

HIGH PRESSURE GRINDING ROLLS MODELLING WITH POPULATION BALANCE MODELS APPLIED TO TANTALUM ORE

Eduard Guasch¹, Hernan Anticoi¹, Sarbast Hamid¹, Josep Oliva¹ and Pura Alfonso¹

*Departament d'Enginyeria Minera, Industrial i TIC
Universitat Politècnica de Catalunya BarcelonaTech
Av. Bases de Manresa 61-63, Manresa (08242) Barcelona, Spain
eduard.guasch@emrn.upc.edu*

ABSTRACT

Tantalum is a strategic metal and an improvement of the mineral processing is an important issue. The main objective of this work is to optimize the grinding technologies for tantalum ores with high pressure grinding rolls. The selected ore for this study was an altered leucogranite from the Penouta Open Pit Mine (NW Spain). In the present work mono-size experiments have been carried out using grinding rolls with controlled pressure. The particle size distribution has been monitored in the input and output of the high pressure grinding rolls for each experiment. The cylinder pressure that is transmitted to the particles has been determined. New population balance models are presented for high pressure grinding rolls with parameter adjust for tantalum ore. The obtained model uses the physical description of particles under the comminution action of the grinding rolls. The obtained results are in agreement with other models and the errors in the adjustment are low. The selection function proposed for this model describes adequately the breakage probability of the particles inside the high pressure grinding rolls. The presented model can be a good alternative for simulating a high pressure grinding roll process.

KEYWORDS

High pressure grinding rolls, Population balance model, Grinding, Modelling, Tantalum.

INTRODUCTION

Technology for grinding have been improved for many years, introducing new variables and parameters involving energy consumption, mechanical stress analysis of the compression particles or pressure application for optimizing the comminution (Morrell et al, 1997). High pressure grinding rolls is a modern technology that is proven to reduce the operating costs in full scale plants when compared with other milling technologies. Its benefits on energy saving and simplicity in the process have been studied and applied, first in the cement clinker industry (Abouzeid & Fuerstenau, 2009) and after in mining activities, especially in metallic ore deposits (Austin et al, 1991; Guevara & Menacho, 1992; Morrel et al, 1997; Torres & Casali 2009; Numbi & Xia, 2015). Many author structures of the High Pressure Grinding Rolls modelling in three main branches; (a) throughput modelling, (b) Power and energy model and (c) particle size distribution modelling (Austin et al, 1991; Guevara & Menacho, 1992; Austin & Trubelja, 1994; Morrel et al, 1997; Torres & Casali, 2009).

Guevara & Menacho (1992) follow several hypothesis about throughput modelling; (a) null displacement between the mineral and the roll in the zone where the pressure reach the maximum value, (b) shear stress over the rolls are governed by Coulomb equation, (c) the internal stress in the bed compression zone does not vary through the length of the rolls.

Austin et al (1993) indicate that the total force measured is the integral of the horizontal compressive forces up to the gap. The specific grinding pressure is expressed in geometric terms of the device. This pressure increases and reaches a maximum compression effect at the gap, leading to a higher bulk density of material passing through the gap. However, a smaller gap means that the separation of the roller at some critical nip angle is lower, so the throughput decreases with the specific grinding pressure. Morrel et al (1997) as well as Austin, indicate that the variation of the throughput is a linear logarithmic function of the specific grinding force, the rolls speed and the gap. Torres & Casali (2009) refers that under steady state conditions the difference of tonnage between the beginning and the end of the particle bed compression zone is equal to zero, then the throughput can be calculated in function of the geometry of the device, the gap and the apparent density of the ore before enter to the nip angle influence and the apparent density in the extrusion zone.

For the power and energy model, the authors specially refer to the energy consumed by the pressure to the rolls as the specific power draw (Guevara & Menacho, 1992) or as the power required by the high pressure grinding rolls at the rolls in terms of the torque and the angular velocity (Morrell et al, 1997). Torres & Casali (2009) indicated that this device is operated in a choke fed condition, so the applied pressure is distributed only in the upper right half of the roll. The power draw is function of the specific pressure, diameter of the roll, the nip angle and the tangential speed of the rolls.

