

A STUDY OF THE ENERGY CONSUMPTION FOR GRINDING AN AUSTRALIAN GOLD ORE IN A HIGH PRESSURE ROLL MACHINE

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ABSTRACT

High pressure roller mills (HPR) are regarded as a potential alternative to replace conventional grinding machines, such as the ball mills which are currently widely used in the minerals processing industries. Their attractiveness arises from their size reduction characteristics and apparent power utilisation efficiency which in the cement industry have reportedly resulted in energy savings of 10 to 30 %.

To assess the applicability of the HPR for a mineral processing case, surveys were conducted on a laboratory scale machine with a gold bearing ore. Tests comprised the grinding of a homogenised sample under various grinding pressures and at two different roller speeds. Further tests consisted of recycling the oversize material from screened HPR products to determine the machine's performance in a steady-state closed circuit configuration.

It was demonstrated that the specific energy consumption of the HPR in closed circuit configuration was significantly lower than that calculated using the well known BOND equation for a hypothetical ball mill doing the same grinding duty.

Keywords: high pressure grinding rolls, energy consumption efficiency, size reduction efficiency, grinding.

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The high pressure roll mill was developed by Schoenert in 1979 after a fundamental study of interparticle crushing (Schoenert, 1979 [1]; Schoenert and Flugel, 1980 [2]) which indicated that the energy consumed for grinding some materials (eg. limestone and cement clinker) in a compressed bed of particles plus the amount used to subsequently deagglomerate the product were half of the energy used in a ball mill (Schoenert, 1988 [3]).

Figure 1 presents a schematic of a laboratory HPR mill.

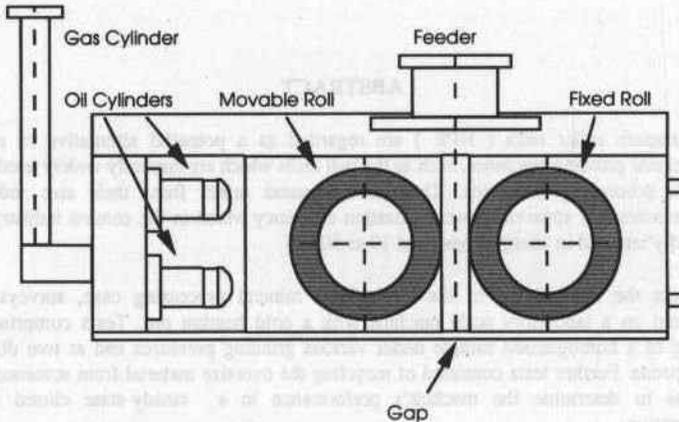


Figure 1. Laboratory Scale High Pressure Roll Mill

Briefly, the material to be ground is introduced into the mill via a feed chute and forms a bed of particles that is highly compressed between two counter rotating rolls. One roll is free to move against an applied hydraulic pressure. As the material is drawn into the gap between the rolls the movable roll is displaced. Due to the applied pressure on the roll, a force is exerted on the bed of particles that forms between the rolls causing the particles to be broken.

HPR OPERATING FEATURES

The variables that the operator has control on the HPR machine are the gas and oil initial pressures, the initial roll gap and the rolls speed.

Gas and Oil Pressures Setting

The operation of the HPR is represented in figures 2a, 2b and 2c (after Krupp Polysius, 1991 [4]) and can be divided in three stages:

- Stage I: the movable roll is in retracted position. There is no grinding operation.
- Stage II: the initial roll gap has been set using a mechanical stop and the basic force is input on the movable roll by building up the nitrogen and oil pressures;
- Stage III: the material to be ground is fed through the mill, causing the movable roll to retract. A hydraulic pressure system presses the movable roll in a resilient way towards the fixed roll via two sliding bearing blocks of the movable roll unit, thus providing the grinding force.

