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High pressure grinding rolls—applications for the platinum industry

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High pressure grinding technology has gained further interest in various industries. So far in the mining industry, machines are in operation in diamond mines and iron ore applications.

In gold and copper ore processing, test work has been conducted showing considerable operational and process benefits.

Similar benefits can be expected from HPGR applications in the platinum industry due to the preferred ore breakage along grain boundaries, thus liberating the PGE particles.

This paper will provide an update on the state of high pressure grinding roll technology. Developments in the design of high pressure grinding rolls, for minimized maintenance requirements and availability just as high as conventional mills, will be presented.

Plant flow sheets and concepts will be discussed, which allow for a reduction of capital and operating cost in comparison to existing two-stage milling circuits.

Introduction

High pressure grinding roll technology has become a standard processing step in several industries (mainly in iron ore and diamond-bearing rock) over the last 15 years. Applications range from iron ore concentrate, where the ore feed is smaller than 1 mm with a moisture content of more than 10%, up to diamond ores with feed sizes of up to 150 mm and a moisture of 3 to 5%. Hundreds of ore samples have been tested to allow for a good prediction of the behaviour of the ore in an HPGR.

Process and economic benefits have been documented from several commercial installations. HPGRs are being evaluated now for hard rock applications in the copper and gold mining industries. There this technology offers significant benefits in comminuting competent and abrasive ores. Benefits may include reduced energy consumption, lower wear cost, higher throughput in milling circuits, and improved metal recovery in heap leaching applications. Recently the platinum industry started looking at the benefits high pressure grinding technology can offer to their operations.

Based on experiences collected from test work with gold and copper ores, an improved liberation and better flotation recovery can be expected at a given grind/crush size after subjecting the ore to the high pressure grinding process. This is due to the formation of microcracks and the fact that breakage occurs around grain boundaries rather than across the grain itself. It is believed that the fracturing occurs predominantly at the weak spots of a grain where the mineralization of the valuable constituents takes place.

Several platinum ores out of South Africa were tested in the laboratory to investigate the comminution properties and the wear characteristics. Test results from a UG2 and a Platreef ore will be shown in the first part of this paper.

In the second part, potential flow sheets for plant upgrades and green field installations will be presented.

The main concerns reported from the platinum industries are the absence of reference installations in the platinum industry, wear rate and the operational availability of the HPGR units. Therefore potential risks with respect to operation, maintenance and availability will be discussed in the third part of the paper and will be compared to the standard milling circuit of the platinum industry, which consists of a SAG or AG–Ball milling circuit.

Results from test work from platinum ore on HPGR

Test work has been conducted on two South African platinum ores. One being a Platreef ore, a sample of which consisted of pebbles from an AG circuit. The second one consisted of a UG2 ore obtained from a crushing plant feeding a rod and a ball mill. Both samples were treated on a pilot scale HPGR and on a small-scale wear testing unit to determine the HPGR abrasion index of that material.

Wear rates

Determination of the wear characteristics of an ore is accomplished by testing a 100 kg sample on a small-scale HPGR. The unit is called ATWAL and is used to establish an HPGR wear index. This ATWAL wear index (ATWI) is applied to determine wear characteristics of different feed materials. The weight of the rolls is determined before and after the test. The specific wear rate is calculated as the ratio of the 'loss of weight of the rolls' divided by the amount of treated material.

The wear rates given above refer to Nihard IV at the specific conditions on the ATWAL abrasion test unit. *They do not reflect the wear rate on full size industrial rolls*. This ATWAL wear index (ATWI) has to be scaled up to full scale industrial units in order to estimate the service life of industrial wear protection surfaces with studs. The scale-up has to take into account the finally selected roll size and speed.

Scale-up factors are derived from a database collected for the various materials, currently high-pressure ground in industrial applications.

