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INFLUENCE OF TYPE OF LINING IN HIGH-PRESSURE GRINDING ROLLS ON EFFECTIVENESS OF COPPER ORE COMMINUTION

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Abstract: Comminution in a High-Pressure Grinding Rolls (HPGR) device is considered as one of the most efficient method to break particles, in terms of the energy utilization. Two main types of the rolls linings are applied in hard ore grinding: studded and hexagonal, which show varied characteristics of operation and have different lifetime of service. The article concerns the analysis of HPGR device operation for various linings of the rolls. Two pilot-scale test programmes were run and performance of both types of rolls was tested in terms of energy consumption, technological effects measured by means of comminution ratio, lifetime service as well as economic aspects. Results of investigation show, that much longer lifetime service was obtained for the studded rolls, while hexagonal ones are more favourable from economic scope. The feed material for the HPGR comminution tests was Polish copper ore from two divisions of processing plants of KGHM Polska Miedz S.A. Taking into account that industrial comminution operations in mining and mineral processing sector consume over 50% of total energy utilized for ore treatment operations, the problem is of a major significance, especially in terms of optimization of hard ore crushing and grinding circuits.

Keywords: *HPGR, comminution, copper ore, high-pressure grinding rolls device, HPGR linings, ore processing, energy consumption*

Introduction

Industrial comminution operations in mining and mineral processing sector consume over 50% of total energy utilized for total ore treatment operations. Key-aspects connected with reduction of that high share in the energy consumption concern the application of more efficient crushing and grinding technology together with more efficient utilization of the existing circuits of ore size reduction. High-pressure

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grinding rolls (HPGR) technology is considered as one of the most efficient method to break particles, in terms of the energy utilization (Schoenert, 1979). The main principle of its operation is compressing of the particle bed between two counter-rotating rolls due to the high pressing force exerted on the one of rolls (called floating roll). Two main types of the rolls linings are applied in hard ore grinding: studded and hexagonal. The studded surface consists in metal ring with the pins (studs) embedded in regular distances from each other. The head of each pin protrudes above the surface of the lining, and an autogenous wear layer can be formed by ore packing itself between the studs on the roll. This layer provides a kind of shield from the abrasive impact of the material on the roll surface (Weir, 2013). The hexagonal type surface is made of hexagonal tires fixed at the roll surface with using hot isostatic pressing technology. Area between the tiles is made of a softer material, which gets worn out, and the fine particles build an autogenous protective layer there (Sesemann et al., 2013).

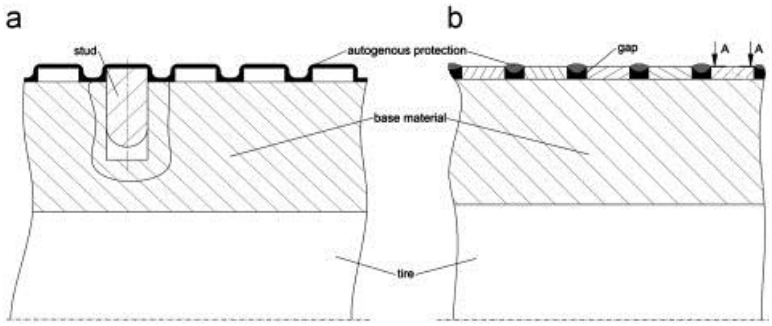

Fig.1. Two types of wear protection: studded (a) and hexagonal (b) surface

Both types of linings show varied characteristics of operation and have different lifetime of service. Data relating to lifetime operational hours for hexagonal rolls are not shown, while studded rolls are expected to operate up to 17,000 hours in coarse iron ore grinding and up to 10,000 hours in harder ore comminution, like kimberlites (Weir, 2013).

Very few data, concerning the relationship between type of lining and the effectives of comminution or the lifetime operation, can be found in literature. Results of some investigation (Daniel and Morell 2004, Saramak, 2012) and experience of authors show that comminution process for HPGR equipped with hexagonal rolls might show slightly lower energy consumption, while comminution ratio might be more favourable for studded rolls. On the other hand, the lifetime service of studded rolls might be longer, while cost of new set of rolls is considered to be lower for hexagonal rolls. It is however hard to state clearly, which type of roll surface is more beneficial for given type of hard ore, without relevant investigations. It is also almost impossible to draw some general conclusions, due to various factors influencing individual processing plant operation along with various ore characteristics. Lack of

respective research articles in literature, is also a significant limitation, because there are no opportunities for verification of own research.

