A Company of ThyssenKrupp Technologies **Polysius**

December 06, 2007

High-Pressure Grinding Tests

on

Copper/Gold/Molybdenum Ore

from the

Morrison Project
British Columbia, Canada

for Pacific Booker Minerals Inc.

at the

Polysius Research Centre

Project No. 2337 2844 / 2220-7959
WE no. 11815

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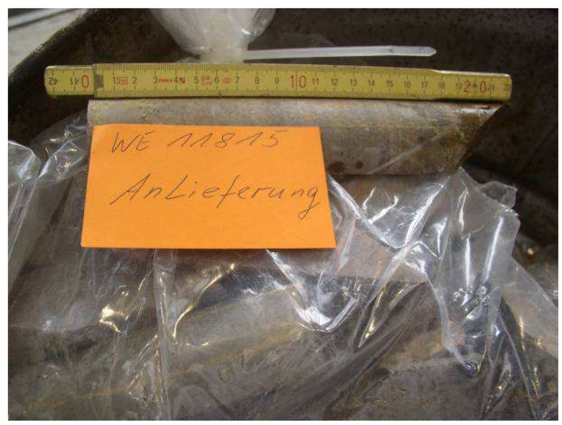
1. Introduction

Pacific Booker Minerals Inc., consulted by Wardrop Engineering, initiated a test program at Polysius AG in Germany to investigate the application of High Pressure Grinding Rolls (HPGR's) at their copper/gold/molybdenum porphyry project in the Morrison Lake area, Northern BC.

Ore samples were received in two shipments, 4 drums each, containing a gross weight of 1720 kg. The samples consisted entirely of drill core, which was crushed to < 1¼" for testing. The tests were carried out in a semi-industrial HPGR at three different pressure levels. Closed-circuit tests were simulated using a 6 mm screen. Standard Bond and POLYSIUS laboratory mill (LABMILL) grinding tests were done on the material before and after pressing to determine the extent of weakening of the material. Furthermore, abrasion tests were carried out at different moisture contents to determine the wear life of the rolls.

Earlier testwork carried out on drill core at SGS Lakefield indicated Bond Work Indices ranging from 11- 23.5 kWh/t, with an average value of 16.4 kWh/t.

Shipment - 2 of 8 drums - 1620 kg net



Drill Core Samples

2. Summary

The feed and product size distributions from open circuit runs in the HPHR on the ore are shown in Figure 1. Increasing pressure had very little effect on the product particle size distributions. Also, moisture content variation had little effect on product PSD's. The main effect of these variables was on the throughput and specific energy consumption. These effects are examined in more detail in the report.

Results from closed-circuit tests with a 6 mm screen are shown in Figure 2. The actual cut size was about 5 mm. The screening was conducted dry, and was quite efficient, resulting in > 90% recovery of the amount of < 5 mm in the HPGR product. The P80 size was about 2.8 mm. It is expected that wet screening would yield very similar results.

The material was of low to medium abrasiveness, with an ATWAL wear index (ATWI) of 9-15 g/t. Wear life for the rolls was estimated at 7000 hours. Bond WI was 17.8 kWh/t before, and 16.1 kWh/t after HPGR, a reduction of 10% in ore hardness.

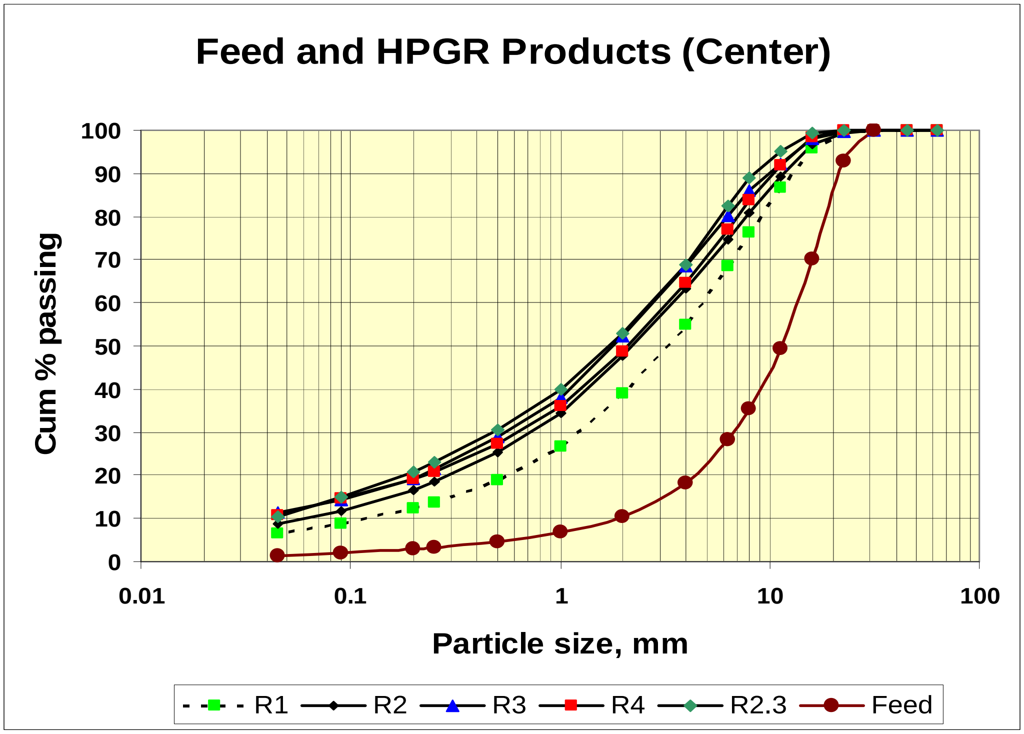


Figure 1. Results of a single pass through the HPGR.