Corresponding wear rates on the ATWAL (ATWI) for other ores, which are industrially high-pressure ground, are:

Kimberlites (Canada)	:	> 6 g/t in most cases > 20 g/t
Lumpy iron ore	:	5 to 10 g/t
Copper/gold ores	:	very abrasive > 40 g/t
	:	medium abrasive 10 to 40 g/t
	:	low abrasive < 10 g/t

Scale-up to full size industrial rolls takes into account the final roll diameter and speed of the rolls selected, type and length of the studs employed, as well as the feed characteristics of the material to be treated, i.e. size and moisture. The scale-up is founded on data collected on various ores treated in industrial high pressure grinding rolls.

Platreef ore

A sample was collected from the discharge of a fully autogenous mill and precrushed to fit the feeding requirements of the test unit. The ATWI obtained was 0.57 g/t. The abrasiveness of this ore sample was among the lowest of the many ores tested in our research lab.

Based on these results, the expected lifetime of roll liners is more than three years, depending on the finally selected size of the unit, the feed size and the operating conditions.

UG2 ore

The UG2 ore sample was obtained from a crushing circuit feeding a rod ball milling plant. The ore tested did produce a wear rate of 18 g/t. It shows a wear characteristic on the rolls, surface like a medium abrasive copper/gold ore. For an industrial sized unit, a lifetime for the studded rolls of about 6 000 operating hours can be expected.

This result for both ores tested is depicted in Figure 1. From this graph it can be seen that platinum ores can be considered as a low wear application for high pressure grinding rolls.

Comminution Properties

Platreef ore

The ore sample tested consisted of crushed pebbles from an AG mill. For a case study, a plant arrangement as depicted in Figure 6 was assumed. Based on the test results of the ore, a scale-up to a size distribution for an industrial sized HPGR was derived. This size distribution is depicted in Figure 2. This assumes a pebble crusher product of minus 25 mm as HPGR feed material. The energy requirement for the HPGR is estimated to be 1.6 kWh/t.

As can be seen from Figure 2 the HPGR discharge already contains 30% of product finer than 240 micron or 16% of product finer than 74 micron. In case the plant layout permits, this material can be fed to the ball mill sump and removed in the cyclone. Depending on the metallurgical properties of the ore, an additional recovery step can be implemented between the HPGR and the ball mill.

Opening up the AG/SAG mill should allow for an increase of throughput of 20 to 40%.

An AG/pebble mill circuit treating iron ore was converted adding an HPGR to crush pebbles of the AG mill. Improvement of plant performance and results were published by McIvor *et al.*[1].

UG2 Ore

A plant treating UG2 ore provided a sample obtained from a crushing circuit feeding a rod/ball mill plant. The HPGR was intended to be used as a fine crushing unit to boost capacity of the existing plant. In this application the HPGR should work in a closed circuit mode via a 4 mm screen.

Based on the test work conducted, an HPGR discharge as depicted in Figure 3 can be expected. The estimated screen product is shown in the same figure.

Such a circuit would supply a product with around 40% passing 74 micron and around 50% passing 210 micron. Also in this case, the screen product should report to the pump sump of the ball mill in a reversed closed circuit (Figure 4). This minimizes overgrinding and potential slimes, formation. It further reduces the recirculating load of the ball mill.

Flow sheet options

Today the standard process for the comminution of platinum ores is two-stage milling and flotation (Figure 5). The first stage usually involves an AG or a SAG mill operating in closed circuit, followed by a second stage ball mill. Usually the AG/SAG mill works in closed circuit with a vibrating screen, with the screen overflow reporting back to the primary mill inlet. Screen product reports to a primary float circuit. The thickener product reports to

