Spring 4-1-2015

Understanding the comminution mechanism of high-pressure grinding rolls: Lower cost, higher efficiency and selectivity

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UNDERSTANDING THE COMMINUTION MECHANISM OF HIGH-PRESSURE GRINDING ROLLS: Lower Cost, Higher Efficiency and Selectivity

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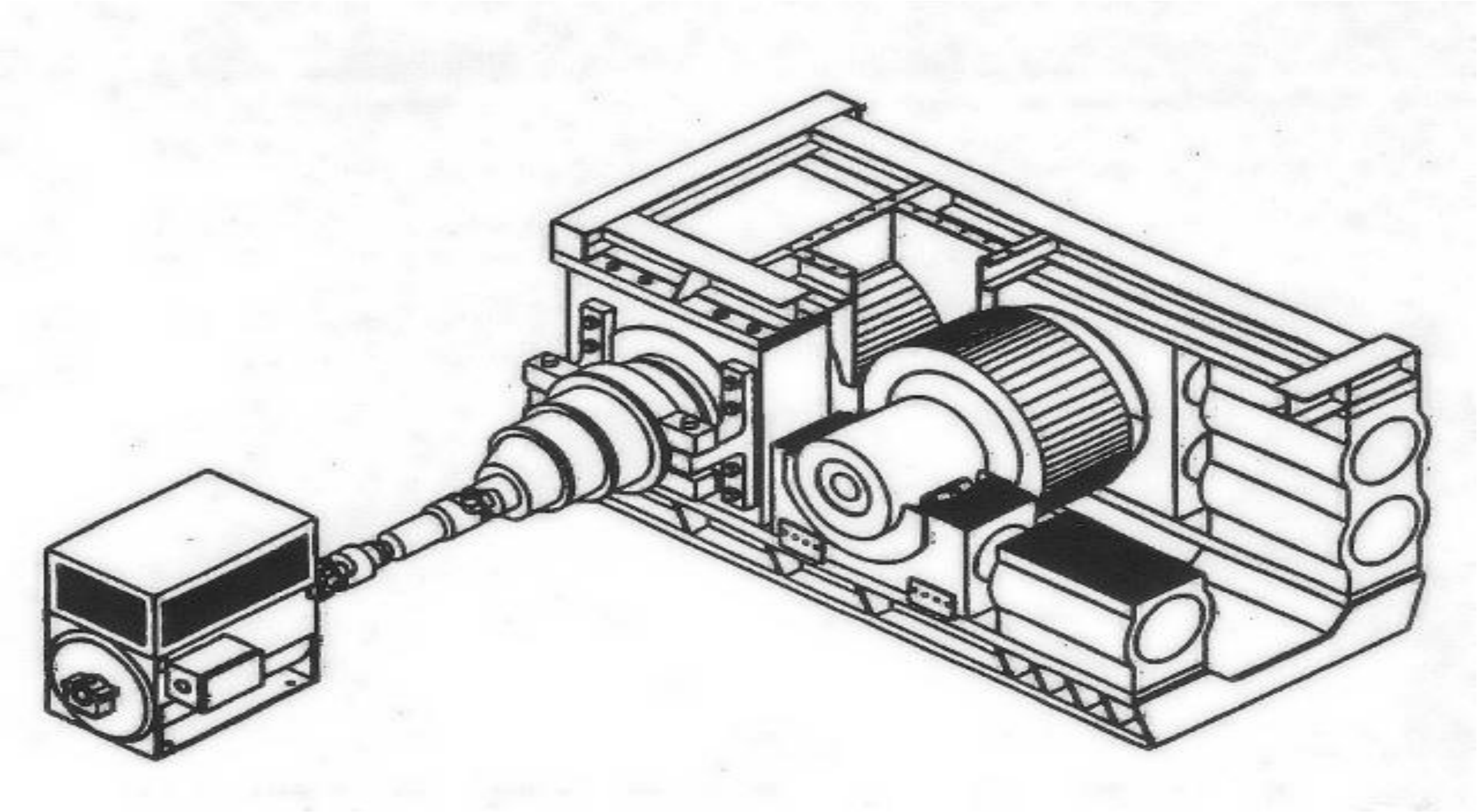
CONTENT

INTRODUCTION



- **Schematic diagram of a High Pressure Grinding Roll (HPGR).**

INTRODUCTION (CONT.)