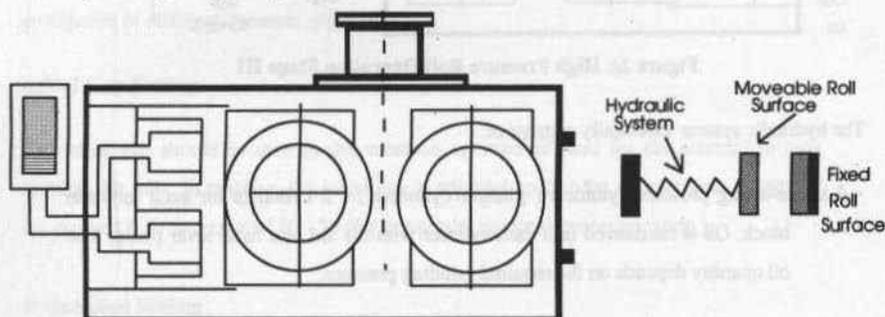


Figure 2a. High Pressure Roll Operation Stage I

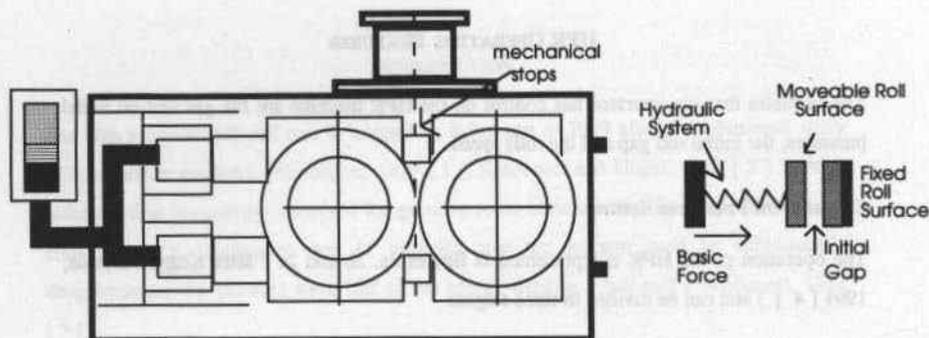


Figure 2b. High Pressure Roll Operation Stage II

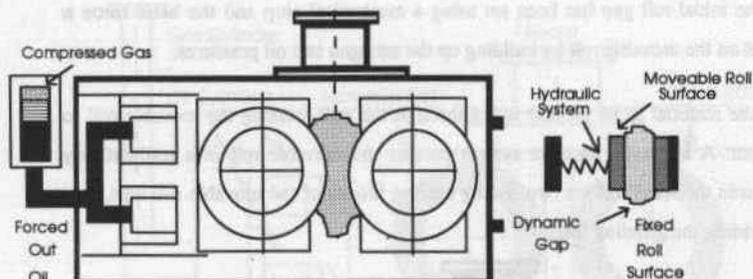


Figure 2c. High Pressure Roll Operation Stage III

The hydraulic system essentially consists of:

- 4 single-acting pressure cylinders (plunger cylinders) - 2 cylinders for each movable block. Oil is introduced into each cylinder with the aid of a hand lever pump. The oil quantity depends on the required grinding pressure;
- 2 piston accumulators - 1 accumulator per side. Each accumulator is filled up with nitrogen. The gas quantity depends on the spring rate required for the applied grinding force.

When the movable roll is pushed backwards, this forces the pistons of the plunger cylinders back on both sides and the forced-out oil flows into the oil accumulators. In the accumulators this leads to a further nitrogen compression until the equilibrium of pressure is restored. The hydraulic system can be thought as a spring system (see schematics in

figures 2a to 2c),with a progressive spring rate formed according to the gas laws, which leads to an increase of the grinding pressure as the rolls are moved apart.