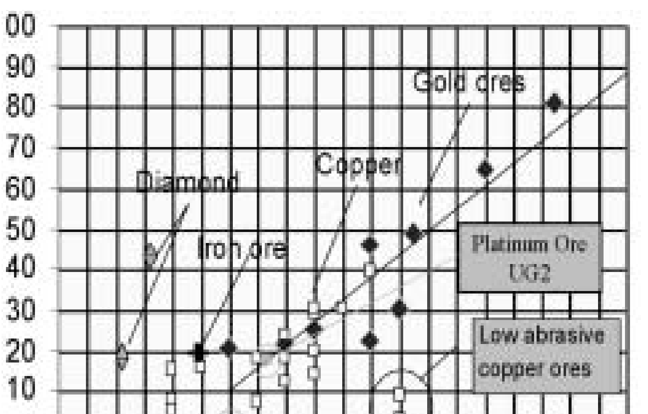

Figure 1—ATWAL wear index for various ores

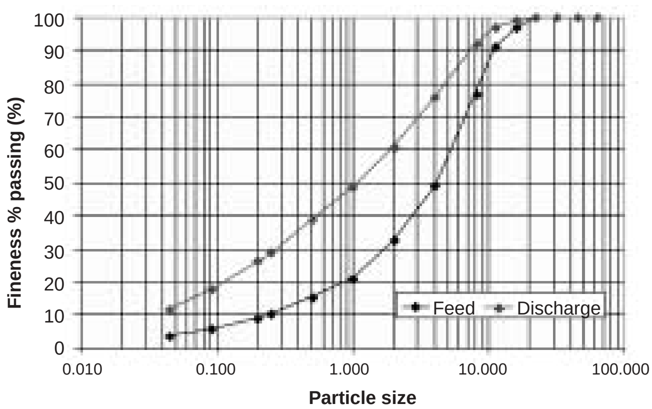

Figure 2. Expected size distribution for an industrial unit

dewatering cyclones. The float tails are fed to the secondary ball mill operating in open circuit.

Plant upgrade—HPGR in an AG/SAG mill circuit

In case the primary mill consists of a SAG or an AG mill, build-up of critical rock sizes in the mill charge can limit the capacity of the plant. These pebbles usually consist of rocks with sizes ranging from 35–50mm to 75–85 mm in diameter. Removing these pebbles from the mill and crushing them reduces this build-up and increases the capacity of the primary mills.

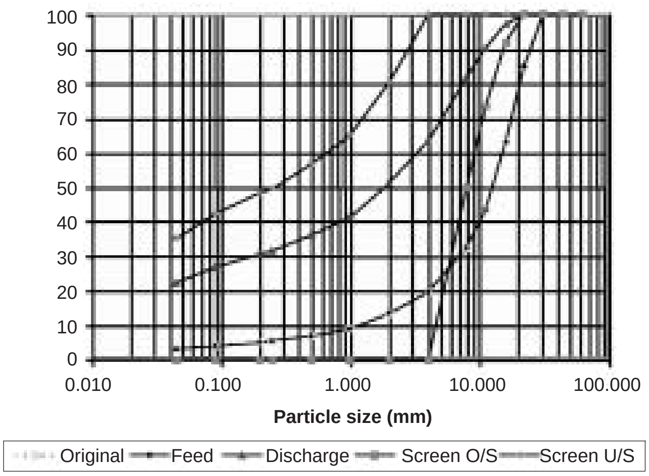

Figure 3. Size distribution for UG2 ore

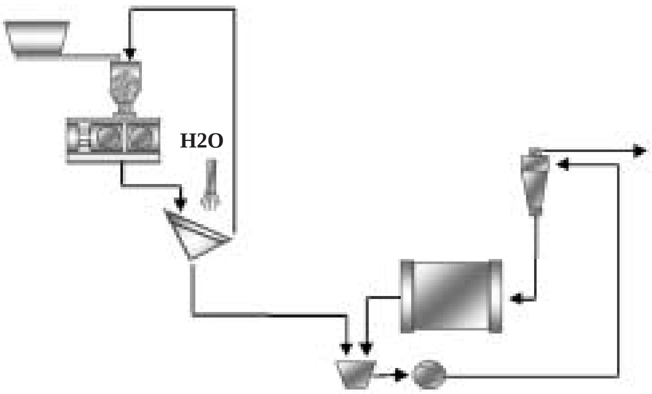

Figure 4. HPGR in closed circuit mode with a ball mill

Crushing these pebbles in a conventional pebble crusher produces a product that is too coarse to be fed to primary flotation and it does not contain sufficient finished product to have it reported to the mill pump sump.

The pebbles being discharged from the AG/SAG mill are too coarse to be fed to the HPGR. Therefore in most cases it is advantageous to install a pebble crusher ahead of the HPGR. Possible configurations are depicted in Figure 6.