For determining the produced particle size distribution, Population Balance Model is mainly used. The simplest case is the Guevara & Menacho model, expressing the product in terms of the kinetic function, the specific energy and the feed in cumulative percentage. In many cases, the comminution is based in the studies on grinding rolls devices and considers two distinctly different ways; first, a single particle compression or pre-crushing zone (Morrell et al, 1997; Torres & Casali, 2009) where the particles break slowly with the simple contact to the rolls under pure compression (Fuesternau et al, 1991). Then, a bed compression zone is defined as a place where the product of the single particle compression form a bed of particle and comminution occurs primarily by very high localized inter-particle stresses generated within the particle bed, due to the contact to the rolls. The piston flow arrangement is produced, because the pressure increase considerably by the lessening of volume as the material approaches to the gap (Fuesternau et al, 1991; Torres & Casali, 2009). It is important to mention that the author distinguish between the particles that are broken by simple compression, but other material bypass without breakage. These particles joint to the product of the single particle compression for forming the bed particle compression zone (Austin et al, 1991; Torres & Casali, 2009; Kwon et al, 2012). Schneider et al (2009) incorporated the specific grinding pressure into the Austin's population balance model and took into account the increase of the gap during grinding test for determining the product. Furthermore, two different

breakage functions were recommended to use; Austin's function and the truncated Rosin-Rambler breakage function, and depending of the ore type, one of them or both can be used to predict the particle size distribution product. Torres & Casali (2009), for modelling the particle size distribution, consider a discretization of N_B blocks through the rolls length where each one have a particular compression force, power consumption and rate of breakage.

The aim of this study is to show a new population balance model and the adjustment of the parameters for Tantalum ore applied to high pressure grinding rolls to improve the physical description of the process and allow better adjustments for this material.

MATERIALS AND METHODS

Methodology is divided in three different stages: (1) Preparation of the materials and determination of operative parameters, (2) Selection of the model and executing experiments, (3) modelling and back-calculation for finding the different parameters of the function for breakage and selection function.

The tested material was a low grade tantalum-rich altered leucogranite from the Penouta Open Pit Mine, Northwest of Spain (Anticoi et al, 2016). About 250 kg of material were sampled and used for the experiments. For the mechanical characterization, single compression tests have been performed. The sample was crushed by a KHD Humblot Wedag jaw crusher, screened and classified by size class from -19 +16 mm, -16 +14 mm, -14 +12.5 mm, -12.5 +11.5 mm, -11.5 +9.5 mm, -9.5 +8 mm, -8 +6.7 mm and -6.7 +5 mm mesh in order to perform mono-size experiments.

A total of 17 tests were performed with a KHD Humblot Wedag roll crusher with controlled pressure. The dimensions of the rolls are 150 mm in width and 250 mm in diameter, with a gap setting from 0 to 7 mm. Pressure was controlled by means of a hydraulic system incorporated to the device with two 60 mm internal diameter pistons. Three gap configurations were used, 3 mm, 4 mm and 5 mm. In order to observe the mechanical behaviour of the material, a transparent cover was used.

The operative parameters were controlled for each test (Table 1). Bulk density of the material was measured at both the inlet and outlet. The product particle size distribution was determined. For parameter adjustment, MATLAB software and backcalculation *globalsearch* solver was used.

Table 1- Operative parameters for all performed tests.

			T-1	T-2	T-3	T-4	T-6	T-7	T-8	T-9
Density	t/m ³	ρ	0.86	0.83	1.07	1.12	0.86	0.83	1.07	1.12
Bulk density	t/m ³	δ	1.57	1.46	1.48	1.47	1.57	1.46	1.48	1.47
Tangencial velocity	m/s	U	1.0	1.0	1.0	1.0	0.8	0.7	0.7	0.7
Velocity	RPM	v	76	76	76	76	61	54	53	53
Pressure	MPa	Po	10	10	10	10	10	10	10	10
Force	kN	F	490	490	490	490	490	490	490	490
Flow	t/h	G	1.2	1.3	1.2	1.4	1.0	0.9	1.0	1.1
Gap	mm	S ₀	5	5	5	5	5	5	5	5
Feed size	mm		-19+16	-16+14	-14+12.5	-12.5+11.5	-6.7+5	-16+14	-14+12.5	-16+14