A dynamic gap is formed as the material passes through the rolls with the minimum dynamic gap width being the initial gap setting. The maximum dynamic gap width is determined by the oil and gas pressure ratio. The position of the piston in the accumulator depends on the current acting force and the initial filling pressure of the piston accumulator. This pressure is set when the piston rests on the bottom of the accumulator (see figure 2a), ie at zero oil pressure. It should be predetermined according to the desired spring rate. If the spring is to be hard, ie a narrow dynamic gap is required, the initial gas pressure has to be low (piston will be in a very high position during operation); if the spring rate is to be soft, the initial gas pressure has to be high (piston will be in a lower position during operation).

The manufacturers provide the characteristic curves of the machine for some grinding pressures (or grinding forces) and gas spring rates. For a given initial gap setting it is possible to work with the same grinding force using different oil/gas pressure ratios, but at an expense of different dynamic gap widths.

Initial Gap Setting

The initial gap should be seen as the minimum aperture allowed for the material to pass through the rolls. In practice, the initial gap is adjusted so that the relative bulk density of the product is in the range of 80 - 85 % (Schoenert, personal communication).

Rolls Speed Setting

The relationship between the rolls speed and the HPR throughput is not linear (Schögenert et al, 1993 [5]), hence there is a maximum speed after which the unit feedrate starts to decrease. Experimental tests should therefore be undertaken to determine this best operating speed.

HPR EXPERIMENTAL TESTWORK PROGRAMME

Tests were carried out grinding a gold bearing ore in a laboratory scale HPR machine with a roll diameter and width of 250 and 100 mm, respectively.

The operating variables chosen for investigation were the initial grinding pressure and the rolls speed. Table I summarises the test conditions. The recycling tests involved combining fresh feed samples with oversize material obtained by screening HPR products from Case A in the cited sieve sizes. These composite samples were afterwards fed to the mill again.

Table I - Operating Conditions for the Testwork

CASE ID	Oil Pressure (bar)	Gas Pressure (bar)	Rolls Speed (rpm)
A	84	42	24
B	84	42	48
C	67	34	24
D	100	50	24
E	50	25	24
Recyc. 2.0 mm	84	42	24
Recyc. 2.8 mm	84	42	24
Recyc. 4.0 mm	84	42	24

HPR PRODUCT DEAGGLOMERATION

Due to the HPR characteristics of energy transfer by compression of a particle bed, the product is discharged as a flake-like material. If the resulting size distribution of the HPR product is to be determined, it is necessary that a deagglomeration step is first undertaken. Depending on the nature of this step a different product size distribution will result. The quantity of micro fractures generated by the substantial pressures involved in the HPR is certainly higher than in any other grinding process. Consequently, the energy applied in the subsequent deagglomeration procedure may propagate some of these microcracks causing further size reductions. Different applied energy levels at the deagglomeration will therefore result in different apparent product size distributions.

The process for determining a suitable method for deagglomerating HPR products has been described elsewhere in detail (Tondo, 1994 [6]). Briefly, it was designed in two stages as follows:

Stage 1: determination of the actual product size distribution of one representative sample ground at a specific grinding pressure, using ultrasonic energy for deagglomerating the flakes;

Stage 2: development of a simplified (less time-consuming than the previous one) deagglomeration method using a laboratory tumbling mill, which showed an acceptable correlation with the results obtained in the ultrasonic bath (UB) deagglomeration and that could be applied for the samples of the remaining tested cases.

RESULTS AND DISCUSSION

Figure 3 presents the comminution pattern of the same material ground in the HPR at different grinding pressures, after deagglomerating the flakes using the method mentioned in the last section.