If the HPGR is operated in an open circuit mode, the discharge can be added to the primary mill feed. However, pebble recycling can be a limiting factor for many plants where the AG/SAG mill throughput is the bottleneck. Operating the HPGR in closed circuit through a screen allows it to produce a perfect ball mill feed.

Test work on a Platreef ore showed that screen underflow may contain 30% to 35%–74 micron material and can therefore be fed to the pump sump of the secondary mill for immediate recovery without loading up the mill and minimizing overgrinding.

The selection of the flow sheet should be done based on the current utilization of the mill power and the plant layout. In an industrial application on hard iron ore, AG mill throughput increased by 30% by installing a HPGR in such a circuit.[1]

Concepts for an HPGR—ball milling circuit

High pressure grinding rolls can be built with throughputs of up to 2 000 tph and more per unit. Thus one HPGR can replace several tertiary crushers at the same time simplifying the plant concept. Maintenance requirements are greatly reduced by the recent developments of the studded rolls, surface with a new side protection system. This allows one to operate the HPGR for several thousand operating hours without the need to stop the unit for maintenance reasons.

There are several flow sheet options possible. The high availability offered by the new side protection and further developments in the stud design have opened the way to coupling the HPGR directly to the ball mill circuit—in a reverse closed-circuit configuration. In this arrangement, full advantage can be taken of the fines produced by the HPGR.

The advantages of this layout can be described as follows:

- Wet screening of the HPGR product eliminates potential dust problem.
- Finer cut sizes possible