			T-10	T-11	T-12	T-13	T-14	T-15	T-16	T-17	T-19
Density	t/m ³	ρ	1.09	1.16	0.86	1.07	1.12	1.09	1.16	0.83	1.01
Bulk density	t/m ³	δ	1.57	1.54	1.57	1.48	1.47	1.57	1.54	1.46	1.51
Tangencial velocity	m/s	U	0.7	0.7	0.4	0.6	0.7	0.7	0.6	0.7	0.6
Velocity	RPM	v	53	30	30	42	53	49	46	53	46
Pressure	MPa	Po	10	10	8	8	8.5	8.5	8.5	8.5	8.5
Force	kN	F	490	490	390	390	417	417	417	417	417
Flow	t/h	G	1.3	1.3	1.2	0.8	1.2	1.0	1.3	1.1	1.0
Gap	mm	S ₀	3	3	3	3	3	3	3	3	4
Feed size	mm		-11.5+9.5	-9.5+6.7	-19+16	-16+14	-14+12.5	-16+14	-6.7+5	-16+14	

MODELLING

In the present work the assumptions are based on Torres & Casali (2009) approach about motion description of the particles passing through the rolls and single compression due to direct contact of the roll to the particles. Moreover, the viewpoint of Austin (Austin, 1993; Austin & Trubelja, 1994) who describes the breakage of the material in several steps and the relationship with a selection function, including parameters dependent on the geometry of the device and the material mechanical characteristic. From Schneider et al (2009), the operative pressure have been calculated in order to insure that no movement occurs in the roller shafts, then all the breakage action is performed by the rotational motion of the rolls (Torres & Casali, 2009).

From there, and under steady conditions, Torres & Casali (2009) present the throughput model and the methodology for compression angle calculation (Equation 1), in terms of change of the bulk density through the rolls, maintaining the flow as constant (Figure 1).

$$\cos(\alpha_{nip}) = \frac{1}{D} \left[(S_0 + D) + \sqrt{(S_0 + D)^2 - \frac{4S_0\delta D}{\rho_a}} \right] \quad [1]$$

$$G_s(\alpha) = 3600 \delta S_0 L U \quad [2]$$

Where $\rho(\alpha_{nip}) = \rho_a$ (t/m³) is the bulk density at the feed zone, $\rho(0) = \delta$ (t/m³) the bulk density at the extrusion zone, L (m) the roll length, U (m/s) the tangential velocity, G_s (t/h) the throughput, D (m) is the diameter and S_0 (m) is the gap.

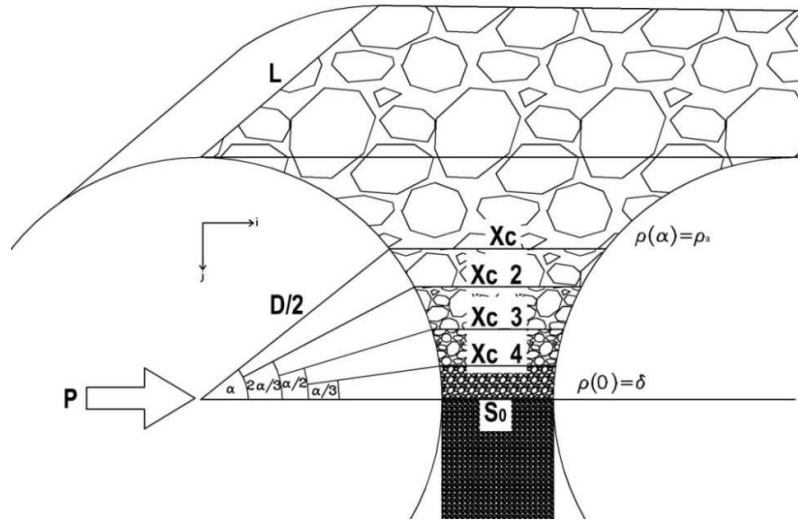


Figure 1 – Description of the device geometry showing the different discretized zones.