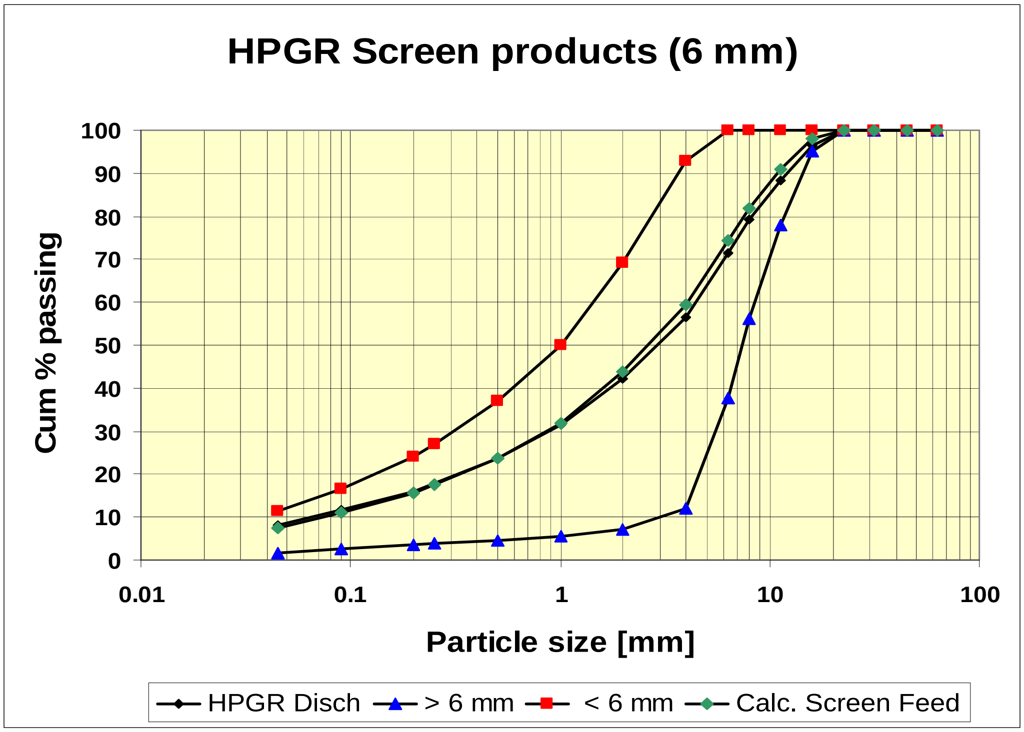


Figure 2. Results of closed-circuit testing in the HPGR.

3. Definition of terms used in testing of High-pressure Grinding Rolls

The key parameters derived from the results of testing in a HPGR are:

- the specific throughput rate
- the specific press force which should be applied to obtain a certain comminution effect
- the specific energy consumption
- the power required for a given throughput and size of rolls.

3.1 Specific Throughput Rate $\dot{m}$

The **specific throughput rate** $\dot{m}$ is defined as the throughput of a given size of machine divided by the projected area and circumferential speed of the rolls:

$$\dot{m} = M / (D * L * u) \quad [ts/hm^3]$$

M	[tph]	:	throughput rate
D	[m]	:	diameter of rolls
L	[m]	:	width of rolls
u	[m/s]	:	circumferential speed of rolls

Note: The **specific throughput rate** $\dot{m}$ has units of ts/hm³, corresponding to the throughput of a HPGR with rolls 1 m in diameter x 1 m wide operating at a roll speed of 1 m/s.

The **specific throughput rate** mainly depends on the properties of the material *(e.g., hardness, the physical density of the material, the particle-size distribution of the feed, and the moisture content);* the grinding pressure, and the type of roll surface employed.

However, the **specific throughput rate** depends only to a limited extent on the diameter and speed of the rolls and is therefore useful for scaling-up from a test unit to a full size industrial unit. HPGRs (and vertical roller mills) are unique among comminution devices in having a specific capacity term which can be assigned to the material and operating conditions.

3.2 Specific Press Force

The **specific press or grinding force** is defined as the total hydraulic force exerted on the rolls divided by the projected area of the rolls in units of N/mm² :

$$F_{(sp)} = F / (1000 * L * D) \quad [N/mm^2]$$

$F_{(sp)}$	[N/mm²]	:	specific grinding force
F	[kN]	:	grinding force
L	[m]	:	width of rolls
D	[m]	:	diameter of rolls

This form is useful for comparing pressures on different sizes of HPGR units.

Note: The maximum grinding pressure in the gap between the rolls will be between 40 and 60 times the applied **specific grinding force**, depending on the nip angle. For mineral applications it is sufficient to define the **specific grinding force**.

3.3 Specific Energy Consumption

The **specific energy consumption $W_{(sp)}$** is the energy input which is absorbed per ton of material. It is proportional to the applied specific grinding force.

$$W_{(sp)} \sim c\,(F_{(sp)},\dot{m}) * (F_{(sp)} / m) \quad [kWh/t]$$

$W_{(sp)}$	[kWh/t]	:	specific energy input
$F_{(sp)}$	[N/mm²]	:	specific grinding force
m	[(t*s)/(m³*h)]	:	specific throughput rate
$c\,(F_{(sp)},\dot{m})$		:	factor (function of $F_{(sp)}$ and $\dot{m}$)

The proportionality is usually linear.

3.4 Power requirements.

The net power required for a given size of rolls is the product of the specific energy input $W_{(sp)}$ and the throughput rate M :

$$P = W_{(sp)} * M \quad [kW]$$

P	[kW]	:	power draw
$W_{(sp)}$	[kWh/t]	:	specific energy input
M	[tph]	:	throughput rate

The minimum motor power required is determined by multiplying the net power by a factor of 1.15 to account for any unevenness in the power draw of each roll. Final motor power is determined by the maximum power that can be transmitted by the gear boxes fitted to a given size of machine.

3.5 Specific Power

The net power required for a given size of rolls may also be derived from the specific power function.

The **specific power P_{SP}** is defined as the power used by a given size of machine divided by the projected area and circumferential speed of the rolls:

$$P_{SP} = P / (D * L * u) \quad [ts/hm^3]$$

P	[kW]	:	power draw
D	[m]	:	diameter of rolls
L	[m]	:	width of rolls
u	[m/s]	:	circumferential speed of rolls

The specific power varies linearly with the specific press force applied, and may be used to determine whether sufficient power has been provided for a unit with a given pressing capacity.

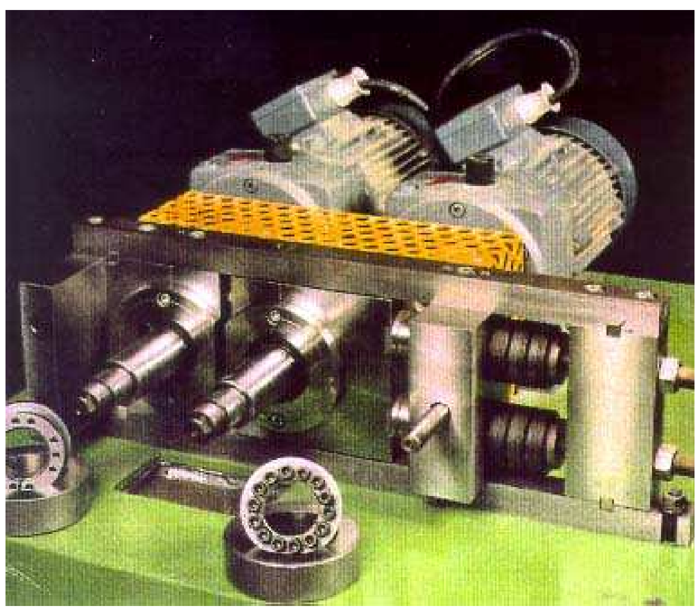
4. Description of Test Facilities

4.1 ATWAL Abrasion Testing High Pressure Grinding Roll

The ATWAL unit is used to determine the wear rates of different ores in High Pressure Grinding Rolls. About 100 kg of material are needed for one test run.

The ATWAL is equipped with smooth solid tyres made of Nihard IV. To ensure nipping of the material between the rolls, the feed is crushed to < 3.15 mm. The rolls are weighed before and after each test, and a specific wear rate is determined from the weight loss divided by the amount of material treated. This specific wear rate is then used to calculate the wear life to be expected on a industrial size HPGR unit.