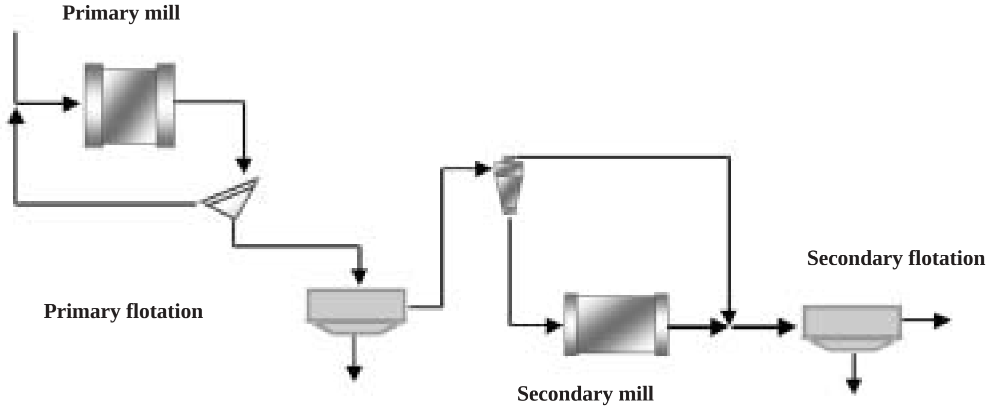

Figure 5. Typical flow sheet for a milling plant in the platinum industry

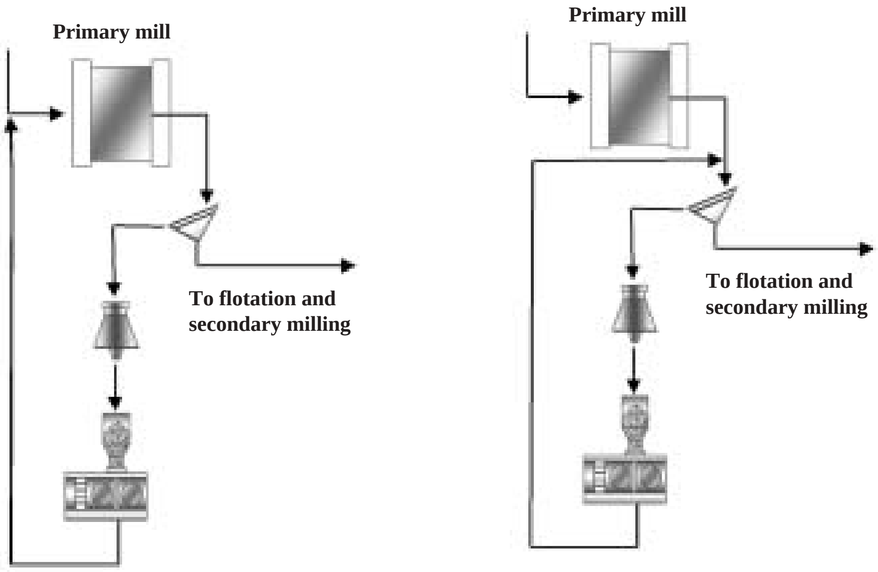

Figure 6. AG/SAG circuit with high pressure grinding rolls for pebble crushing

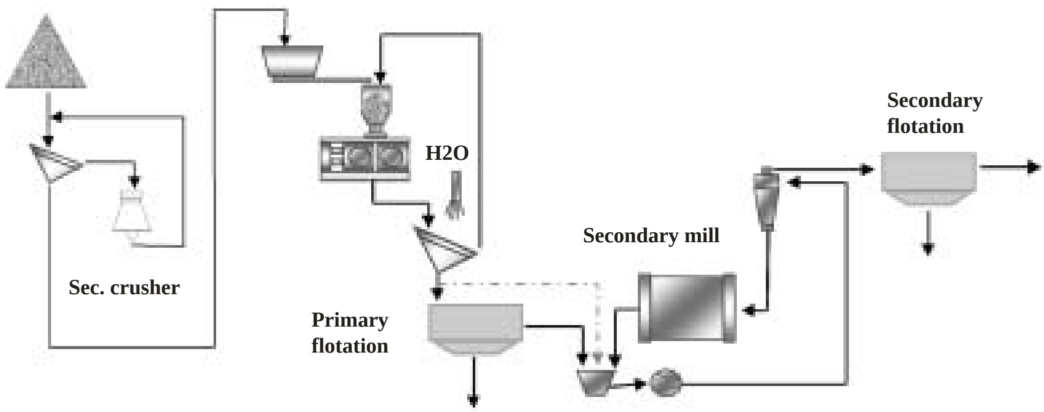

Figure 7. HPGR in closed circuit 'wet mode' (separating HPGR from the crushing circuit and combining it with the ball mill grinding plant)

- In most cases, excellent deagglomeration of HPGR product.

For the reasons explained above, the flow sheet as depicted in Figure 7 currently represents the favoured option.

In cases where the 'wet plant' consisting of the ball mill and the associated cyclone and the pump are to be separated from the 'dry–part' , the HPGR can be allocated within the crushing plant. This is depicted in Figure 8. There is a fine ore bin arranged in front of the 'wet plant'. The grinding mill can be operated independently from the crushing plant. The ball mill will be fed from this bin. Therefore the high availability of the wet grinding ball mill can fully be utilized.

In case the downstream ball mill is operated in open circuit, its feed rate can be adjusted in such a way that the desired grind size can be accomplished independently from the performance of the comminution equipment upstream from the ball mill.

Outlook—HPGR in dry grinding mode for finished product

Dry grinding of platinum ore in an HPGR working in closed circuit with an air separator can be accomplished as depicted in Figure 9. HPGR discharge material reports to a coarse separator where agglomerates impact to baffle plates and are dispersed in an air stream. Coarse particles, which cannot be lifted, will be collected at the lower end of the coarse classifier and recirculated to the HPGR. The finer part of the ore will be raised in a duct where the drying is accomplished. Finished product will be removed in a fine classifier and collected in a bag house. The grids are recombined with the fresh feed to the HPGR. Drying energy needs to be provided either by a hot gas generator or, where available, off gases from a smelter can be used.