The pressure R_p (MPa) given by the hydraulic system is transformed in a force F (kN) to the rolls shaft. If this force reaches a value that does not generate displacement, it will be optimal for each material with minimum work pressure and the least energy consumption. This force acts into all the surface contact between mineral and the rolls, including the tension and compression effect.

$$F = 250 N_p R_p \pi D_p^2 \quad [3]$$

Where N_p is the number of piston and D_p (m) is the piston diameter. The specific pressure over the roll surface P_{ef} (MPa) is given by:

$$P_{ef} = \frac{F}{S} = \frac{F \alpha_{nip}}{360000 \pi D L} \quad [4]$$

Taking into account that the rolls have point contact due to the porosity (ϕ) of the material, the real specific pressure P_r (MPa) can be expressed by:

$$P_r = (1 - \phi)P_{ef} \quad [5]$$

Although the size reduction process in a high pressure grinding roll is continuous, the comminution action can be considered as discrete actions. One mathematical solution to describe this physical process is to consider the size reduction as several steps of breakage actions in which a selection function S splits the flow into particles with a great probability to be comminute and others bypass to the next step. In physical terms, when a particle enters to the zone where the comminution starts, if it is bigger than a critical size defined by the nip angle, that particle will break under single particle compression. The other undersize particles will have a percentage of breakage, but the probability decreases with smaller size class, and other ones practically cannot be ground, and this behaviour will be defined by the selection function. The physical process continues with other comminution actions. This other step will be driven with another critical size where single compression can be again produced and the smallest size class break with a probability defined by the parameter in the selection function which define the size of the particles that do not break. The behaviour of the breakage and selection function will be the same in all the steps. Then it can be represented as a discretization for many stages but in this work four steps have been presented (Figure 2).

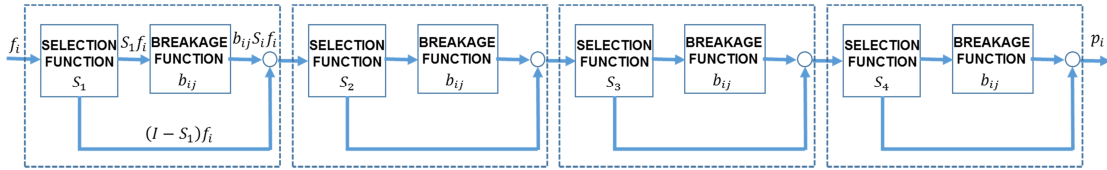


Figure 2 – Scheme of the proposed population balance model for high pressure grinding rolls.

The selection function from Whiten et al. (1979) mainly used for cone crushers, also applicable to roll crushers and high pressure grinding rolls (Equation 6) describes adequately this physical process. This function has the particularity of fixing upper and under edges, related to the device geometry and the mineral characteristics.

$$\begin{aligned} S_n &= 1 - \left(\frac{dp - x_n}{d_1 - x_n} \right)^\gamma & \text{for } d_1 < dp < x_n \\ S_n &= 0 & \text{for } dp < d_1 \\ S_n &= 1 & \text{for } dp > x_n \end{aligned} \quad [6]$$

Where, the upper limit x_n is given by the distance between the rolls when the nipping action begins, the under limit d_1 represents those particles that cannot be retained in the comminution zone due to their size that slip through the larger particles and the parameter γ can be related to mineral characteristics and describes the behaviour of the curve.

The mathematical relation of the distance between the rolls and the compression angle is shown in Equation 7.

$$x_n(\alpha) = S_0 + D(1 - \cos \alpha) \quad [7]$$

For the breakage function, the standard form presented by Whiten et al. (1979) is used in equation 8.

$$B_{ij} = k \left(\frac{x}{y} \right)^m + (1 - k) \left(\frac{x}{y} \right)^l \quad [8]$$

where k , m and l are the parameters of the model.