- The technology used in the High Pressure Grinding Roll (HPGR) has demonstrated that:
  - Constitutes the only real development, and the most significant innovation of the 20th Century in comminution.
  - Applies a Bed of Particles Comminution Mechanism, allowing selective grinding.
  - Reduces the total energy consumption by 10% to 50% of that consumed by tumbling mills (rod and ball mills, etc.).
  - Increases grinding throughput by 15% to 30% with respect to that of conventional comminution systems.
  - Occupies less floor space (smaller plant print).

INTRODUCTION (CONT.)

- The technology used in the High Pressure Grinding Roll (HPGR) has demonstrated that:
  - Has similar or lower CAPEX than other comminution technologies.
  - Reduces iron consumption (lower wear rate) by using different rolls profiles according to the type of ore process, and the operating conditions.
  - Operates under a wide range of ore moisture content, up to 30% moisture.
  - Produces a wide particle size distribution (PSD) with relative high content of fines.
  - Is easy to scale-up to grind hundred of tons of solids per hour.

CONCEPTS

- Traditionally, crushing and grinding are unit operations that are non-selective since minerals are broken by applying pressure using comminution surfaces (metallic plates, steel rods and balls, etc.).
- Under these conditions, the particles are loaded predominantly in compression and fails in tension.
- As the particle is subjected to an increasing stress, existing flaws intensify the applied stress, and particles fails at the largest flaw.
- This process is subjected to probabilities; a_1, for being submitted to compression by grinding media; a_2, of having crystallographic defects or flaws; a_3, of being in the right position; a_4, of being broken by the applied compression.

- **Thus, it is the least selective and the lowest efficient comminution mechanism**.

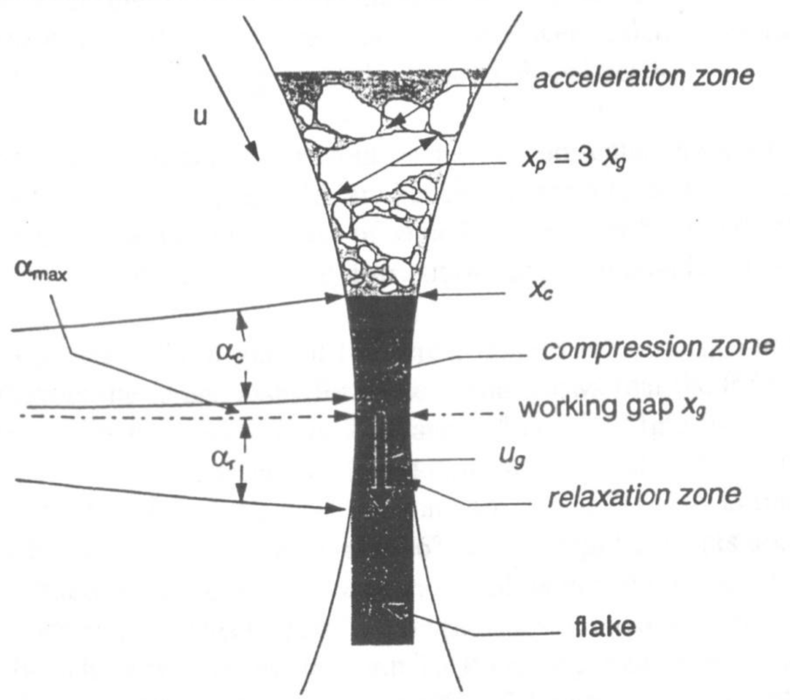
CONCEPTS (CONT.)

- The most efficient comminution mechanism is that of individual particle grinding, but it has not been possible to be applied to industrial grinding yet.
- Grinding in a Bed of Particles is the second most energy efficient and selective mechanism, and it is applicable to industrial comminution.
- High Pressure Grinding Rolls (HPGR) operate under this mechanism of Bed of Particles Comminution that allows selective grinding of different mineralogical species in the ore.
- In a HPGR, grinding in a Bed of Particles Mechanism depends on the:
  - Strength of the material.
  - Internal friction between particles.
  - Friction with the machine surfaces.
  - Type and size distribution of the feed material.
  - Surface moisture content.
  - Grain borders between different mineralogical species in the feed material.