The ATWAL is choke fed in order to achieve the maximum possible throughput. The grinding force, energy and specific throughput are measured, and the grinding force adjusted, if required.



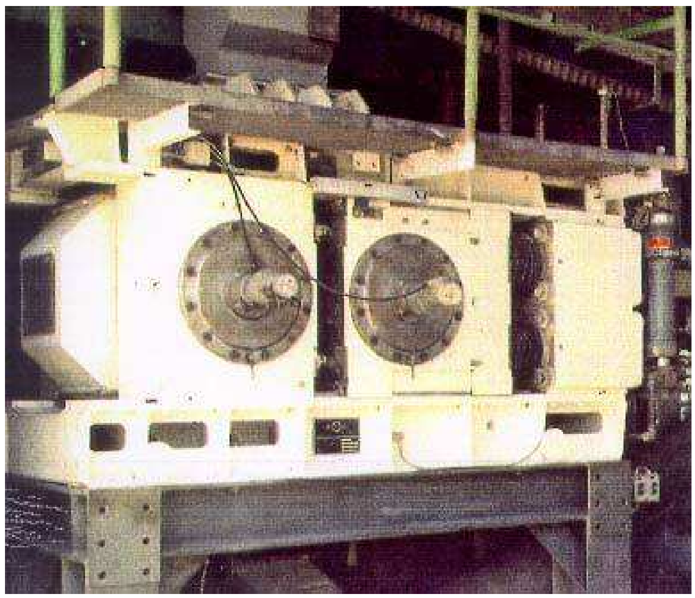
Data of test unit:

Diameter of rolls	: 0.10 m
Width of rolls	: 0.03 m
Speed of rolls	: 0.46 m/s
Top feed size	: 3.15 mm

4.2 REGRO Semi-industrial High Pressure Grinding Roll

Data of test unit:

Diameter of rolls	: 0.71 m	Speed of rolls	: 0.29 - 1.10 m/s
Width of rolls	: 0.21 m	Top feed size	: 16 - 35 mm



The REGRO is equipped with an autogenous wear protection surface in the form of studded liners.

Process data obtained from test work allows the sizing of industrial scale machines.

Data logging: feed rate,
zero gap ,cake thickness
preset nitrogen pressure, zero hydraulic pressure
operating hydraulic pressure
power draw of motors
circumferential speed of rolls

These data allow the calculation of process data such as:

- specific throughput rate
- grinding force and specific energy input
  required for achieving a certain product fineness

5. Test Programme & Results

5.1 Test Programme

The following test programme was approved by Wardrop Engineering. The client, Pacific Booker Minerals, witnessed the tests.

TEST PROGRAMME:

200 KLY
19/09/2007

Project: 2337 2992
WE: 11815

						Analysis		
Provided material		< 25 mm 1500 kg				**PSD**, MC, BD, PD		
REGRO feed	< 25 mm					PSD, MC, BD		
ATWAL feed	< 3.15 mm					Fineness at 90, 250 and 1000 µm		
	Test	**Feed size**	**Quantity**	**Moisture**	**Pressure**	**Analysis Centre**	**Edge**	**Discharge**
ATWAL	A1	< 3.15 mm	100 kg	1%	4 N/mm²			
	A2	< 3.15 mm	100 kg	3%	4 N/mm²			
REGRO	R1	< 25 mm	150 kg	natural	30/25	**PSD**, CD	**PSD**	
	R2	< 25 mm	150 kg	natural	40/30	**PSD**, CD	**PSD**	
	R3	< 25 mm	150 kg	natural	50/40	**PSD**, CD	**PSD**	
	R4	< 25 mm	150 kg	6%	40/30	**PSD**, CD	**PSD**	
Feed preparation: cont'd with product of R2								
Locked-cycle	R2.2	< 25 mm	150 kg	natural	40/30	**PSD**, CD	**PSD**	
with 6 mm screen	R2.3	< 25 mm	150 kg	natural	40/30			
	R2.4	< 25 mm	150 kg	natural	40/30	**PSD**, CD	**PSD**	
Screen products								**PSD**
Bond	B1 (before)	< 3.15 mm	10 kg	dry				**PSD**
	B2 (after)	< 3.15 mm	10 kg	dry	*			**PSD**
LaborMühle	LM1	Crush < 6 m	10 kg	dry				
	LM2	R2.3 < 6 mm	10 kg	dry				

Abbreviations and comments

PSD: Particle size analysis
45, 90, 200, 250 and 500 µm
1, 2, 4, 8, 11.2, 16, 22.4, 31.5 mm, etc.

MC: Moisture content
BD: Bulk density
CD: Cake density
PD: Material density

5.2 ATWAL Wear Test Results

Two ATWAL Wear Tests were carried out on the test material, one on dry material with 1% moisture, and one on wet material with 3% moisture. The results of these tests are given below.

Test	Material	Feed size	Moisture	Specific throughput	Spec. grinding force	Specific wear rate
		[mm]	[%]	[ts/(h m³)]	[N/mm²]	[g/t]
A 1	copper ore	0 x 3.15	1.0	118.4	4.0	9.84
A 2	copper ore	0 x 3.15	3.0	155.8	4.0	15.7

Table 2: ATWAL high pressure grinding wear tests

The tests indicated a low to medium wear rates of 9-15 g/t for the material on the ATWAL testing unit. The wear rates given 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.

Corresponding wear rates on the ATWAL for other ores are given below:

Other 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 based on a data collected on various ores treated in industrial High Pressure Grinding Rolls.

Preliminary estimates for an industrial size unit would indicate a wear life for the rolls of approx. 7000 h.

5.3 Semi-industrial High-pressure Grinding Tests on the REGRO

Preliminary REGRO tests were run at three different press forces on dry material. Then locked-cycle tests were run with medium pressure in closed-circuit with a 6mm dry screen. The influence of press force and recycle of the oversize on:

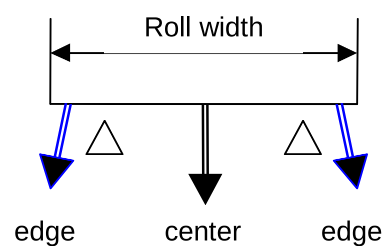
- the specific throughput
- the specific energy input
- the product fineness.

is given in the Table below.

Test no:	Moisture	Specific	Specific	Specific	Specific	Product fineness (center)		
		Press Force	Throughput	Power	Energy	Cumulative % passing		
	[%]	[N/mm²]	[ts/hm³]	[kWs/m³]	[kWh/t]	8 mm	2 mm	0.025 mm
Open- circuit								
R1	1.00	2.59	229.6	320	1.40	76.18	38.80	13.70
R 2/2.1	1.00	3.49	218.0	386	1.77	80.95	47.60	18.40
R3	1.00	4.22	210.6	445	2.11	86.17	52.40	21.60
R4	4.10	3.45	221.8	438	1.97	83.68	48.80	20.70
R2.2	1.00	3.59	220.6	383	1.74	-	-	-
Closed-circuit with 6mm screen								
R2.3	1.00	3.69	225.8	384	1.70	88.87	52.80	23.00

Table 3: Summary of REGRO semi-industrial scale test results.