Therefore, the main aim of the paper is to provide some comparative investigations over the performance of hexagonal and studded rolls. A pilot-scale investigative programme for copper ore, presented in the paper, concerns some selected aspects of operation of both types of linings, and the authors, to some extent, aimed to fill the gap in research within the issue. Another goal of these investigations was to learn about possible effects of copper ore HPGR comminution achieved for different types of device's linings.

Experimental programme

The pilot-scale research programme included testing the efficiency of copper ore crushing in the press equipped with different types of rolls lining. Similar research programmes were carried out by two HPGR manufacturers at the request of KGHM "Polska Miedź" S.A. The feed material for testing was copper ore from two divisions of processing plants: Rudna and Polkowice (called Rudna plant and Polkowice plant, or Rudna and Polkowice, respectively). The aims of investigations were investigations on copper ore comminution effectiveness depending the type of linings, determination of lifetime service of both types of linings, and economic assessment of two types of linings operation.

Feed material characteristics

The material from Rudna was a rod mill feed with the top size 40 mm, while ore from Polkowice constitutes the oversize product from the screen, operating on the first technological circuit. Particle size distributions of both materials are presented in Fig. 2., while ore lithologic composition and Bond's work index value are presented in Table 1.

Table 1. Feed material characteristics

	Rudna	Polkowice
Bond's work index [MJ/Mg]	50.868	40.428
	Share of individual lithologic fractions [%]	
Sandstone	47	27
Shale	11	11
Dolomite	42	62

Inspecting Table 1 it can be seen that feed material from Rudna was of a higher value of Bond's work index, and sandstone content nearly 50 percent. Ore from Polkowice, in turn, contains over 60% of dolomite fraction and is characterized by lower Bond's index value for nearly 10.8 MJ/Mg, comparing to feed material from

Rudna. Various investigations show (Tumidajski et al., 2010) that diverse content of individual lithologic fractions results in different comminution effects and energy consumption. Energy consumption was given in SI units (MJ/Mg), but in industrial practice [kWh] units are used more frequently than [MJ] (1 MJ = 0.278 kWh).

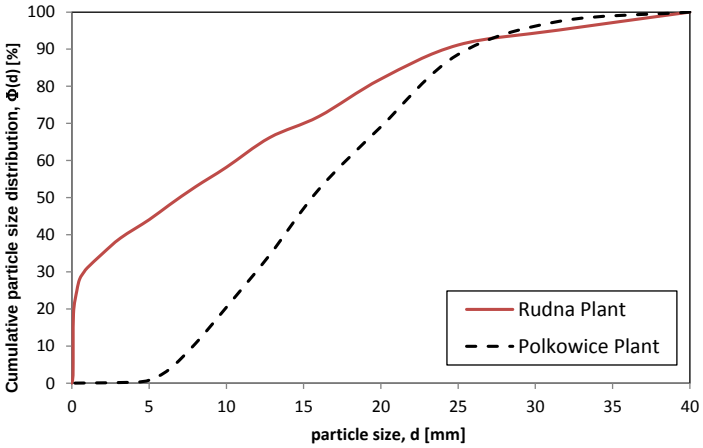

Fig. 2. Particle size distribution curves of feed materials from Rudna and Polkowice plants

Ore characteristics were supplemented with the grinding kinetics tests for both ores. The tests were carried out in a standard Bond's mill and particle size distributions of grinding products after 1, 3, 5 and 10 minutes were determined (Figs. 3 and 4), along with comminution ratios S_{50}, S_{80} and S_{95} (Table 2).

Table 2. Comminution ratio values after 1, 3, 5 and 10 minutes of grinding in laboratory Bond mill

	Comminution ratio S	Grinding time [minutes]			
		1	3	5	10
Rudna	S50	4.23	5.60	7.17	11.93
	S80	1.17	1.72	6.04	24.33
	S95	1.06	1.11	1.16	1.33
Polkowice	S50	2.42	8.86	17.33	24.67
	S80	1.11	1.32	1.77	34.10
	S95	1.05	1.08	1.15	1.27

Comparing data in Table 2 it can be noticed that more intense comminution is observed for material from Polkowice. After ten minutes of grinding particle size distribution curves of both material were similar, but comminution effectiveness measured by means of comminution degree value were higher for ore from Polkowice.