CONCEPTS (CONT.)

- Therefore, applying the mechanism of Bed Particles Comminution in a HPGR resulted in:
  - The gap of the HPGR only defining the maximum particle size to be produced.
  - Selective grinding of the soft mineral species by the hard mineral species in an autogenous grinding system.
  - High fraction of the energy applied to the HPGR is consumed in grinding since the particles are hold in a pseudo-confine space.
  - Residual stresses and micro-cracks that reduce energy consumption in downstream attrition scrubbing, comminution, and enhance leaching, etc.

CONCEPTS (CONT.)



- **Schematic of particle bed regions between rolls in a HPGR.**

CONCEPTS (CONT.)

- Thus, HPGR is chocked-fed at not less than 50 MPa to maintain a Bed of Particles Comminution Mechanism.

- Recent Studies on Crushing, and rod and ball mill grinding have pointed out the importance of developing practical methods of enhancing liberation of minerals from each other, mainly by using inter-particles breakage occurring in particle bed comminution process.

- New jaw and cone crushers are operated in such a way that the crushing chamber could develop a bed of particles comminution area before discharging the crushed material.

CHARACTERIZATION STUDIES

- Florida pebble samples were representative of different types of high-dolomite phosphate pebbles with MgO content of 0.69% to 3.15%, and the Australian Phosphate samples were representative of sedimentary phosphate ores with high-clay content, 4.10% and 11.87%

- The pebble samples exhibit a mean particle size in the range of 1.63 mm for Mine I, 1.94 mm for Mine II, 1.72 mm for Mine III, and 1.37 mm for Mine IV; whereas, the Australian Phosphate ores showed 0.150 mm and 1.69 mm for the ultra-high-clay and high clay ores, respectively.

- The chemical analyses of the high-dolomite phosphate ores accounted for 96% to 99% of the mineralogical species, and those of the Australian phosphate ores accounted for 99%.

CHARACTERIZATION STUDIES (CONT.)

	Florida Pebbles				Australian Ores	
Data	Mine I	Mine II	Mine III	Mine IV	Ultra-High-Clay	High-Clay
Chemical Analysis						
P_2O_5, %	23.24	26.60	22.76	24.39	6.04	20.80
MgO, %	0.69	1.53	3.15	1.64		
Al_2O_3, %					11.87	4.10
Insol, %	26.98	13.06	17.29	19.68	63.01	46.00
Moisture, %	9.88	9.60	11.60	8.93	8.50	8.00
Physical Properties						
Specific Gravity	2.56	2.66	2.57	2.76	2.69	2.70
Angle of Repose, degree	44.58	41.00	48.08	36.83	35.00	35.00
d_{50} (mean size), mm	1.63	1.94	1.72	1.37	0.15	1.69
Mineralogical Analysis						
Francolite, %	66.12	76.24	65.22	69.91		
Apatite, %					21.50	67.51
Dolomite, %	1.77	5.24	12.92	5.90		
Kaolinite, %					35.03	12.10
Quartz, %	26.98	13.06	17.29	19.68	41.00	16.30
Total Minerals, %	99.23	96.01	98.13	97.53	98.90	99.10

PERUSA'S MODEL – INSTRON TESTS

- The precursor PerUsa's Model-INSTRON Tests were aimed at determining, on a small scale, if selective grinding occurs.

- These tests were carried out only on Florida High-dolomite Phosphate pebbles, providing information regarding the energy absorbed, mechanical behavior (relaxation tests), effect on the particle size distribution, and P_2O_5 and MgO distributions.