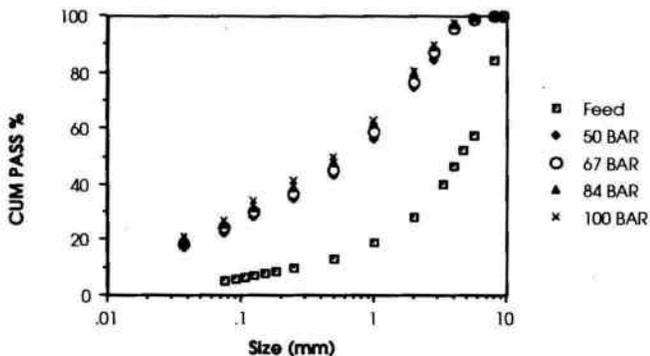


Figure 3. Size Distr. Curves of a gold ore grinded in a HPR at different grinding pressures

It can be noticed that the size distribution curves shift towards the left side as the grinding pressure is increased, ie, finer products are generated with higher grinding pressures, as expected. These results are in accordance with what has been described in literature regarding the self similar pattern of the curves (Fuerstenau et al, 1990 [7]). This phenomenon as applied to single particle breakage has also been described by Narayanan and Whiten, 1983 [8], where a consistent pattern of behaviour of breakage was observed. The resultant size distribution could be described by a one-parameter ('t') family of curves. A point on the linear fines region of the curves was found to be an appropriate parameter to describe the family of breakage curves. This parameter, t (or t10) was defined as the cumulative percent passing a characteristic size which was taken as one-tenth of the average initial size, Y, of the particles used in breakage tests.

Using this concept, the t10 parameter was calculated for each case using the F50 (average feed size) and the product size distribution curves generated by the breakage in the HPR.

Figure 4 shows the relationship between the calculated t10 parameters and the specific grinding power measured for each HPR tested case. It can be seen that the t10 parameter increases with increasing specific energy in a linear manner and reflects the increasing amount of comminution.

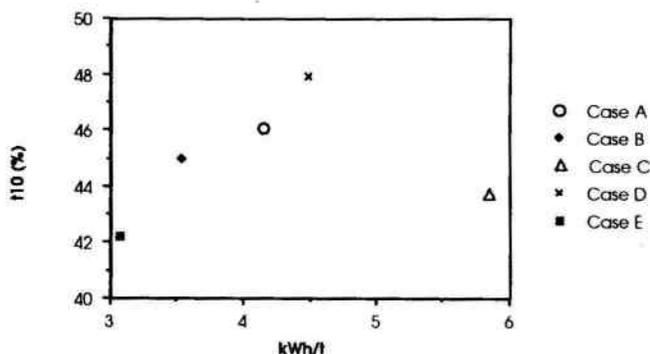


Figure 4. Power Consum. Versus t10 Relationship for the Open Circuit HPR Tests

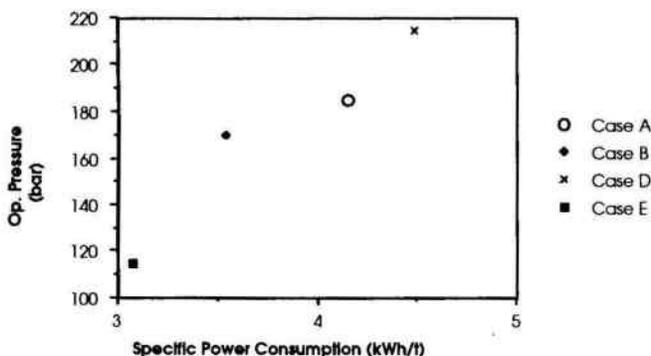
Problems with power measurements were experienced in Case C, and can explain the unusually high power value obtained in this case. Given the relatively low grinding pressure

(67 bar) that the mill was run under the result is considered to be an outlier and was excluded from further analysis.

In general, as expected, as the specific grinding pressure increases so does the comminution effect. Noteworthy is the lower specific power consumption obtained for a higher roll speed (case B), compared with case A when the same initial grinding pressure was applied at half the roller velocity. The coarser product obtained at a higher speed is in accordance with results presented by Austin (Austin et al, 1993 [9]).

Figure 5 presents the relationship between specific power consumption and operating grinding pressure.

As has been described by many authors, the specific power consumption seems to depend mainly on the grinding pressure applied.



