index shows strong relationships with the sandstone content in the feed material. However even though the correlation coefficient value is high \((r = 0.967)\) and it is statistically significant on the probability level \(1 − α = 0.90\), the statistical sample should contain larger number of measurements, in order to formulate stronger conclusion. Nevertheless, the content of sandstone fractions in the material might influence on its comminution characteristics.

3. Results of investigations

Comminution tests in HPGR were carried out for four different values of the pressing force \(F\): 4, 6, 8 and 10 kN. The rolls diameter was 200 mm, while the width: 100 mm. Four comminution products were obtained for each material sample. Particle size distribution curves of HPGR product for each sample were presented in figures 2 - 4.
**Figure 2.** Results of comminution in HPGR for sample 1.

**Figure 3.** Results of comminution in HPGR for sample 2.
Figure 4. Results of comminution in HPGR for sample 3.

In the next stage of investigations the values of Bond’s work indices were determined for each HPGR samples. Results of the twelve values of Bond’s work indices are presented in table 3.

Table 3. Values of Bond’s work indices for all HPGR products.

| F [kN] | Sample 1 | Sample 2 | Sample 3 |
|--------|----------|----------|----------|
| 4      | 12.6     | 11.2     | 12.9     |
| 6      | 11.4     | 10.3     | 11.8     |
| 8      | 10.9     | 9.8      | 11.3     |
| 10     | 10.2     | 9.0      | 10.9     |

Comparing values presented in tables 2 and 3 it can be seen, that the most favorable savings on the grinding energy were obtained for the material sample 1 (27.7%), but for all samples the energy savings were higher than 20%. For the material sample 2, the energy savings equaled 24.1%, and for the material 3: 26.8%. In general, the more favorable energy savings were obtained for the materials with increased content of sandstone fractions.

In the last stage of investigations there were determined the regression models describing the Bond’s values of each material as a function of operational pressing force F. Approximation was performed with using the hyperbolic function:

\[ y = \frac{a}{x^b} \]  

where:
\[ y \] – Bond index value,
\[ x \] – HPGR operational pressing force,
\[ a, b \] – coefficients.

The type of approximation function used for determination of the models have its justification in literature [9,10]. The results are presented in table 4 and figure 5.
Table 4. Functional models of Bond values as a function of operational pressing force in HPGR.

| Type of material | Model       | R² value |
|------------------|-------------|----------|
| Sample 1         | $y = \frac{14.17}{x^{0.19}}$ | 0.992    |
| Sample 2         | $y = \frac{11.31}{x^{0.15}}$ | 0.957    |
| Sample 3         | $y = \frac{14.87}{x^{0.20}}$ | 0.997    |

Figure 5. Functional models of Bond values.

All approximation functions describe the phenomenon well enough, R-square values are higher than 95% and they are even higher for the samples with higher content of sandstone fractions. There are also visible some relationships between values of a and b coefficients and the type of material. Together with an increase of sandstone fraction content, the coefficient increases too, while the b coefficient decreases. The above relationships are true for all materials under examinations.

4. Results and conclusions

The results of investigations show that operating pressure in HPGR significantly influences on reduction of Bond’s work index. Similar results were obtained for both types of material, however the content of sandstone fraction in feed results in various values of Bond’s working index Wi. Higher reduction in Bond’s index value were observed for the material with higher sandstone content. For the material crushed in HPGR at pressing force 10 kN, Wi reduction achieved 28%, while for the sample 2, where the content of sandstone was the lowest, the reduction of Wi achieved 20%. Nevertheless, the results of investigations show that application of HPGR device for that type of ore can generate significant reductions in potential energy consumption in downstream grinding processes.

The results of second part of investigation showed that it is possible to build a suitable functional relationship between operating pressure in HPGR and Bond index Wi. The shape of relationship indicates that together with increasing of operating pressure in HPGR further reductions of Wi index are lower. Therefore, it can be determined an optimal value of operating pressure, for which the
potential effect in terms of energy savings are the most favourable. This issue will be the subject of further investigations.

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