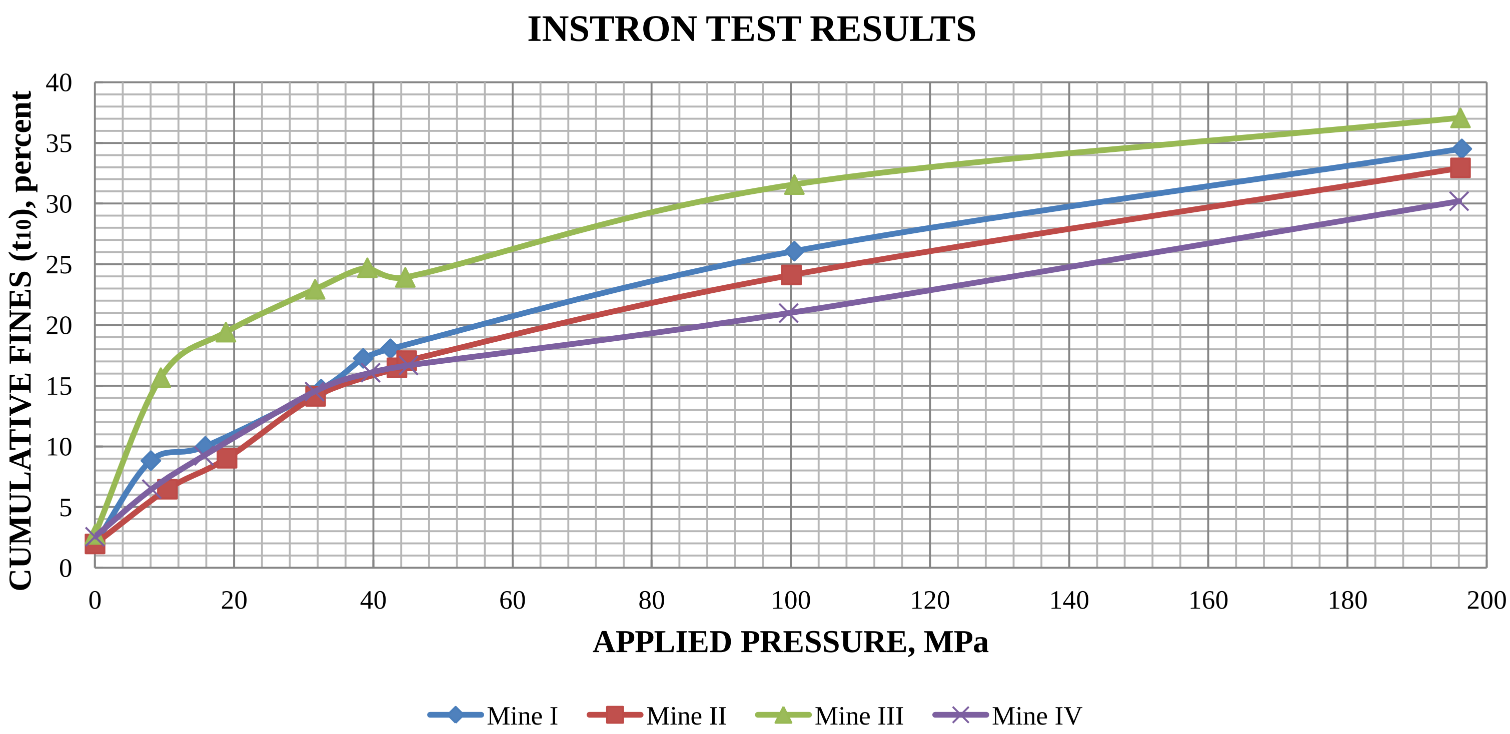
- INSTRON Tests results followed by screening at 106 µm demonstrated that it was possible to selective grind dolomite from each of the four Florida mines.

- P_2O_5 grade was between 22.2% and 26.3% with MgO grade between 0.53% to 1.08%, resulting in P_2O_5 recovery between 83% to 88% and MgO rejection between 41% to 82%.

PERUSA'S MODEL - INSTRON TESTS (CONT.)