The feed and product particle size distributions were analysed by dry screening. The discharge of the REGRO was split into a centre and an edge portion. Both portions were analysed separately. Part of the products from the rolls were in the form of compacted flakes, which required de-agglomeration for sizing. The material was de-agglomerated in a rotating drum prior to screen analysis.



The size analysis of the feed and HPGR products are shown in Figures 3-4. The average P80 size achieved in the total discharge was 10 mm; the avg. P80 size in the centre product was 7 mm. The size distributions varied narrowly around these points, indicating that the effect of pressure and recycle on the size reduction was minimal.

The material formed weak flakes, and screening was quite efficient even on a dry basis, Figures 5-6. The circulating load obtained from the dry screening was < 60%, and was expected to be slightly lower from the wet screening.

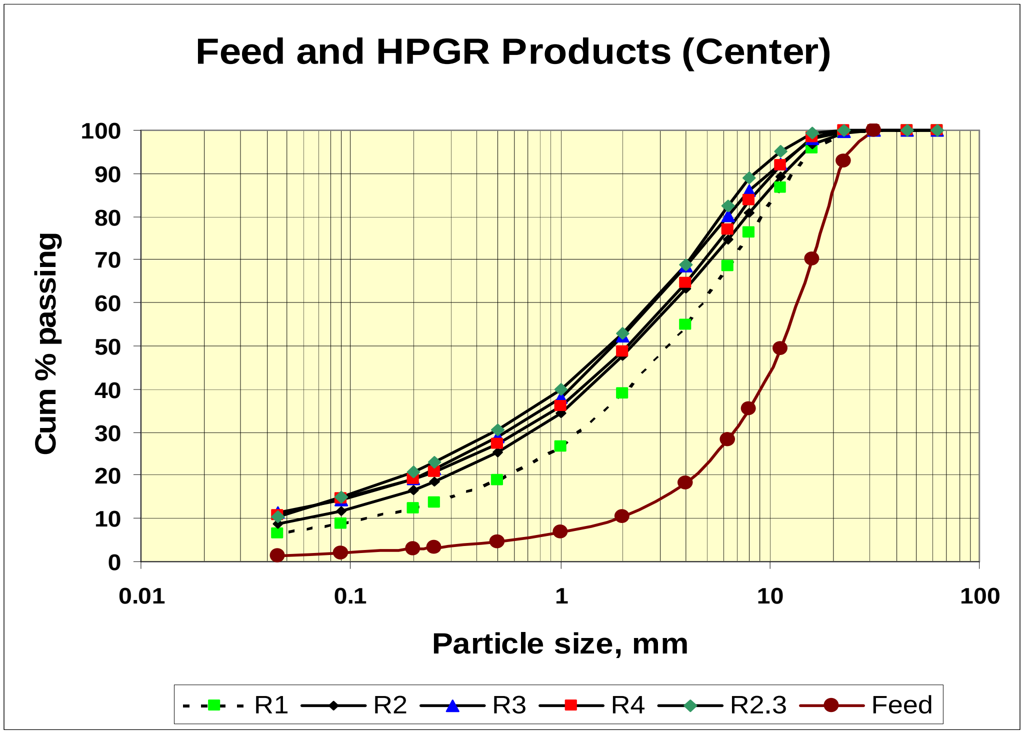


Figure 3. Size distributions feed and center products.

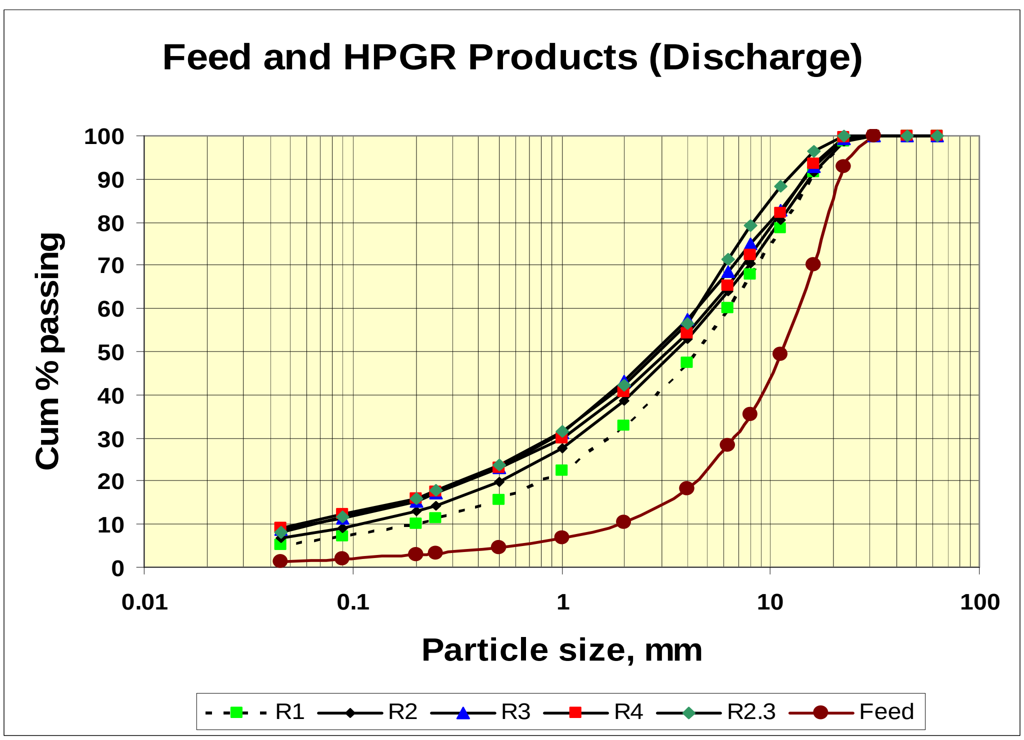


Figure 4. Size distributions feed and total discharge.