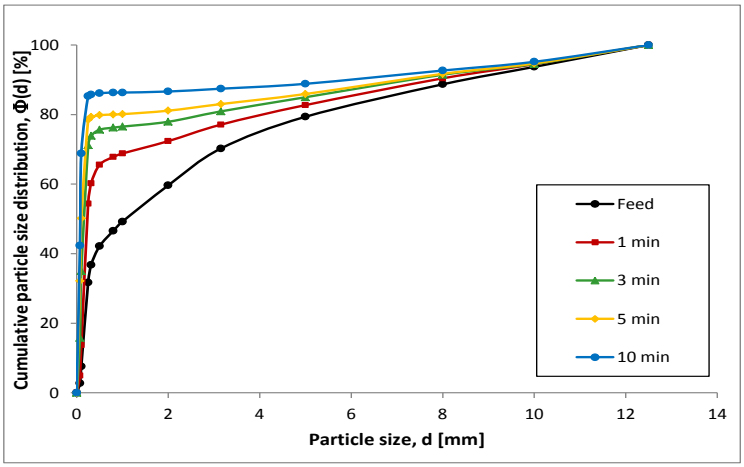

Fig. 3. Grinding kinetics for feed material from Rudna

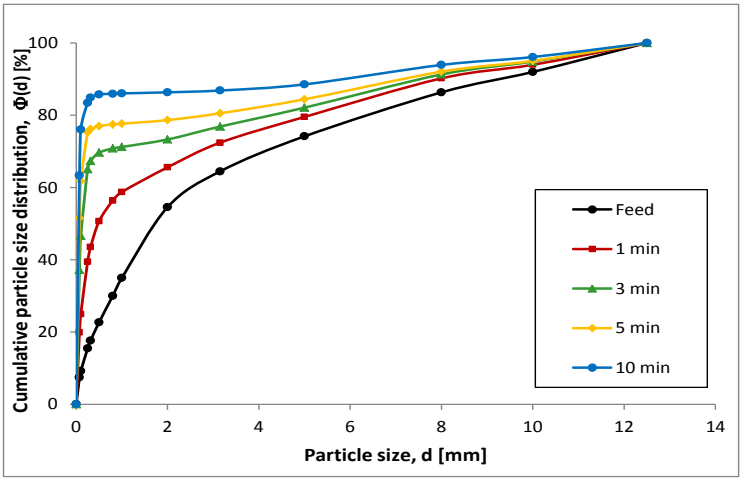

Fig. 4. Grinding kinetics for feed material from Polkowice

Results of investigations

As it was mentioned in previous section, research programme included investigations over lifetime performance of individual type of rolls; technological effectiveness in terms of comminution ratio and throughput and economic effects (energy consumption, capital cost). Manufacturers of each type of rolls have carried out tests, which enabled them to determine an approximate time of roll service when crushing Polish copper ores. Results of these tests are presented in Table 3.

Table 3. Service time of different type of HPGR linings, for ore from Rudna and Polkowice plant

Type of roll's lining	Estimated period of service [hours]	
	Rudna	Polkowice
Hexagonal	5 500	8 500
Studded	15 000	15 000

Table 3 shows that the studded linings have a much longer estimated time of service in crushing of Polish copper ore, comparing with hexagonal rolls. One can deduct that in this case hexagonal linings are sensitive to the type of ore in favor of Polkowice feed material. Studded linings, in turn, have similar time of service, regardless the ore type. In general, service time for studded rolls is 44% longer for Polkowice ore and 53% longer for Rudna feed material, comparing to hexagonal linings. The results presented in Table 3 confirm, to a some extend, incomplete literature data and information that can be found in HPGR catalogues. However, the results from Table 3 are valid only for specific type of material (here: Polish copper ore), and drawing a more general conclusions on the basis of these tests cannot be justified.

Linings lifetime service is a very significant issue, influencing the HPGR effectiveness performance, but there are also some other operating parameters of a key influence on high-pressure grinding process. The next aspect under investigation was technological effects. Table 4 presents comminution degrees obtained for both types of ore depending the type of linings.

Table 4. Comminution degrees for Rudna and Polkowice ore obtained for two types of linings under investigation

Comminution degree	Rudna		Polkowice	
	Studded	Hexagonal	Studded	Hexagonal
S50	6.66	5.70	10.31	8.53
S80	2.57	3.43	4.10	3.81
S95	1.91	2.90	1.35	2.47

The most favorable values of comminution ratio in terms of average index (S_{50}) were obtained for Polkowice ore, and comminution process in HPGR device equipped with studded rolls, was more effective. On the other hand, maximum comminution degrees (S_{95}) were more favorable for Rudna feed material and here hexagonal rolls have performed in a better manner than studded ones.