RESULTS AND DISCUSSION

The results of the single compression tests of the Penouta leucogranite show a wide range of values, up to 90 MPa. The operative pressure of the hydraulic system is 10 MPa and this pressure drives a force to the rolls shaft of around 490 kN. The rolls transmit that force into the particle handling a real specific pressure P_r of approximately 1000 MPa, enough to avoid any movement of the rolls in front of the particles load. Experimental monitoring shows any displacement of the rolls during the experiments.

The size reduction was simulated in four steps. For the selection function, the upper parameter value $x_n(\alpha)$ has been evaluated using equation [7] for the angles α_{nip} , $2/3 \alpha_{nip}$, $1/2 \alpha_{nip}$ and $1/3 \alpha_{nip}$ (Figure 3). The parameters d_1 and γ were back-calculated using MATLAB software and the parameter d_1 shows an average value around 0.0014 m. This result is in accordance with the visual observations. The parameter γ defines the behaviour of the curve between the upper and lower boundaries defined by the parameters x_n and d_1 .

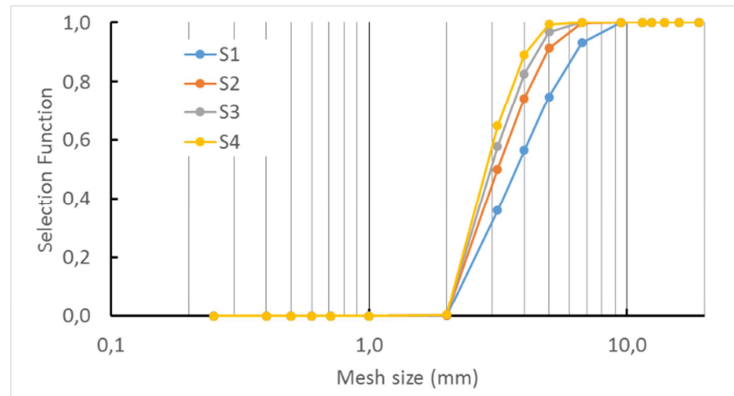


Figure 3 – Plot of the selection function for the test T-1. S1 to S4 represent the different steps.

The breakage function and the selection function parameters have been calculated by means of Matlab procedure. The error is the cumulative difference between the estimated product and the experimental product. For the assays T-2, T-7 and T-8 the error were around 0.026 and 0.067 (Table 2). The wide range in the values of the parameters could be attributed to the heterogeneous resistance of the leucogranite due to the variability in the degree of alteration.

Table 2 – Back-calculated parameters of the breakage and selection functions of the selected tests. The parameter d_i is in meters

Parameters	T-1	T-2	T-3	T-4	T-6	T-7	T-8	T-9
k	0.061	0.096	0.235	0.078	0.074	0.173	0.251	0.250
m	0.001	0.069	0.360	0.001	0.002	0.221	0.366	0.345
l	1.104	1.303	2.490	1.087	1.101	1.510	2.830	2.277
γ	2.593	1.785	3.487	0.610	2.502	1.889	8.910	2.359
d_i	0.0020	0.0017	0.0018	0.0015	0.0019	0.0017	0.0019	0.0016

Parameters	T-10	T-11	T-12	T-13	T-14	T-15	T-16	T-17
k	0.273	0.115	0.088	0.156	0.302	0.213	0.117	0.164
m	0.383	0.008	0.001	0.147	0.374	0.232	0.009	0.152
l	4.298	1.070	1.033	1.396	3.085	1.768	1.057	1.295
γ	1.587	0.120	0.533	0.503	0.913	0.631	0.116	0.438
d_i	0.0011	0.0010	0.0012	0.0009	0.0011	0.0011	0.0010	0.0010

The particle size distributions of the experimental and simulated model are plotted in Figure 4. They are compared with the Torres & Casali (2009) model, the Guevara & Menacho (1992) model and the experimental data. The simulations of all the models present an excellent adjustment with the experimental values. The simulation developed with the proposed model shows a great fitting, being the best in experiment T-2 (Figure 5). The error in this case is 0.026 (Table 3) that represents an error reduction of more than 95%. Experiments T-7 and T-8 are also well adjusted, 0.067 and 0.064, respectively. The error reduction in experiment T-7 is more than 26% respect Guevara & Menacho (1992) model and the error in the experiment T-8 is slightly higher than Guevara & Menacho (1992) model.