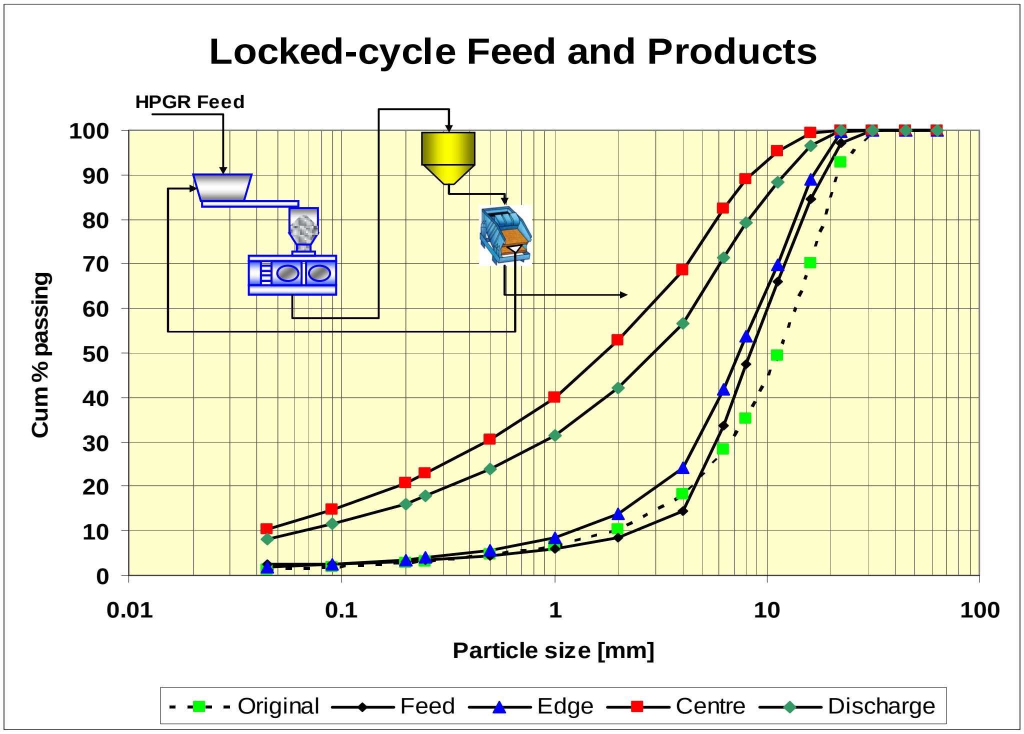


Figure 5. Locked-cycle test results, Test R2.3.

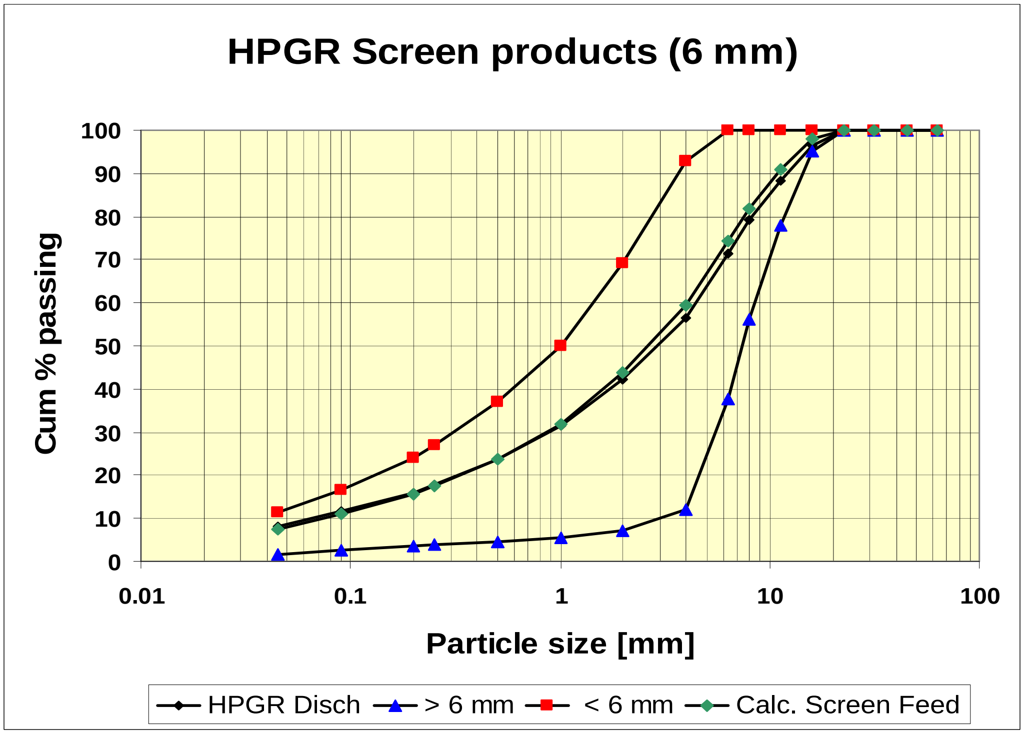
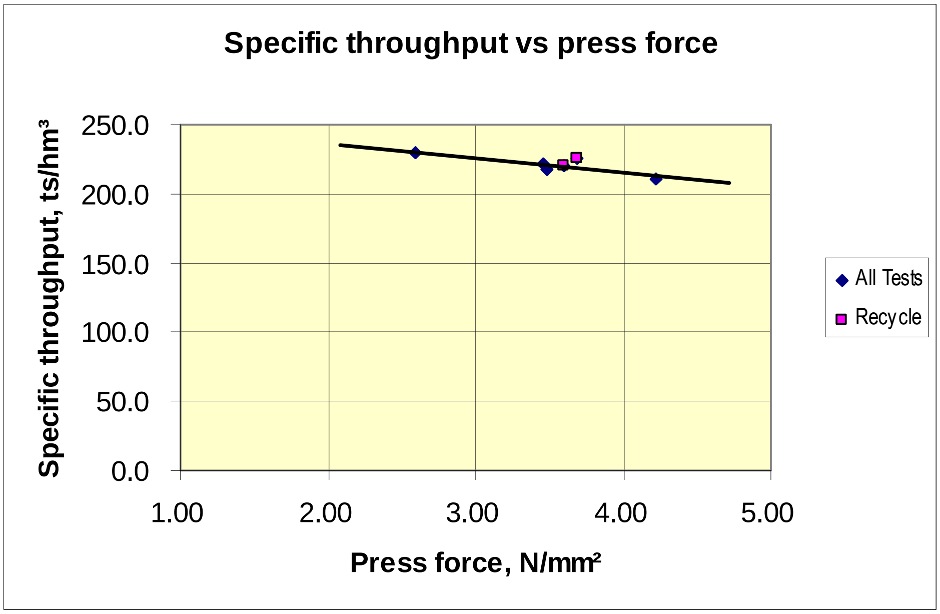


Figure 6. Size distributions dry screen products, Test R2.3.

5.4 Influence of operating conditions.

The influence of the specific press force and moisture on the specific throughput and power draw is shown in Figures 7 and 8. Both press force and moisture had little effect on the throughput. Average specific throughput was 220 ts/hm³ at 3.5 N/mm². However they had a significant effect on the power draw. Fig. 8. Moisture increased the power draw by 20%.



Figures 7. Variation of specific throughput with pressure.