Energetic results

Energy consumption is another factor of a key significance, influencing the overall effectiveness of comminution operations. On the basis of power draw values of both HPGR devices and their productivities, the specific energy consumption index (E_{sp}) was calculated according to formula (1):

$$E_{sp} = \frac{P}{Q}, \left[\frac{\text{kWh}}{\text{Mg}}\right], \tag{1}$$

where: P – total power draw during individual test [kW], Q – throughput of device [Mg/h].

Figure 5 presents the obtained results. It can be noticed, that operation of HPGR with hexagonal linings received higher energy consumption value, comparing to HPGR device with studded linings. Various values of E_{sp} were also obtained, depending on whether the feed material was from Rudna or Polkowice. In general, more favorable energetic results were achieved for ore from Rudna. Depending the type of linings, E_{sp} values were lower by 5 and 20 per cent for hexagonal and studded linings, respectively. Studded lining might possibly consume nearly 30% less energy (for Rudna) and roughly 15% (for Polkowice) comparing to hexagonal ones.

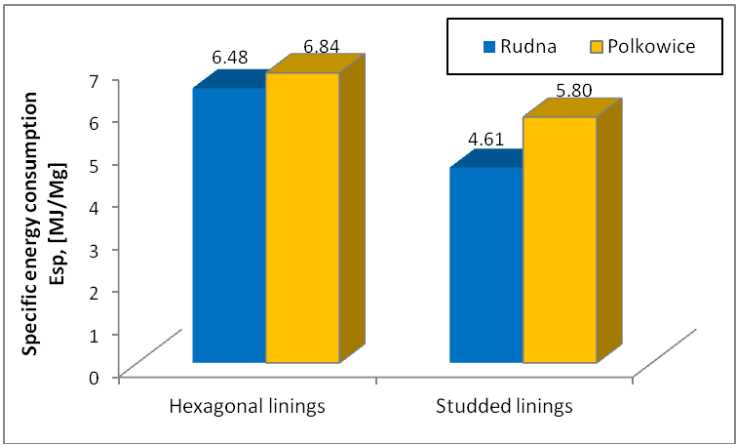

Fig. 5. E_{sp} values for HPGR equipped with studded and hexagonal linings obtained for feed material from Rudna and Polkowice plants

Table 5 presents results concerning the throughput of HPGR comminution process for both types of linings. The comparison of throughput is not an easy task, considering that both machines have operated at slightly different operating conditions, defined independently by each manufacturer. To overcome this problem the index of specific throughput (M_{dot}) was used, defined by formula (2):

$$M_{dot} = \frac{Q}{D \cdot l \cdot v}, \left[\frac{\text{Mg·s}}{\text{h·m}^3}\right] \tag{2}$$

where: Q – throughput [Mg/h], D – rolls diameter [m], l – width of rolls [m], v – peripheral speed of rolls [m/s].

Table 5. M_{dot} values for ore from Rudna and Polkowice, obtained in HPGR equipped with various type of linings

	Rudna		Polkowice	
	studded	hexagonal	studded	hexagonal
M_{dot} [Mg·s/h·m^3]	306	239	203	208

Even though this index is commonly used in evaluation of HPGR productivity, it's interpretation might not be obvious for those who are not familiar with HPGR scaling-up procedure. However it is very important index, because it allows for comparing the productivities of HPGR with various dimensions. In general, the index characterizes a "volumetric" throughput, i.e. the throughput which can be obtained per unit of operational volume of HPGR. The higher value of the index, the more favorable productivity of HPGR is achieved for specific operational conditions and given type of feed material. Results in Table 5 show that more favorable effects of high-pressure comminution in terms of productivity were registered for studded rolls for Rudna, while for Polkowice slightly better results were observed for hexagonal rolls. In general, better throughput results were obtained for feed material from Rudna.

Assessment of HPGR product grindability

The HPGR comminution effects have a potential impact on the course of downstream grinding operations in ore enrichment circuit. According to various publications, possible energy savings in downstream grinding operations for HPGR products can reach up from 10 to 40% (Rule et al., 2008; Pahl, 1993; Fuerstenau et al., 1991).

HPGR products from each HPGR test was subject to ball mill grinding in order to determine potential benefits resulting from high-pressure compression of material in HPGR working chamber. In order to verify the results obtained for Polish copper ore, an assessment of HPGR product energy-consumption in ball mill, was performed by determination of the Bond's work index value. Results are presented in Table 6.