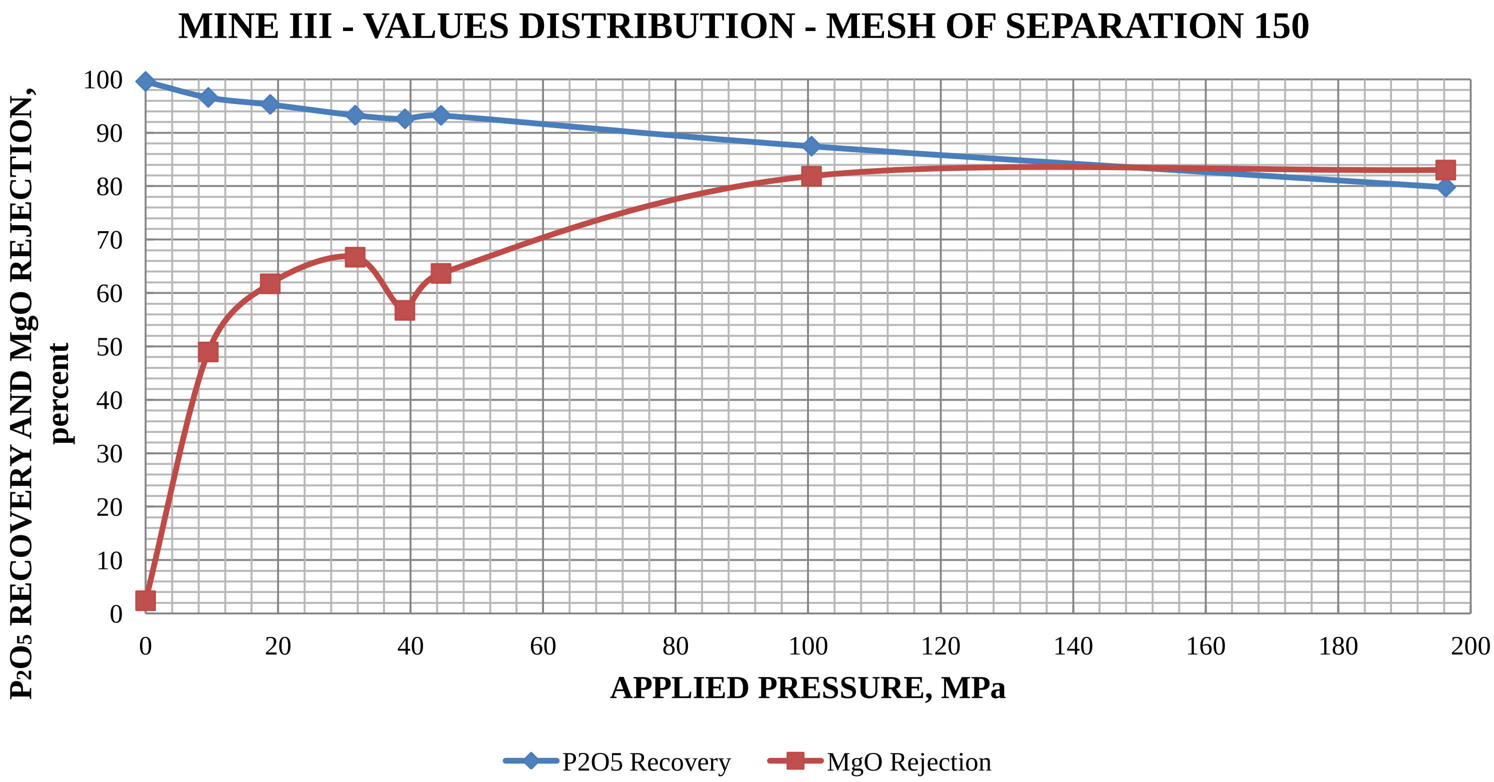
	Florida Pebbles			
Data	Mine I	Mine II	Mine III	Mine IV
Feed				
P_2O_5, %	23.24	26.60	22.76	24.39
MgO, %	0.69	1.53	3.15	1.64
Ground Product (+150 M)				
d_{50} (mean size), mm	0.93	0.73	0.65	0.74
P_2O_5, %	22.82	26.19	25.52	24.72
MgO, %	0.53	0.80	0.75	1.08
P_2O_5 Recovery, %	87.75	84.64	87.48	83.15
MgO, Rejection, %	41.11	52.29	81.87	44.99
Energy Abs, E_m, KWh/ton	0.41	0.72	0.69	0.82
Mechanical Behavior	Elasto-Plastic	Elasto-Plastic	Elasto-Plastic	Elasto-Plastic

PERUSA'S MODEL - INSTRON TESTS (CONT.)



