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HIGH PRESSURE GRINDING ROLLS—A PROMISING AND COST-EFFECTIVE TECHNOLOGY OF ORE PRETREATMENT IN MINERAL PROCESSING

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Mineral mining and processing industry increasingly focuses on efficient grinding systems in recent years worldwide, mainly, because of growing energy cost and global water deficit. This trend will only intensify in years to come; as ore reserves are being depleted, the time and energy consumed to recover ore will simultaneously grow. Energy-efficient grinding systems, such as high pressure grinding rolls technology, are the technically and economically viable solution to challenges that mining and processing industry faces or will face soon. From the practical evidence, HPGR raise competitive capacity in mineral mining and processing, which is particularly crucial at the time of unstable or tumbling prices of mineral raw materials. Today HPGR are used in various production processes.

HPGR work in tertiary crushing circuits to prepare feed for the next-following ball milling, or as quaternary grinders aimed to enhance productivity. Furthermore, HPGR serve for pebble crushing in semiautogenous milling, iron ore grinding and final disintegration.

High pressure grinding rolls offer solution to a number of key problems in mineral dressing. Majority of ore bodies contain lower grade ore that is harder or difficult-to-process as against previous time; therefore high productivity processing plants need minimization of operating cost in order to reach profitability.

The article gives a review of the experience gained in the use of high pressure grinding rolls (HPGR).

Grinding efficiency has been acquiring more importance in the world's mining and processing industry in recent years, mainly, because of growing energy costs and global water deficiency. This trend is going to intensify from now on. The time and energy consumed for ore disintegration will grow in proportion to the depletion of ore reserves. Energy-efficient grinding, such as HPRG, is the technology- and energy-healthy solution to the problems that mining and processing industry is and will be facing. Experience practice shows that HPRG raise competitive capacity of mining and processing industry, which is exceptionally important in the days of unstable or loosing market of raw materials. Since its introduction to cement production in the 1980s, HPGR have become the commonly accepted and proved technology of hard and abrasive ore processing. Currently, HPGR enjoy wide application in various raw material treatment technologies.

HPGR are included in fine crushing installations to prepare a feedstock for ball mills, or to re-crush ore for the enhancement of output. Furthermore, HPGR are used to produce pebble, which is a semi-autogenous milling product, iron ore, etc.

Key words: *high pressure grinding rolls, rolling press, rocks, minerals, ball mills, fine crushing, regrinding, pelletizing.*

High pressure grinding rolls were successfully introduced in the cement industry in the late 1980s and enabled appreciable reduction in energy consumption. Promptly enough their potential was realized in mineral mining industry. Strikingly efficient in diamond ore processing, HPGR immediately found application there in spite of imperfect technology and stringent requirements under conditions of highly abrasive media.

Following the diamond industry, the iron ore industry introduced HPGR technology in the mid-1990s, mainly in regrinding circuits.

Nevertheless it took certain time to design HPGR capable of hard rock destruction. One of development stages of the new grinding technology is the increase in the wear resistance of roll faces aimed at saving of maintenance cost and at higher rate of equipment use even in processing of strong abrasive and high-silica ore. **Fig. 1** illustrates growth in number of HPGR in service in mineral mining and processing industry within recent years.

Fine crushing with HPGR

Great many HPGR work at mineral processing plants at the stage of fine crushing before ball milling. Cerro Verde Mine (Freeport-Mc-MoRan, Peru), Newmont's Boddington Gold Mine (Western Australia) and Anglo Platinum's Mogalakwena operations (South Africa) are the first and large users of HPGR technology in new processing plants (**Fig. 2**).

Four HPGR Polycom-24/17 manufactured by ThyssenKrupp Resource, each equipped with two 2500 kW motors, came into operation in Cerro Verde mine in 2006 and have the longest service life by now. Mogalakwena began using one HPGR Polycom-22/16 in 2008, and four HPGR Polycom-24/17 have been operated in Boddington mine since 2009.