**Figure 5. Specific Power Consumption Versus Working Grinding Pressure
Relationship for the HPR Open Circuit Testwork**

Figures 6 and 7 show another important aspect of HPR grinding, ie, the decoupling effect between the unit throughput and specific energy consumption (and thus grinding pressure), and is in agreement with results presented by Schoenert (1993, [5]). The high throughput value in both figures refers to Case B (higher rolls speed), indicating that throughput is closely linked to rolls velocity.

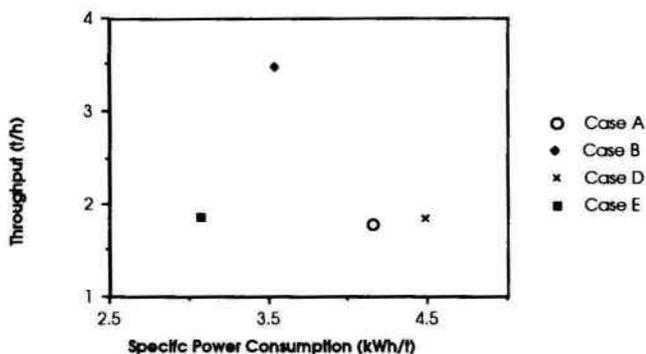


Figure 6. Specific Power Consumption Versus HPR Throughput for the Open Circuit Testwork

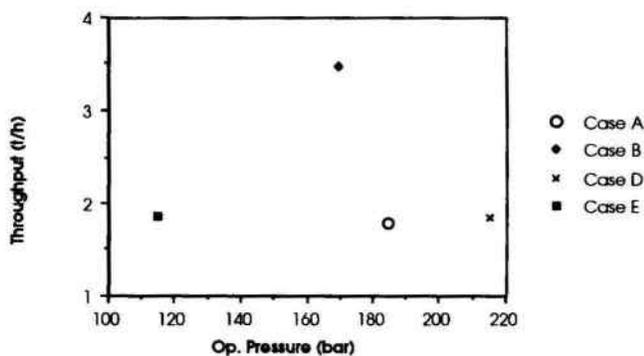


Figure 7. Working Grinding Pressure Versus HPR Throughput for the Open Circuit Testwork

Figure 8 shows the energy-size reduction efficiency for the products obtained in the HPR open and recycle testwork. The size reduction has been characterised by the reduction ratio, where F80 and P80 refer to the 80 % passing the feed size and 80 % passing the product size, respectively.

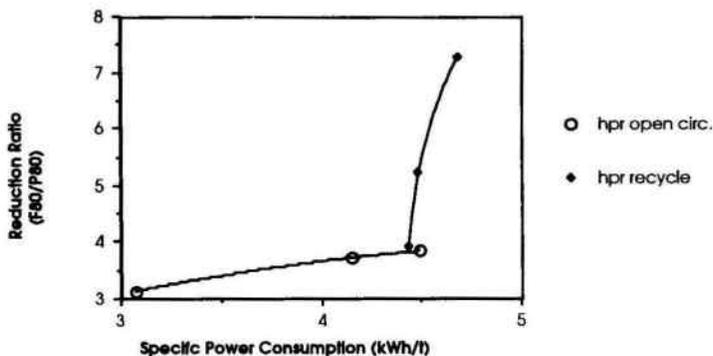


Figure 8 - Energy-Size Reduction Comparison Between HPR (Open Circuit and Recycle Condition)

From the graph, it can be seen that there is a the substantial increase in the reduction ratio when recycled oversize is fed to the HPR compared to the open circuit results, with only a marginally higher amount of power consumption.

To compare the HPR product size with a conventional mill, feed samples were batch ground in a rod mill. Figure 9 shows the size distribution curves of the products obtained in the HPR and from the rod mill when grinding the same feed material and generating the same product P80.