• The Mean Particle size (d_{50}) decreases as the Applied Pressure increases; thus, the Cumulative Fines (t_{10}) increasing. Cautiously, due to grinding in a confine space, it could be infer that Mine IV is the hardest phosphate pebble (rejected of heavy media plant), followed by Mine II, Mine I, Mine III being the softest.

PERUSA'S MODEL - INSTRON TESTS (CONT.)



- INSTRON Tests demonstrated that selective grinding of dolomite in a bed of particles takes place liberating it. For Example for Mine III, liberation of dolomite did not increased after 100 MPa of applied pressure due to phosphate pebbles starting to grind, resulting in 87.5% P_2O_5 recovery and 81.9% MgO rejection .

EXAMPLES OF APPLICATIONS

- Even though the application of HPGR has just start to be looked at in the Phosphate Industry, it is a mature technology in other Mineral Industries.
- Based on the understanding of the Bed of Particles Comminution Mechanism, it is clear that:
  - HPGR is not only a size reduction piece of equipment with great advantages on water and energy consumption.
  - HPGR must be tied to a suitable classification, desliming, and/or additional comminution unit operations to take full advantage of this technology (selective grinding).
  - HPGR products with better liberation of mineral species enhanced separation processes performance, such as flotation.
  - HPGR comminution residual stresses and micro-cracks production reduce the energy consumption in downstream comminution units, and enhance leaching processes.
  - HPGR produces better results than attrition scrubbing alone, heavy media and conventional grinding, and enhances flotation and leaching separation processes.

EXAMPLES OF APPLICATIONS (CONT.)

- **In the Phosphate Industry, HPGR could be used for:**
  - Selective grinding of Dolomitic Phosphate Ores:
    - To produce high grade phosphate concentrates.
    - To reduce acidulation problems, such as:
      - High sulfuric acid consumption.
      - Reactors foaming.
      - Reduction on P_2O_5 production.
      - Filtration and gypsum production problems.
      - Difficulties in downstream operations and handling.
  - Selective Grind of Clayed Phosphate Ores.

- These dolomitic and clayed problems are known to be present in the future Phosphate Florida Reserves.

EXAMPLE OF APPLICATIONS (CONT.)

Representative Potential Applications - Quantitative Examples.