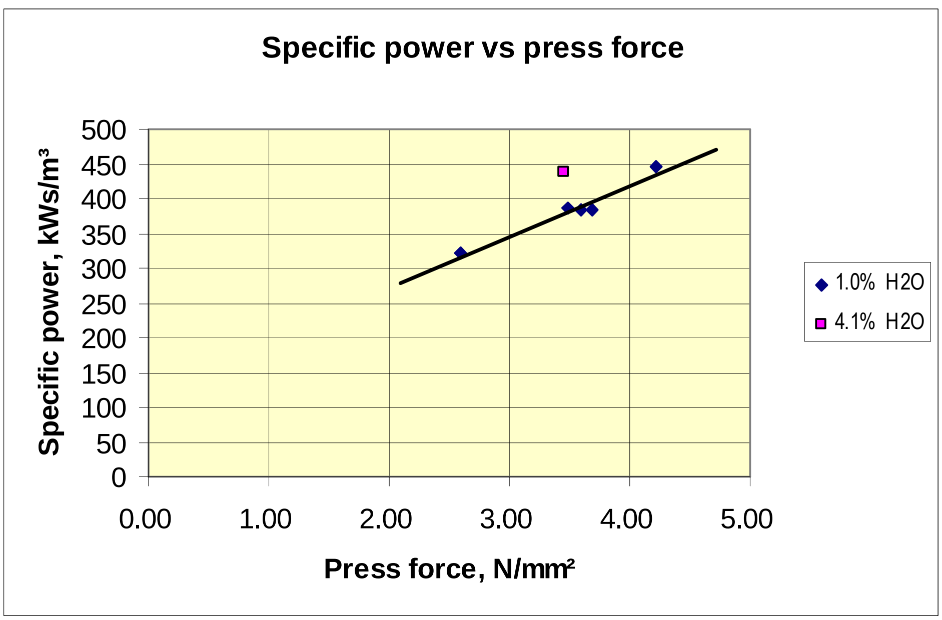


Figure 8. Variation of specific power with pressure.

For dry material, the specific power draw at 3.5 N/mm² was average for copper ores, 380 kWs/m³. Moisture increased this value to about 450 kWs/m³. The specific energy mirrored the specific power trend, resulting in 1.7 kWh/t for dry material and 2.0 kWh/t for wet material at a press force of 3.5 N/mm².

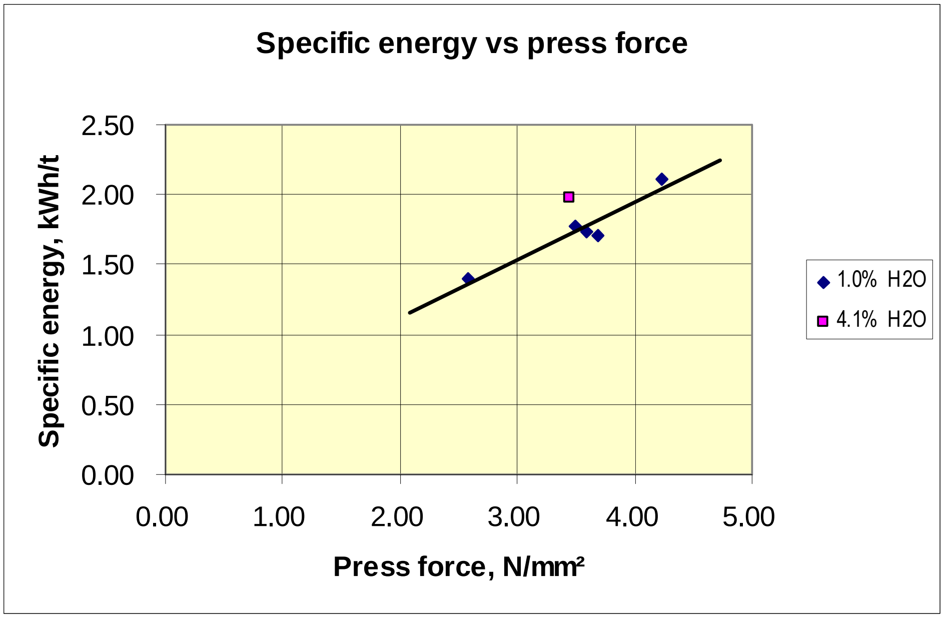


Figure 9. Variation of specific energy with pressure.

Figures 10 and 11 show the effect of grinding pressures on the product fineness. At pressures > 3.5 mm, there was little increase in product fineness, Figure 10. The optimum press force necessary was found to be 3.5 N/mm², see Figure 11.

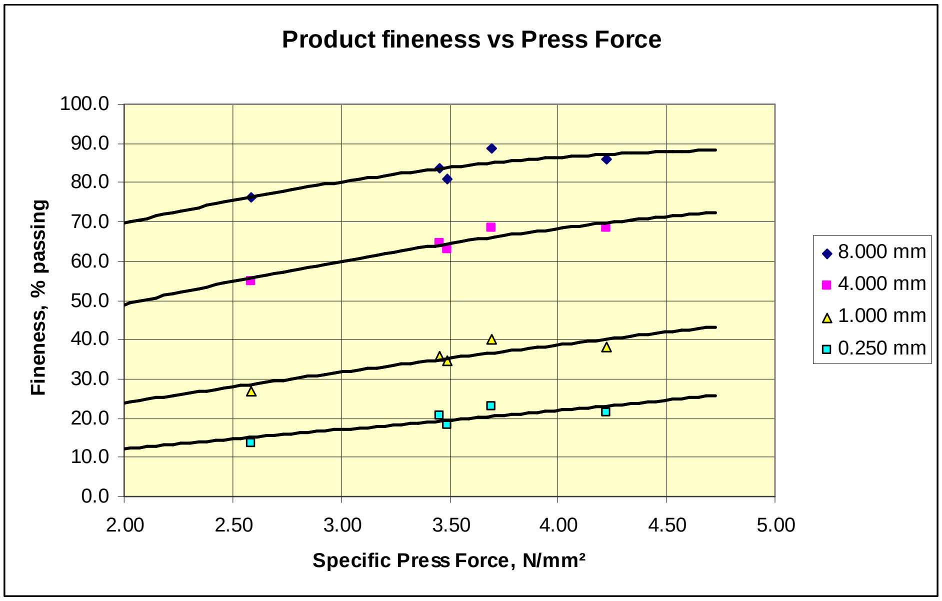


Figure 10. Variation of Product fineness with pressure.

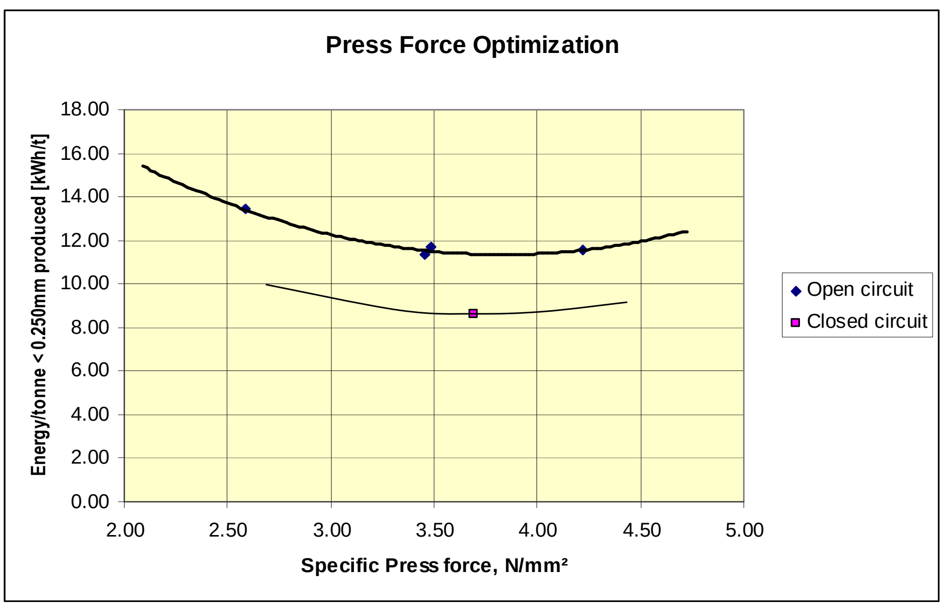


Figure 11. Variation of Product fineness with pressure.