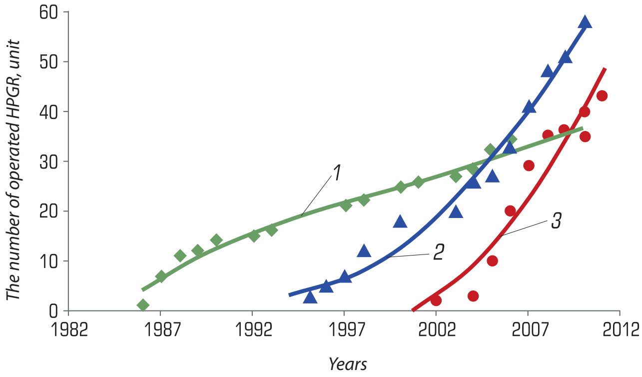

Fig. 1. Number of HPGR in service in various mineral processing by years:
1 — diamond ore; *2* — iron ore; *3* — hard rocks

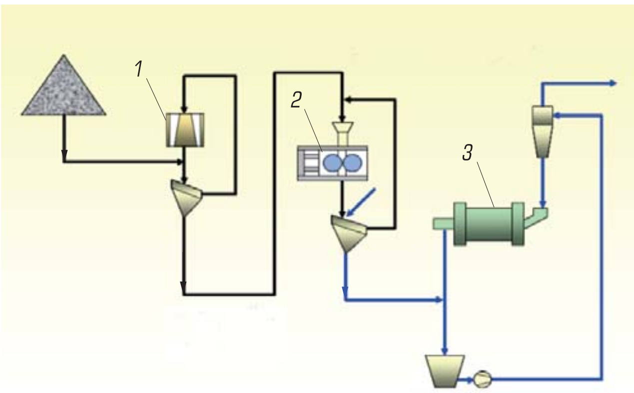

Fig. 2. Standard fine crushing with HPGR:
1 — medium crusher; *2* — HPGR; *3* — ball mill

These grinding rolls exhibited higher capacity and lower energy consumption than was expected. A single Polycom-24/17 treated over 3 thousand tons of gold-bearing copper ore per hour. Cerro Verde mine HPGHR grinds 120 thousand t/day as against 108 thousand t specified by the equipment standard. This can be explained by the underrated standards excepted initially since there was no long service experience and the expanded performance capabilities were doubtful. However, HPGR proved higher capacity with lower specific energy consumption as compared to the initially expected performance.

The first wear protection methods for grinding rolls were successfully improved in accord with characteristics of a particular ore type subjected to processing, which greatly cut down expenditures associated with the wear and raised operational preparedness of HPGR up to more than 96%. A copper processing plant in South Africa managed to extend service life of rolls by more than 200%.

Sometimes HPGR can improve economic performance due to reduction in maintenance cost as compared with the conventional semiautogenous (SAG) milling, especially if ore is very hard. SAG mills are extremely sensitive to variation in ore strength, and hard ore processing may consume up to 15 kW·h/t of electric energy, while the energy consumption by HPGR is never more than 2.5–3.5 kW·h/t even in grinding the hardest ores. Nevertheless advantages and shortcomings of HPGR should be compared with SAG mills in each individual case.

Energy consumed in medium crushing, HPGR grinding and ball milling can be 40% lower as against SAG milling, which allows reduction of cost by more than USD 1 per ton for some types of ore. As a rule, HPGR is more advantageous for harder ore. Insensitiveness of HPGR to variation in ore properties favors sustainable performance of the entire processing plant.

The experience gained in Cerro Verde, Mogalakwena and Boddington has been fruitfully used. Last year, Vale's Salobo copper project phase I was put into production. Treatment of ore in amount of 33 thousand t/day uses four HPGR Polycom-20/15, each equipped with two 1800 kW motors, and four ball mills with a diameter of 7.9 m and 13.4 m long, run by 17 MW gearless drives.

At Sierra Gorda project, Chile, a new copper processing plant with a capacity of 110 thousand t/day will use four HPGR Polycom-24/17 and three ball mills (diameter 7.9 m, length 11.34 m, gearless drive 17 MW), and Peru's program of productivity boosting up to 240 thou t/day envisages using eight HPGR Polycom-24/17 and six ball mills (diameter 8.2 m, length 14.6 m, gearless drive 22 MW).

Quaternary crushing with HPGR

HPGR are efficiently included at stage IV of the current tertiary crushing circuit to produce finer feed for ball milling and to raise overall productivity. Single pass grinding by HPGR is the simplest solution (**Fig. 3**). A plant's capacity in terms of the final output grows owing to larger volume of flotation feed (with its coarseness unchanged), or due to reduction of size of the ball mill discharge at the same yield of product. Two HPGR Polycom-20/15 entered into service in Grasberg gold mine, Indonesia, posses the longest operation life in that mode. According to the available evidence, the ore pretreatment output grew by 15%.

As a rule, adding stage IV with HPGR contributes to growth of productivity of a processing plant by 10% and sometimes by more than 30%. In a short time, HPGR Polycom-24/17 is going to come in the same mode operation in Cuajone copper mine, Peru.