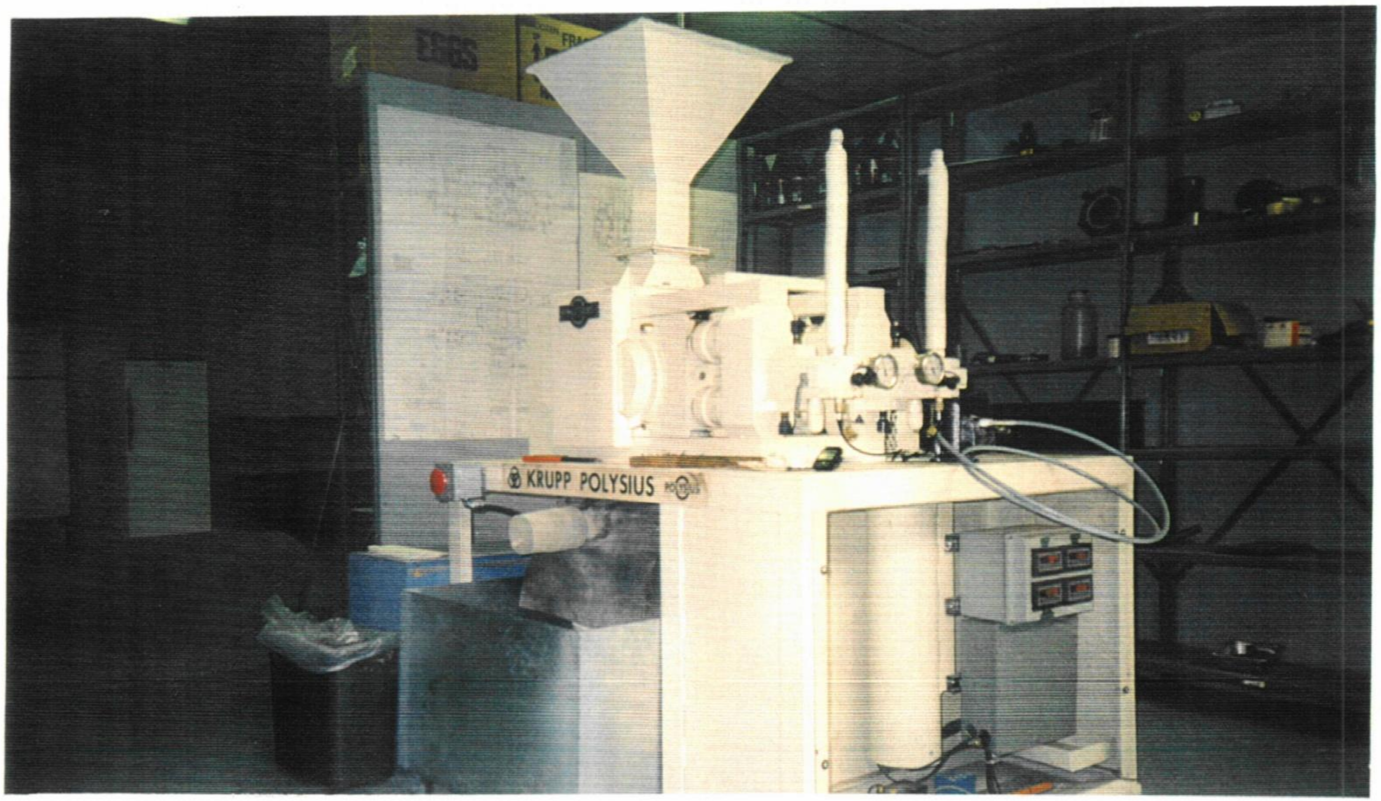
- **Tests on Dolomitic Phosphate Pebbles from four mines and after on pass through a HPGR and desliming were considered with the following results:**

	FEED		PRODUCTS						
	Grades				Grades		Recovery	Rejection	Sp. Energy
Mine	P_2O_5, %	MgO, %	d_{50}, µm	t_{10}, %	P_2O_5, %	MgO, %	P_2O_5, %	MgO, %	Kwh/ton
I	23.06	0.91	0.26	42.40	22.44	0.46	74.06	61.08	4.19
II	27.60	2.01	0.31	41.20	28.16	0.95	82.22	61.95	4.03
III	23.15	3.85	0.21	48.40	26.20	0.96	77.46	82.87	6.69
IV	24.72	1.99	0.30	34.40	24.50	1.33	80.47	45.69	4.15

- Rod mill grinding for comparison showed a specific energy consumption of **14.46 to 20.55 Kw-h/ton**, P_2O_5 grade of 23.22 to 28.09% and MgO grade of 0.56 to 1.44% with P_2O_5 recovery at same d_{50} than HPGR of about 67.66%, and MgO rejection of about 56%. Thus, inferior results on both P_2O_5 and MgO grades, recovery, and rejection with higher energy consumption.

EXAMPLES OF APPLICATIONS (CONT.)