Even though this system requires some effort to dry the ore and to install a gas handling system, it offers at the same time several advantages:

- Finish grinding can be done in a single-stage grinding plant. Depending on the rolls, size selected, the feed size can be up to 50 mm. Product sizes of 99% passing 44 microns are achieved in several industrial applications grinding slag
- This dry grinding circuit provides a steeper product size distribution through high efficiency separator as compared to a wet grinding plant with cyclones. The

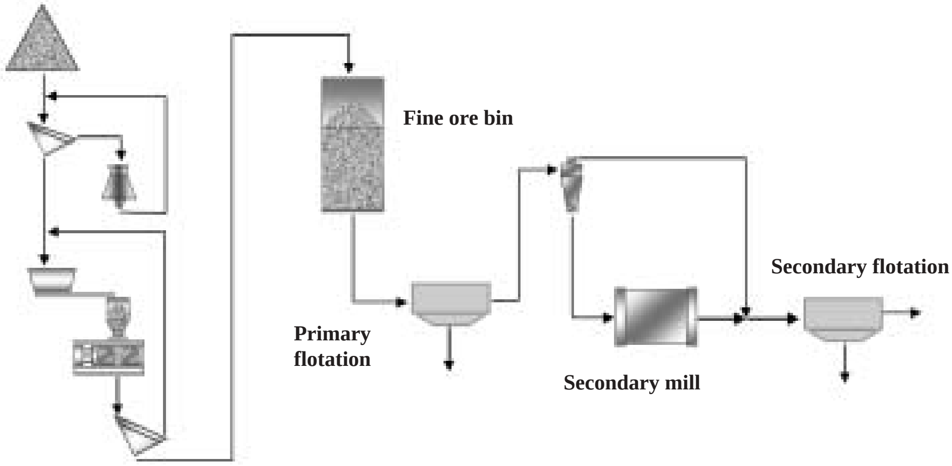

Figure 8. HPGR in closed circuit—'dry mode'

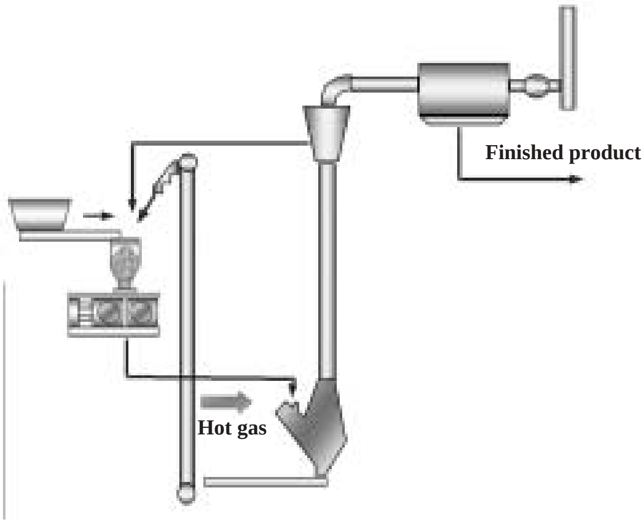

Figure 9. HPGR in dry grinding mode

product contains less oversize and ultra fine material and should result in better flotation efficiency
- Overgrinding is minimized due to the short residence time in the comminution equipment
- Such a circuit eliminates, as well, the need for a primary flotation stage
- Dry product can easily be stored. This allows feeding the downstream process independently from the grinding plant at a constant rate for optimum operating conditions
- If no off gases are available, the heating energy has to be provided by a hot gas generator. The amount depends on the moisture content of the ore. The cost for the drying energy has to be taken into account and balanced vs. savings on grinding media and potential metallurgical benefits from the downstream plant
- High pressure grinding is different from conventional comminution processes. Fracturing of particles occurs predominantly along the grain boundaries where the mineralization of the valuable constituents takes place. Thus it may be possible to operate the plant with coarser product size for optimum recovery. This, however, is ore specific and requires further research work.

The application of dry grinding requires an approach away from pushing tonnage towards optimizing recovery of the valuable constituents of the ore.

Risk aspects of an HPGR plant

Implementation of high pressure grinding rolls in the hard rock industry always faces the argument of the absence of experience due to the lack of an industrial application.

In the following section the potential risk aspects between SAG mills and an HPGR with respect to mechanical issues, operation, process and maintenance shall be discussed.

Mechanical and electrical components

Structure

Until now 250 HPGRs POLYCOM were sold by POLYSIUS only. There is not one single structural failure reported.