6. Grinding Tests

6.1 Standard Bond Tests

Two standard Bond grinding tests were performed on the material: one on the original feed; the second on product of Test R 2.3 (from closed-circuit with dry screening). The results are given in the Table below. Size analyses of the Bond test feed and products are shown in Figures 12 & 13. The value obtained on the original feed was 17.8 kWh/mt. Treatment in HPGR resulted in a 10% reduction in the WI to 16.1 kWh/t.

Table 4. Summary of Standard Bond Test Results.

	Pi	Gbp	F80	P80	Wi (st)	Wi (mt)
Original ore	90	0.92	2541	64.7	16.2	17.8
R2.3 Product	90	1.06	2108	64.5	14.6	16.1

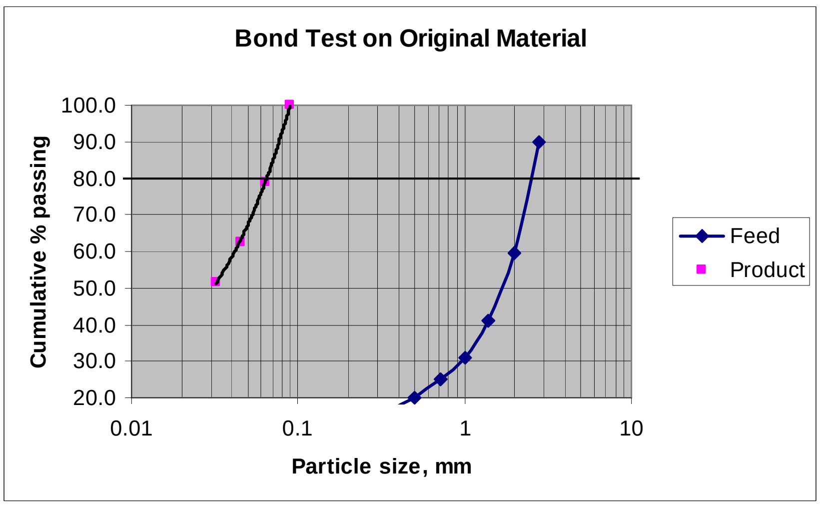


Figure 12.

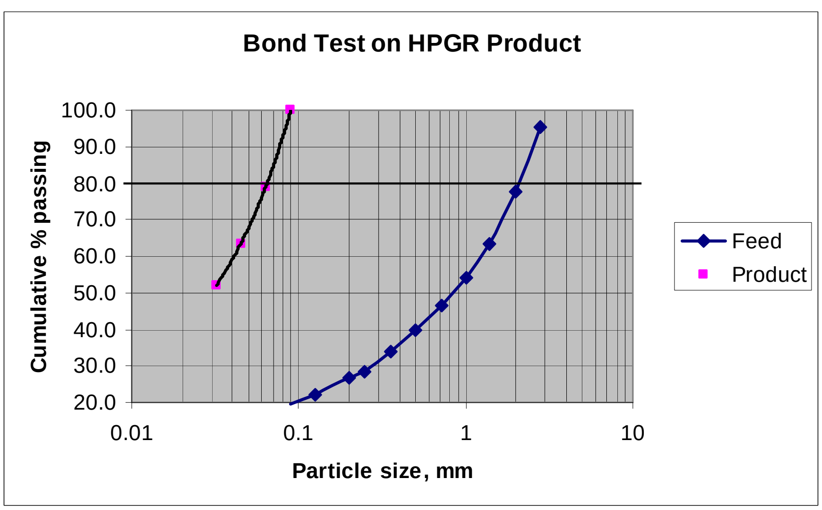
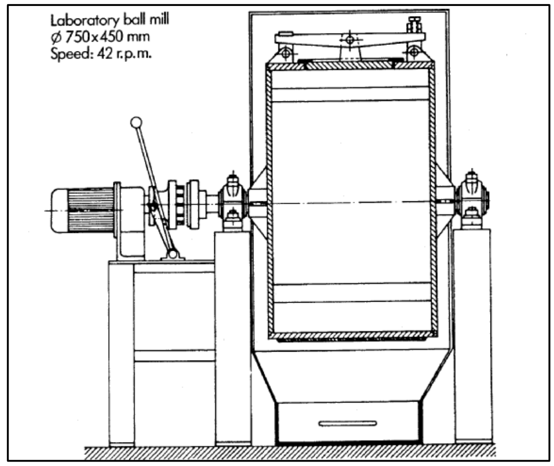


Figure 13.

6.2 POLYSIUS LABMILL Grinding Tests

The LABMILL grinding test was designed specifically for testing HPGR products without pre-crushing of the product for the test. The test is conducted dry in a 750 mm diam. x 450 mm wide ball mill on 7.5 litres of material. The feed, up to 30 mm in size, is ground stepwise using different ball gradings. The ball grading for each step is selected according to the material fineness. The energy consumption and material fineness is determined after each step.

The results are evaluated by plotting the specific energy consumption, in kWh/t, against the product fineness at a given size. Usually two sizes are selected, 90 µm and 200 µm. Linear regression lines are drawn through the points, and estimates are made of the energy required to achieve 80% passing a given size.



A comparison is then made between the energy required for the original feed and for the HPGR product, and the energy savings are calculated from the results. To even up the comparison, the feed was crushed to the top size of the product.

Industrial energy requirements may be calculated from the test results by applying scale-up factors. The LABMILL test is able to provide a realistic comparison of the ball mill energy required for materials with different size distributions. A summary of the LABMILL test results is given in the Table below.

Table 5. Summary LABMILL test results.

	LABMILL Grindability Test Results				
GRIND	**HPGR Feed**		**HPGR Prod.**		**Savings, %**
80% < 200µm	7.07	**kWh/t**	6.06	**kWh/t**	14.2
80% < 90µm	10.62	**kWh/t**	9.27	**kWh/t**	12.7
100% < 90µm	13.76	**kWh/t**	12.28	**kWh/t**	10.8

These indicated a potential energy saving at a P80 of 200 µm of 14% and at a P80 of 90 µm of 12%. Size analyses of the feed size distributions used in the tests are shown in Figure 14.