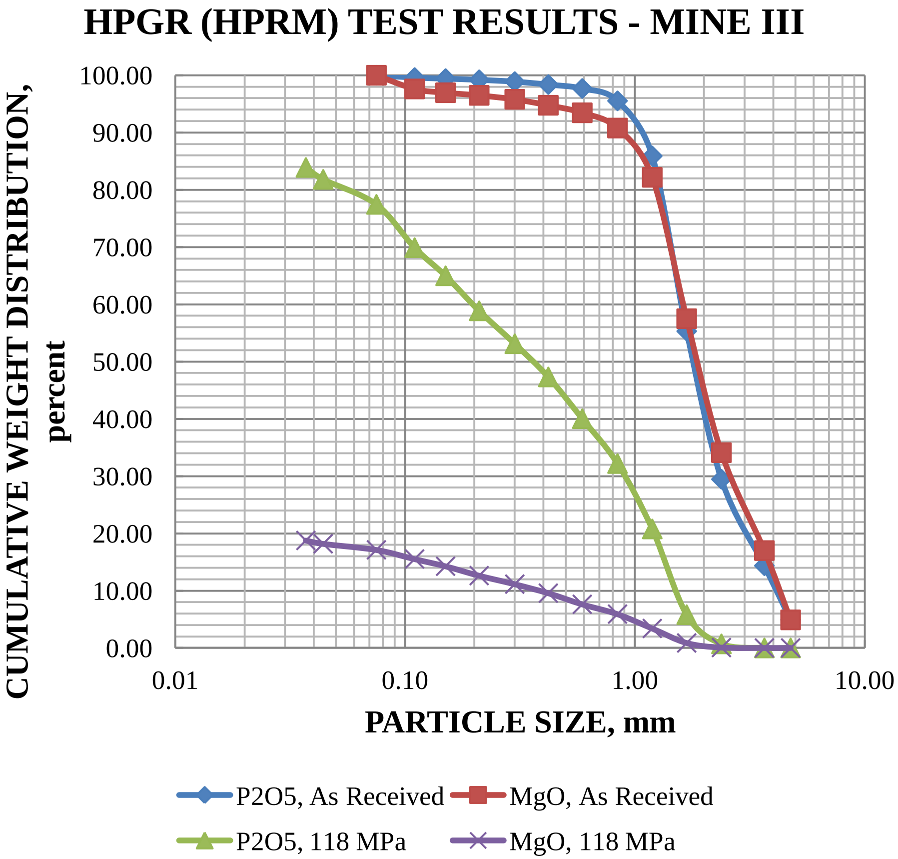
Picture of Lab HPGR



EXAMPLES OF APPLICATIONS (CONT.)

Distribution of values

- Distributions of P_2O_5 and MgO showed that they were similar without HPGR grinding; whereas, the distributions were divergent with HPGR grinding.



EXAMPLE OF APPLICATIONS (CONT.)

- Flotation of the 14x400-mesh fraction of the HPGR product resulted in 90% of P_2O_5 recovery with an additional 11% of MgO rejection using Crago process. For carbonate flotation, a HPGR plus a rod mill would result in better liberation of dolomite, significant lower energy consumption, higher recovery of P_2O_5 and rejection of MgO.
- **Selective HPGR grind of clayed phosphate ore prepared at 2x0.020-mm size fraction resulted in:**

		FEED		PRODUCTS					
		Grades		Yield	Grades		Recovery	Rejection	Sp. Energy
Process	Ore	P_2O_5, %	Al_2O_3, %	%	P_2O_5, %	Al_2O_3, %	P_2O_5, %	Al_2O_3, %	Kwh/ton
Standard	High Clay	20.80	4.10	62.52	20.80	2.14	63.45	69.82	5.40
HPGR	High Clay	20.80	4.10	60.00	22.82	2.28	78.82	75.76	3.88
HPGR	U.-H. Clay	6.25	11.87	36.34	8.11	4.38	42.45	80.81	1.34

- Results of in this case showed more P_2O_5 recovery and Al_2O_3 rejection. In addition, lower water, and energy consumption were observed.

SUMMARY AND CONCLUSIONS

- Understanding the mechanism of comminution of High Pressure Grinding Rolls (HPGR) is of utmost importance to take full advantage of the benefits of this technology.

- Based on the unique possibilities that this technology offers of being able to preferentially grind certain mineral species on a pseudo-confine-autogenous mode, selective grinding is possible for the liberation of troublesome impurities.

- The Bed of Particles Comminution Mechanism of the HPGR resulted in residual stresses and micro-cracks that could enhance downstream attrition scrubbing, leaching processes, and/or reduce energy consumption in fine grinding.

- Consequently, the objective of the process to be designed must be clearly established. Under this condition, full advantage of HPGR technology could be taken for downstream separation processes, such as classification and desliming, gravity separation, magnetic separation, flotation, and leaching.