The design allows for a protection against overload conditions:

- safety devices, which control the crush forces by limiting the hydraulic pressure.
- the drive torque is controlled through a proven torque limiting clutch.

Even in cases where large tramp metal (like the teeth of shovel loaders) were fed to the HPGR, no failure of structural components occurred. The sturdy design of the unit and the safety devices limited the damage to a relatively small area of the rolls' surface, which could be repaired without causing major downtime.

Furthermore, certain operating conditions critical to the structure or the liners in the case of SAG and Ball mills, do not exist in the case of high pressure grinding rolls:

- Frozen charge—this phenomenon does not occur with HPGRs
- Grind outs are not an issue with HPGRs
- Operating conditions with cataracting grinding media being overthrown and smashing liners do not occur
- Lower sensitivity to ore variability i.e. grinding index.

Drive system

Motors

- An HPGR uses significantly less power as compared to

a SAG Mill. Also, there are two motors used for each HPGR. Therefore the motors used are usually standard motors, which can be sourced and maintained more locally. This results in better availability and lower cost for spare parts and service
- HPGRs start up under no load. This means less load on the power grid and less load on the drive system.

Mechanical part

- An HPGR is driven through two planetary reducers. Open gear drives are not required. This eliminates the need for maintenance and the risk of damaging drives through misalignment of ring gear and pinion. No cleaning of waste grease from the gear guard
- The number of parts involved in the drive train of a HPGR is less and has a lower loading. Lower number of parts with lower load results in less risk.
  The torque from the motor is transmitted from the motors through cardan shafts and the reducers directly to the rolls' shaft. No need for air clutches, pinion bearings and their lube units, pinions, ring gears, ring gear housings with the seals associated with it, greasing system etc.
- The drive train is efficiently protected against shock loads by safety couplings
- Wet grinding mills with large diameter ring gears and the associated seal face the risk of pulp ingress into the housing with the corresponding consequences. The same holds true for gearless driven grinding mills. HPGRs do not operate with pulp. Therefore the risk of pulp leakage through liner bolts or flanges does not exist.

Liner system

- There are reliable methods available to determine the lifetime of the wear liners of the rolls. Only a small material sample is required for testing.
- As opposed to wet grinding mills, liner surface can be inspected during operation through inspection doors. A locally damaged rolls' surface can be discovered and further action can be taken.
- The feed bin on top of the HPGR holds material for about 30 seconds. Therefore the unit is cleared of material in less than a minute. Access to the rolls' surface and to the components of the unit is right after stop of the unit.
- In case of local damage of surface by tramp metal, repair is possible through replacement of studs or local welding.

Operation

- HPGR uses only pressure to control the operation of the unit. Changes in press force does have an instantaneous impact on the fineness of the HPGR discharge. There is no need to control the level of mill charge and the addition of grinding media or pulp density. Therefore risk for wrong or suboptimal operation is less than in the case of wet grinding mills
- Due to the short residence time of material in the gap, steady state conditions are reached within a few seconds. After a crash stop i.e. in the case of a power failure, throughput and fineness of HPGR product are restored in a much shorter time, as is the case with any wet grinding mill
- In the case of variable speed drives, throughput can be changed within seconds to meet the requirements of the downstream equipment
- During start-up and stoppage of wet grinding plants, there is a certain amount of off spec material. In the case of HPGR application this is minimized.

HPGR faces the risk of damaging the liner surface through tramp metal. So metal detectors and a tramp metal removal system need to be installed to control the HPGR feed. This is not the case for AG/SAG mills. However, in case a pebble re-crush circuit is required, the same issue exists there as well.

Conclusions

- Wear rates from the platinum ore samples provided are among the lowest of all hard rock materials being tested
- The advanced studded roll liners with a new side protection system eliminates the need for maintenance on the rolls' surface. No welding of the sides is required. Maintenance of the whole unit is restricted to inspection and control functions between change-outs of roll liners. Most of these can be done while the unit is in operation.

Decision makers today have the option to choose either 'proven' technology with lower efficiency or to take the 'risk' of new technology with better economics.

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