Table 6. Values of Bond's indices for HPGR feed and products

Material	Bond's index value [MJ/Mg]			Potential energy savings [%]	
	HPGR feed	HPGR product (studded)	HPGR product (hexagonal)	studded	hexagonal
Rudna	50.868	40.932	41.04	19.5	19.3
Polkowice	40.428	35.316	36.936	12.6	8.6

Results show that the HPGR effect, considered as lower ball mill energy consumption, is generally higher for ore from Rudna (greater than 19%), than for ore from Polkowice (from 8.6% to 12.6%). Both types of lining are capable to reduce ball mill energy consumption for the Rudna ore by more than 19%, while for the Polkowice ore, the results are more favorable for studded rolls.

Results of grinding kinetic tests, carried out in a laboratory Bond mill, are presented in Table 6. Each HPGR product was ground for 10 minutes, and its particle size composition after 1, 3, 5 and 10 minutes were determined, along with values of d_{50}, d_{80} and d_{95}.

Table 6. Ball mill grinding results for ore from Polkowice and Rudna, obtained for various types of linings

Type of ore	Grinding time [minutes]	Type of lining	S50	S80	S95
Rudna	1	studded	29.90	4.68	3.05
		hexagonal	36.21	7.97	3.40
	3	studded	43.08	6.87	3.06
		hexagonal	57.69	66.04	3.80
	5	studded	70.06	24.96	3.08
		hexagonal	82.21	86.96	4.15
	10	studded	88.02	95.36	3.17
		hexagonal	88.59	109.26	4.91
Polkowice	1	studded	32.25	4.44	2.85
		hexagonal	40.86	4.72	2.75
	3	studded	122.06	5.35	2.95
		hexagonal	125.88	6.31	2.78
	5	studded	226.25	8.07	2.98
		hexagonal	189.33	27.14	2.80
	10	studded	277.92	126.74	3.30
		hexagonal	193.69	106.70	2.84

Analyzing data in Table 6 it can be noticed that in most cases the obtained values of comminution ration were more favorable for HPGR equipped with studded rolls. The hexagonal rolls, in turn, reached better grinding effects for ore from Rudna for an average (d_{50}) and eighty-percent (d_{80}) comminution ratio.

Economic effects

Economic effect were assessed through analysis of capital costs of HPGR devices and cost of spare set of rolls. Table 7 presents respective types of costs in percentage values, because in each variant of HPGR press equipped with studded rolls appeared to be more expensive than HPGR with hexagonal linings. For purposes of more clear comparison, all costs concerning the hexagonal lining were presented as a percentage values of respective cost for studded HPGR press.

Table 7. Investment costs of HPGR devices equipped with different types of linings (percentage)

	Rudna	
	studded	hexagonal
HPGR device	100%	84%
Spare rolls	100%	78%
	Polkowice	
	studded	hexagonal
HPGR device	100%	65%
Spare rolls	100%	90%

In terms of economy hexagonal linings appear to be more beneficial, both for HPGR device and spare sets of rolls.

Final discussion and conclusions

The main aim of this paper was to compare the effectiveness of HPGR operation due to different linings of rolls. The obtained results show that the type of roll surface in HPGR significantly influences the high-pressure comminution process both in terms of technological effects measured through comminution ratio values, and from economic point of view. Summarizing the investigations, important conclusions may be drawn.

More favorable energetic effects were generally obtained for studded linings and for material from Rudna. In terms of throughput indices, studded rolls achieved values by 21% higher, comparing hexagonal linings, and better results were also obtained for material from Rudna.

Higher values of comminution ratio were obtained for ore from the Polkowice, however it is difficult to state unequivocally which type of linings have more favorable impact on the HPGR crushing effect. On the basis of the above research programme, it can be assumed, that comminution effects for both types of rolls are comparable.

Potential application of the HPGR devices in comminution of Polish copper ores would effect in reduction of the HPGR product grindability (lower values of Bond's working index) and energy saving in downstream ball mill grinding process.

On the basis of the above conclusions it can be stated that application of high-pressure grinding rolls into technological circuit of Polish copper ore processing should be beneficial in terms of technological and economic aspects. These investigations, however, should be rather regarded as initial research and further analysis will be necessary before potential application of HPGR. Some simulation models of HPGR performance should be developed, which enable us to characterize the effectiveness of HPGR in terms of technology, economy and ecology (Morrell et al., 1997; Tavares, 2005; Cleary et al., 2008; Saramak, 2013).

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