It can be seen that, at least for the ore tested, the grinding obtained by the HPR mill produces a pattern of comminution that generates more, but is less able to mill coarser particles, when compared to the rod mill. Hence it is concluded the relationship between the P80 and the remainder of the product size distribution is different for the HPR when compared to a conventional mill.

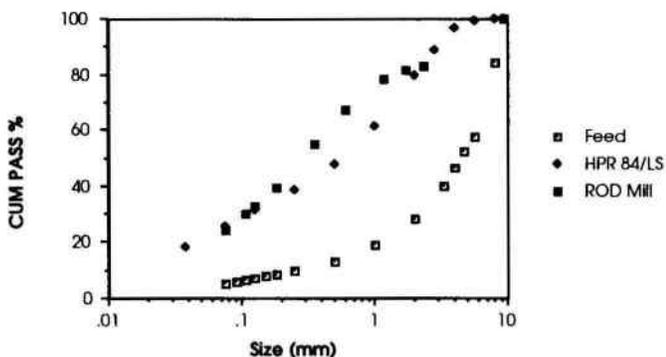


Figure 9 - Laboratory Scale Comparison Between HPR and Rod Milling Products

This fact is noteworthy, since efforts to compare the energy consumption in a HPR with a ball mill are usually undertaken by calculating the power using the well known Bond's third law equation:

$$W = 10WI \left(\frac{1}{\sqrt{P80}} - \frac{1}{\sqrt{F80}} \right) \quad (1)$$

where,

W = specific power consumption in kWh/t predicted to a circuit according to Bond's conditions;

WI = ore work index, in kWh/t;

$P80$ = 80 % passing the product size, in micrometers;

$F80$ = 80 % passing the feed size, in micrometers.

The difference in the relationship between the $P80$ and the product size distribution for HPR and conventional milling introduces a bias in the Bond calculation that is unfavourable to the HPR. However, even given this bias it does not account for the relatively low energy efficiency of the HPR when compared to that predicted for a ball mill using the Bond equation (Figure 10). For the ore used in this testwork the Bond work index was determined using a Bond laboratory ball mill, giving a value of 16.93 kWh/tonne. It should

be noted that the HPR was run in open circuit and some recycled product whilst the Bond ball mill power efficiency is for a fully closed circuit. Recycling screened HPR product clearly results in an apparent increase in grinding efficiency (Figure 8). Given that the Bond ball mill power efficiency is based in close circuit operation it seems only fair that it is compared to HPR performance in close circuit.

To this end, a final programme was executed in which the HPR was run in closed circuit. The test was performed with a classifying screen of 212 microns, which would produce a product with a P80 similar to the one produced in the Dominion Mining gold treatment plant where the ore was taken.

For logistics reasons a locked cycle test was conducted. The initial grinding pressure was reduced to 50 bar to avoid unnecessary energy dissipation and a consequent higher specific energy consumption, while the gas pressure was established at 25 bar to keep the same ratio of oil and gas pressures of the previous tests. Prior to screening the product was deagglomerated using the standard procedure outlined earlier in the paper.

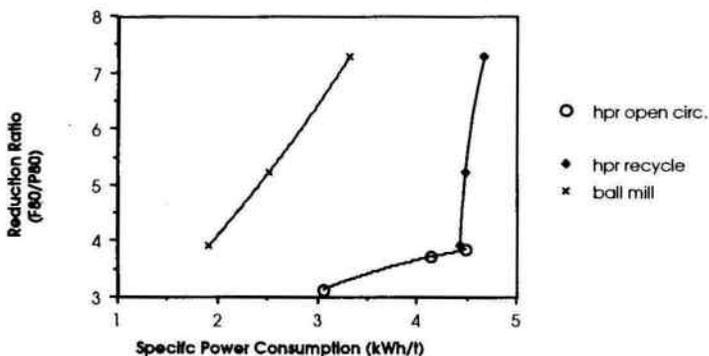


Figure 10 - Size-Reduction Comparison Between HPR (Open Circuit, Recycled Condition) and Bond Milling Circuit

What remained to be checked was whether the wet oversize material (after the deagglomeration procedure) would not slip on the rolls surface, causing some operating problems. However, at the calculated moisture level (15 % by wt) this did not happen.

though care had to be taken to ensure that the ore was not allowed to stick in the feed hopper.