Semiautogenous milling of ball mill feed

Since the mid-1990s, HPGR were thought to be a promising alternative for ball mill feed pretreatment. However, no sooner than by 2010, HPGR was the first time put in operation in hard rock crushing circuit at Penasquito project in Mexico (**Fig. 4**). HPGR Polycom-24/17 is entered in close-circuited grinding of SAG mill discharge, which enables open circuit SAG milling.

That scheme yields the highest efficiency when very hard rock conditions high yield of coarse grains in SAG mill discharge. Open circuit operation of SAG mill will ensure maximized productivity.

In 2012 Cadia Hill open pit mine in Australia modified HPGR Polycom-24/17 to implement pretreatment of SAG mill feed and concurrently produce crushed stone. In recent years stronger ore is expected to come and productivity decline is anticipated; for this reason, HPGR have been timely installed as a preact. At the present time, two HPGR Polycom-20/15 are manufactured for ball mill feed pretreatment for two copper mines in Kazakhstan.

All in all, upgrading or HPGR introduction in SAG milling circuit will enable growth of productivity by 10–25% in case a SAG mill is a "neck stage" and there is sufficient margin of power of ball mills. Various flow charts can be selected subject to demands of a particular consumer.

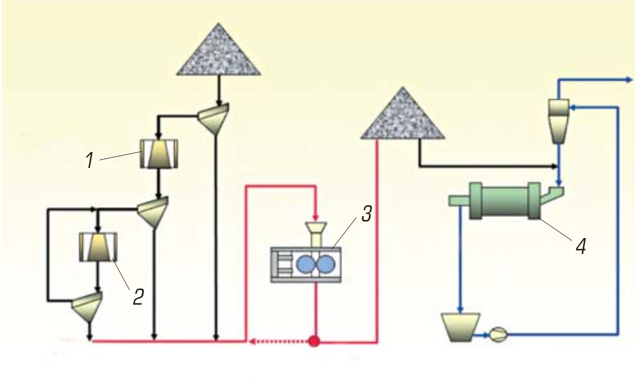

Fig. 3. Flow chart with crushing stage IV with HPGR:
1, *2* — crushing stage II and II crushers, respectively;
3 — HPGR; *4* — ball mill

HPGR in iron ore industry

ThyssenKrupp HPGR mills have shown themselves good in iron ore industry. The first HPGR was employed in iron ore mining industry in the 1990s in grinding iron concentrates for pelletizing. That time the grinding rolls had smooth or ribbed wrought shells (lining). That technology was borrowed from cement industry where it has still been applied as clinker and limestone possesses low abrasiveness. Studded surface grinding rolls in service in these days have the same durability, and even higher, in different operating modes.

Typically, iron ore concentrate is treated in ball mills up to a size suitable for agglomeration (pelletizing). Pelletizing requirements limit moisture content of feed down to 8–9%; therefore, ball mill slurry should be dewatered and filtered (**Fig. 5**). At the same time, it is known that it is more complicated and costly to remove excess water (dewatering and filtering) from smaller size grains. It would be reasonable to replace, totally or partly, ball milling for HPGR wet grinding after filtering. This substitution makes it possible to shorten the time of iron ore inside a ball mill, the ball mill output grows as a result, and a larger size product is obtained. The grain size required for pelletizing is reached in further HPGR grinding (Fig. 5). In so doing, energy consumed by milling, ball mill wear and power taken by filters are reduced.

Another scenario of the flow chart is to keep the duration of grinding to have the required size product of the ball milling at the higher reduction number as against the circuit without additional HPGR grinding. This flow chart is used by Vale's pelletizing plant in Vitoria, Brazil. The flow chart involves three ball mills manufactured by ThyssenKrupp (diameter 5.5 m, length 12 m) with 5.35 MW Combiflex drives and one HPGR Polycom-20/15 with a capacity of 3.3 MW. The ball milling product has a specific surface area of 1500 cm^2/g. Single pass HPGR grinding yields a pelletizing product with a specific surface area of 2000 cm^2/g at an overall capacity of 1000 t/h. Pre-pelletizing grinding by HPGR is used by San Luis plant, Brazil, too. This flow chart includes three HPGR Polycom-17/12 with a capacity of 2 MW. The grinding product has a specific surface area of