The energy-size relationships obtained in the tests are shown in Figure 15.

The results indicated higher energy savings than the Bond Tests. The difference in the results is attributable to the larger amount of fines generated in the product by the HPGR, which is not accounted for in the Bond calculations.

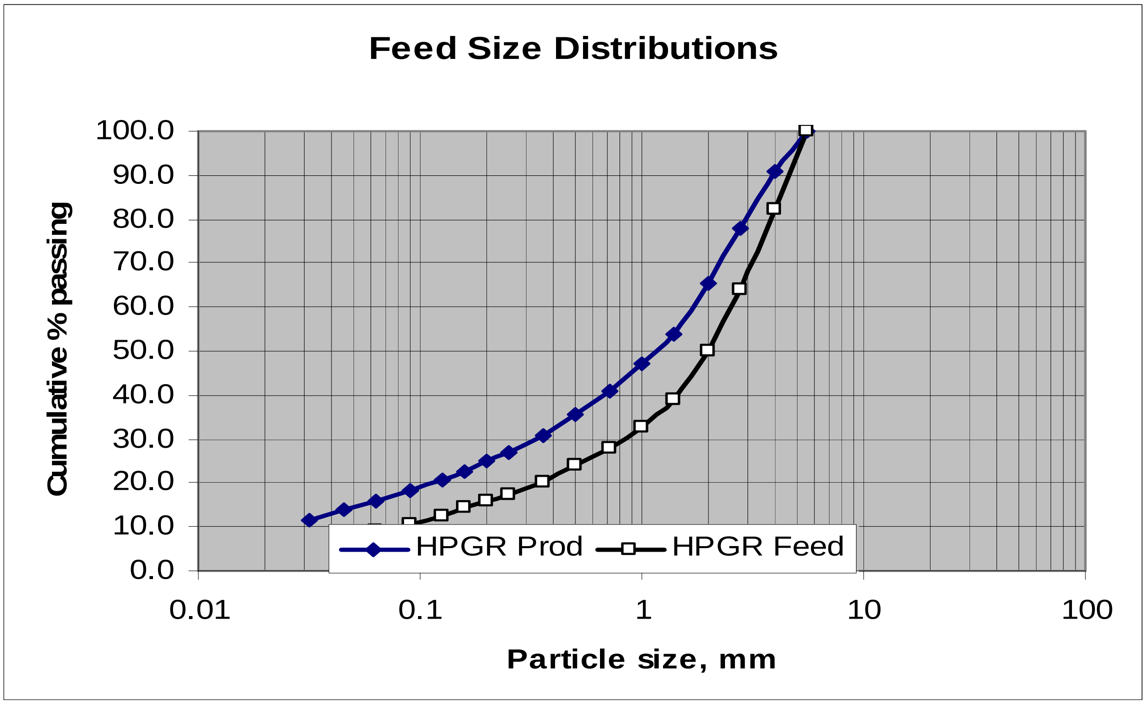


Figure 14. Feed to the LABMILL tests.

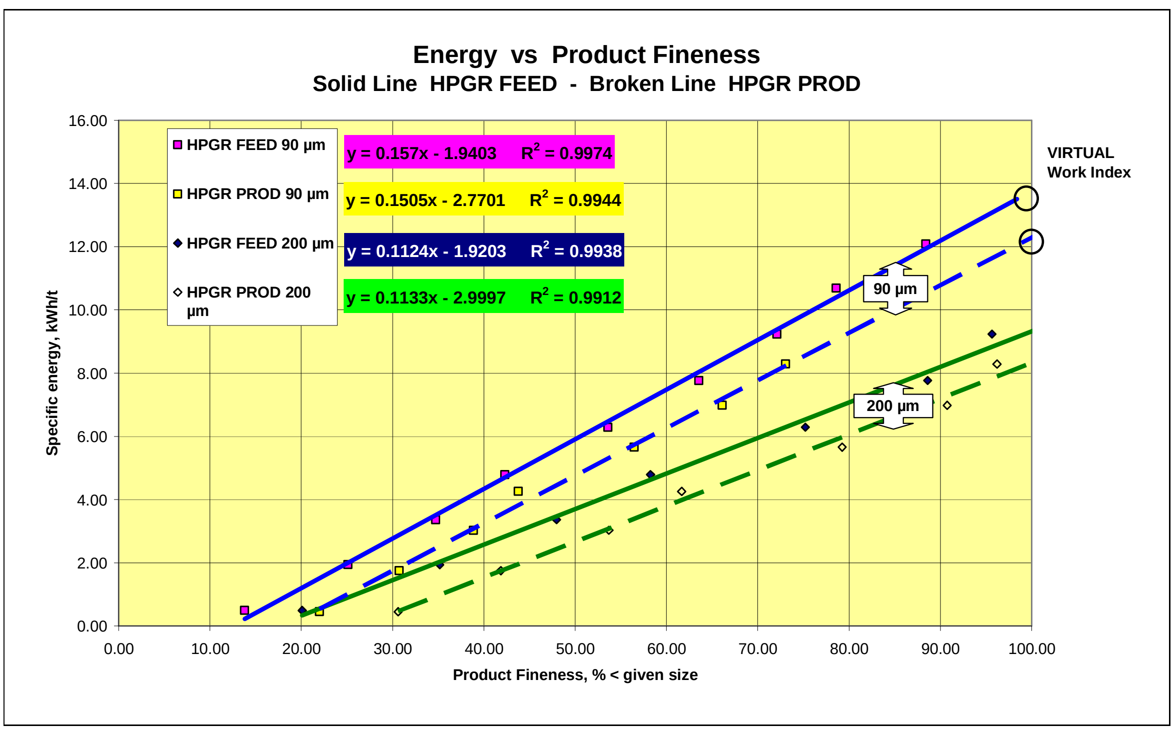


Figure 15. LABMILL energy vs product fineness.

7. Conclusions

1. The material was found to be of low to medium abrasiveness, ATWI index 9-15 g/t. The wear life of the rolls was estimated at 7000 h.

2. The size reduction achieved was better than average for copper ores, > 80% < 8.0 mm, >50% < 2 mm, >20% < 0.2 mm. Increasing pressure had a minimal effect. The max specific press force necessary was 3.5 N/mm^2.

3. The specific throughput for design purposes was 220 ts/hm^3. Recycling of oversize in a closed-circuit operation had no significant effect.

4. The net specific energy consumption was 1.7 kWh/t at a specific press force of 3.5 N/mm^2 for dry material, and 2.0 kWh/t for wet material with 4-5% moisture content.

5. The material did not form competent flakes on pressing, and could be screened with relatively high efficiency.

6. The Bond Work index of the sample tested was 17.8 kWh/t before and 16.1 kWh/t after HPGR. Pressing in the HPGR resulted in a 10% weakening of the material, through the formation of micro-cracks.

7. LABMILL tests indicated potential energy savings in the order of 14% at a P80 size of 200 µm and 12% at 90 µm from the greater amount of fines created by the HPGR.