Table 3 – Comparative errors among different models.

Reference	T-2	T-7	T-8
Torres & Casali, 2009	17.160	8.930	5.081
Guevara & Menacho, 1992	0.569	0.091	0.061
This work	0.026	0.067	0.064
% error reduction	95.43%	26.49%	-5.83%

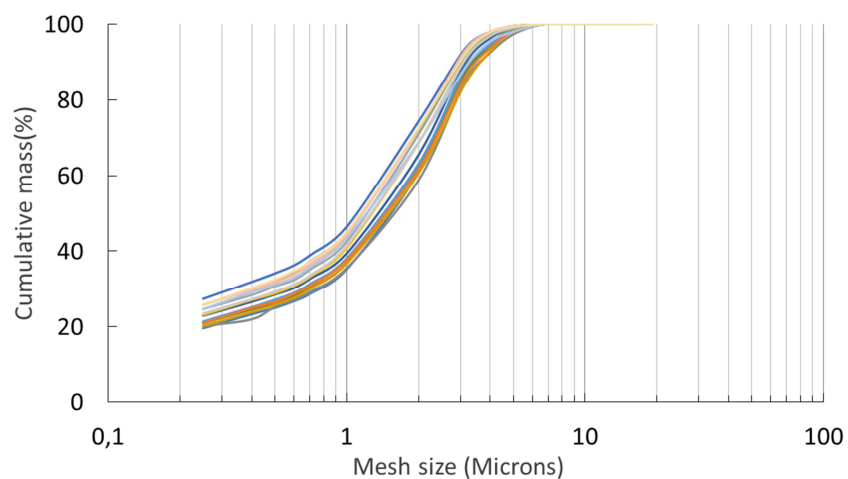


Figure 4 – Particle size distribution for all performed tests

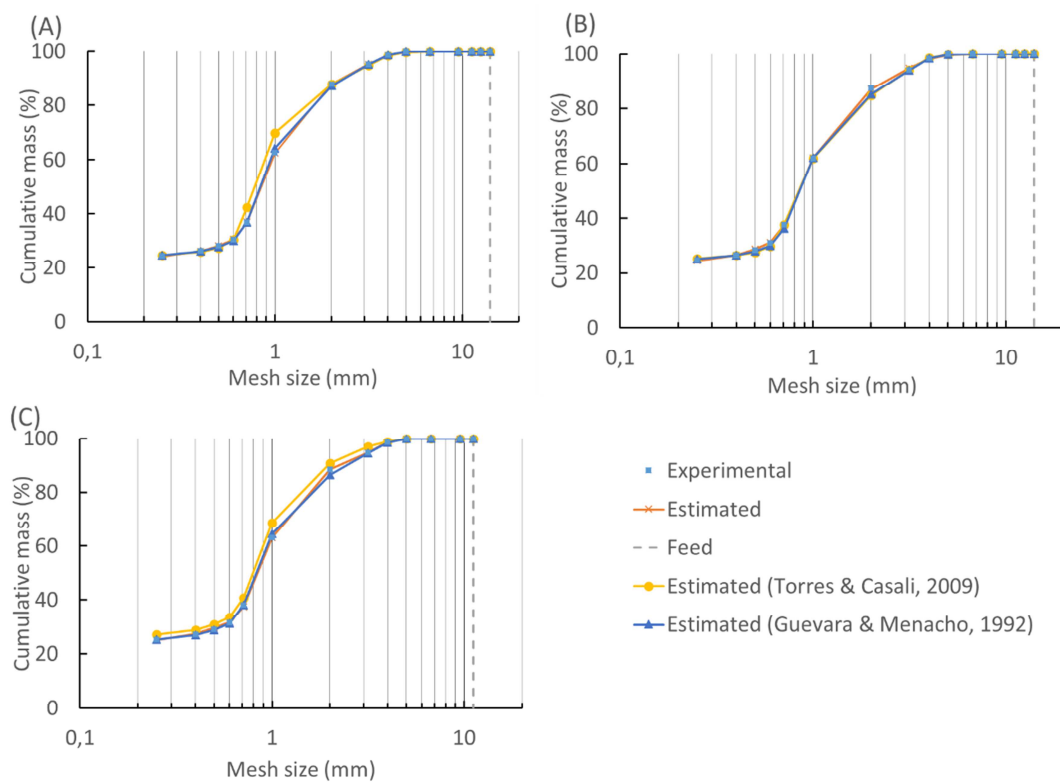


Figure 5 – Particle size distributions of the experimental and simulated values of the representative experiments. (A), (B) and (C) are T-2, T-7 and T-8 tests, respectively.

CONCLUSIONS

This model is based on a physical description of particles under the comminution action of the grinding rolls and its main advantage is the simplicity. In addition, the model presented can be a good alternative for simulating a high pressure grinding roll process. The simulations show low errors in the adjustment with the experimental data and with the other models. The mechanical behaviour are based on the visual observations of the experiments and indeed the breakage function for each steps can vary depending on the nature of the particle interaction between the rolls or the inter-particle breakage, this behavior was not introduced into the model.

Although the selection function was developed for cone crushers, it describes adequately the breakage probability of the particles inside the high pressure grinding rolls.

ACKNOWLEDGMENTS

This work is part of the OptimOre project. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 642201. The Strategic Minerals enterprise helped in the sampling of Penouta.

REFERENCES

- Abdel-Zaher, M. & Fuesternau, D. (2009). Grinding of mineral mixture in high pressure grinding rolls. *International journal of mineral processing*, 93, 59-65.
- Anticoi, H., Ahmad, S., Guasch, E., Alfonso, P., Oliva, J. & García-Valles, M. (2016). Low grade tantalum ores: mineral liberation analysis modelling. In: *Proc. Eedings of the XXVIII International Mineral Congress. IMPC*, Quebec, Canada.