After 7 cycles the test reached a steady-state condition with a final circulating load of approximately 180 %.

Table II shows a summary of the power and throughput obtained during test.

TABLE II - Specific Power Consumption for the HPR 212 micron Closed Circuit

Testwork

Cycle No	Initial Pressure (bar)	Working Pressure (bar)	Nett Power (kW)	Throughput (t/h)	HPR Power (kWh/t)
1	45.81	107.29	4.95	1.47	3.38
2	46.81	87.39	4.20	0.84	5.03
3	46.77	80.10	3.33	0.64	5.19
4	49.00	73.98	2.98	0.47	6.34
5	49.29	69.19	2.61	0.37	6.98
6	50.61	69.05	2.49	0.36	6.87
7	49.14	67.62	2.43	0.34	7.11

The average specific power consumption for the last three cycles is 6.99 kWh/t. When compared to the power predicted by Bond's equation to produce the same size reduction, it can be seen that a major energy saving of approximately 51 % was achieved for the HPR mill, as follows:

HPR feed F80 = 7510 microns (fresh feed)

HPR product P80 = 109 microns (average of cycles 6 and 7)

Bond WI = 16.93 kWh/t

Bond Energy Consumption = 14.26 kWh/t

HPR Energy Consumption = 6.99 kWh/t (average of last three cycles)

Difference HPR versus BOND Energy = - 50.99 %

CONCLUSIONS

On the basis of results from a laboratory high pressure grinding roll machine it was found that open circuit operation when treating a gold ore was less energy efficient when compared to that predicted using Bond's formula for a similar size reduction in a closed circuit ball mill. By running the HPR in closed circuit, however, it was found that the energy efficiency greatly increased and resulted in a specific energy of half that predicted for a closed circuit ball mill.

REFERENCES

1. Schoenert, K., 1979. Energetische Aspekte der Zerkleinerns sproder Stoffe, Zement-Halk-Gips, 32 : 1-9.
2. Schoenert, K. & Flugel, F., 1980. Zerkleinerung sproder Minerale im Hochkomprimierten Gutbett, Europ. Symp. Particle Technology, Preprints Vol. A, Dechema, Frankfurt, pp. 82-95.
3. Schoenert, K., 1988. A First Survey of Grinding with High-Compression Roller Mills, International Journal of Mineral Processing, 22, pp401-412.
4. Krupp (Australia) Pty. Ltd, 1991. Laboratory Polycom High-Pressure Grinding Roll, Machine Manual.
5. Lubjung, U. & Schoenert, K, 1993. Material Flow in the Acceleration Zone and Throughput of High Pressure Roller Mills, XVIII International Mineral Processing Congress, Sydney, pp161-168.
6. Tondo, L. A., 1994. Evaluation of the Size Reduction Characteristics of a Laboratory Scale HPR Grinding Machine, MSCQual Thesis, University of Queensland, Australia.
7. Fuerstenau, D. W., Kapur, P. C., Schoenert, K & Marketscheffel, M., 1990. Comparison of Energy Consumption in the Breakage of Single Particles in a Rigidly Mounted Roll Mill with Ball Mill Grinding, International Journal of Mineral Processing, 18:109-125.
8. Narayanan, S. S. & Whiten, W. J., 1983. Breakage Characteristics for Ores for Ball Mill Modelling, Proc. Australasia. Inst. Metall. No. 286.
9. Austin, L. G., Weller, K. R. & Lim, I. L., 1993. Phenomenological Modelling of the High Pressure Grinding Rolls, XVIII International Mineral Processing Congress, Sydney, pp 87-95.