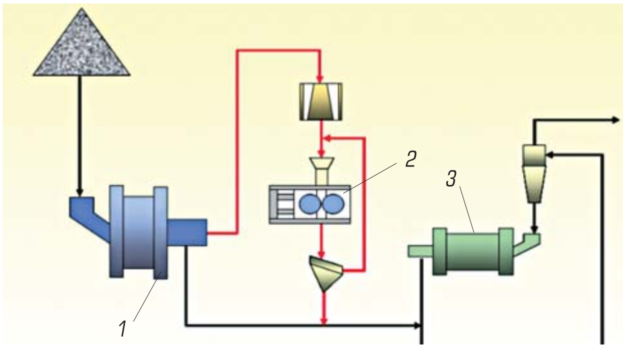

Fig. 4. HGPGR in grinding coarse fraction of SAG mill discharge:
1 — SAG mill; *2* — HPGR; *3* — ball mill

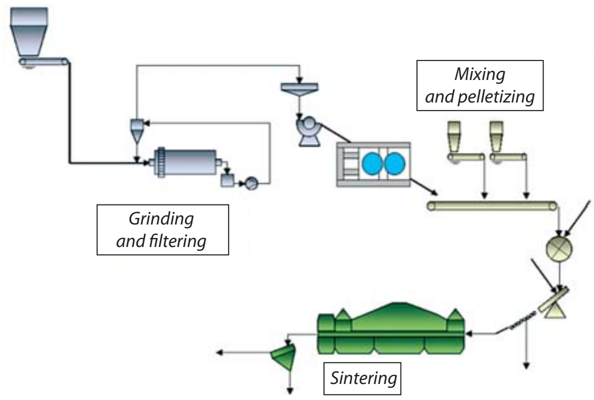

Fig. 5. Ball mill and HPGR chart for iron concentrate grinding before pelletizing

Fig. 6. HPGR Polycom-30/20 model

2000 cm^2/g at a capacity of 650 t/h. Ball milling stage I becomes unnecessary as the iron ore concentrate feed for pelletizing has a specific surface are of 1200 cm^2/g. So, grinding is only performed by HPGR.

Currently ThyssenKrupp develops projects toward total elimination of ball mills from mineral preparation flow charts. That will allow up to 50% saving of energy as compared to standard grinding charts with ball mills, depending on physico-mechanical parameters of a particular ore type.

Within recent 15 years, ThyssenKrupp has supplied more than 25 HPGR mills, mostly, to Brazil and China. In 2012 Gindalbie Metals Ltd commissioned the Karara magnetite project in Australia. For ore processing in amount of more than 50 thousand t/day, four ball mills (diameter 6.3 m, length 10.3 m) with 4.1 MW Combiflex double drives were added with two HPGR Polycom-24/17. Three HPGR Polycom-24/17 are put in service at Anglo-American's Minas Rio project in Brazil to produce fine ground feed for ball mills.

Prospect objectives

HPGR allow handling a few key challenges in mineral dressing. Majority of ore bodies currently under mining feature low content of commercial value components, as well as increased coarseness and low dressability of ore. In connection with this, a mineral mining and processing plant has to continuously improve the accepted technology to be profitable.

Energy cost grows, too. Moreover, probable introduction of CO_2-based certification may result in reduction of available energy for future plants. Full output of a plant may be abridged by energy input of ore pretreatment cycle, so it is urgent to find ways of energy saving.

At the moment market offers a number of high-performance HPGR models. The largest model manufactured by ThyssenKrupp is Polycom-30/20 with the ensured capacity up to 6 thousand t/h in terms of gold ore (**Fig. 6**). High unit capacity equipment is very appealing to processing plants. However, consideration should be given to total purchase cost of equipment, and its assembly and maintenance costs. Higher capacity machines have pros and cons, and it will be interesting to see how they are accepted by the mining and processing industry.

The current research and development aims at reduction of capital and operating costs associated with HPGR and, mainly, at the potential expansion of HPGR range of application. Earlier, cement industry proved higher efficiency of HPGR as against standard ball mills, and there is a chance to improve mineral dressing performance by entirely avoiding standard ball milling.

The cement industry employs HPGR for limestone, slag and clinker grinding down to final size of 45–90 µm. HPGR operate in closed circuit with pneumatic classifiers. A cement plant in India grinds hard limestone with the Bond Ball Mill Index to 16 kW/t to a size of 90 µm at the energy consumption of 11 kW·h/t, including all loading and hauling equipment and a system fan.

Application of HPGR to fine crushing can reduce water consumption. For instance, in magnetite processing, it is possible to expand application range of dry magnetic separation owing to finer grinding by HPGR close-circuited with pneumatic classifier. This will both save energy consumed by grinding and reduce water loss owing to larger amount of dry tailings obtained at the end.

Surely, HPGR do no miracles but they have proved their ability to turn not-paying business into profitable production. EM

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