- Austin, L. G. & Trubelja, P. M. (1994). The capacity and product size distribution of high pressure grinding rolls. Mineral Processing and environment. In: Castro, S. & Concha, F. (Eds.), *Mineral Processing and Environment. Proceedings of the IV Meeting of the southern hemisphere of mineral technology*. 49-67. Universidad de Concepción, Chile.
- Austin, L. G., Weller, K. R. and & Lim, I. L. (1993). Phenomenological Modelling of the High Pressure Grinding Rolls, *Proceedings of the XVIII International Mineral Processing Congress*, 1, 87-95.
- Guevara F. & Menacho J. (1993) Mechanical and metallurgical modelling of the high pressure roll mill Modelación mecánica y metalúrgica del molino de rodillos de alta presión. Centro de Investigación Minera y Metalúrgica, Santiago de Chile. , 547-563
- King, R.P. (2001). *Modelling and simulation of mineral processing systems*. Butterworth-Heinemann. ISBN 0 7506 4884 8.
- Kwon, J., Cho, H., Mun, M. & Kim, K. (2012). Modelling of coal breakage in a double roll crusher considering the reagglomeration phenomena. *Powder Technology*, 232, 113-123.
- Morrel, S., Lim, W. & Tondo, L. (1997). Modelling and scale up of the high pressure grinding rolls. In: *Proceedings of the. XX International Mineral Congress. IMPC*, Aachen, Germany.
- Numbi, B.P. & Xia, X. (2015). Systems optimization model for energy management of a parallel HPGR crushing process. *Applied Energy*, 149, 133-147.
- Schneider, C., Alves, V. & Austin, L. (2009). Modelling the contribution of specific grinding pressure for the calculation of HPGR product size distribution. *Minerals Engineering*, 22, 642-649.

- Torres, M. & Casali, A., (2009) .A novel approach for the modelling of high-pressure grinding rolls. *Minerals Engineering*, 22, 1137-1146.
- Whiten, W. J., Walter, G. W. & White, M. E., (1979). A breakage function suitable for crusher models. *4th Tewkesbury Symposium*, Melbourne, pp 19.1-19.3.