Optimization of HPGR-Based Clinker Grinding Circuit at Abyek Cement Plant Using Steady-State Process Simulations

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Abstract

Abyek cement plant is equipped with four clinker grinding lines; every grinding line consists of a two-compartment tube ball mill. Recently, in a retrofit project, two high pressure grinding rolls (HPGR) units were installed in two grinding lines before the tube ball mills to grind clinker feed. The efficiency of these HPGR units is reported to be under design specification. In this study, an approach based on population balance modelling of grinding process and circuit simulations was used to optimize HPGR milling operation. Representative samples were taken from HPGR units' feed and product streams to obtain HPGR model parameters, namely, breakage distribution function and selection function or specific rate of breakage. Screen analysis tests were carried out to determine Particle Size Distribution (PSD) of every powder sample and its d80 as powder size index. Tumbling grinding tests with laboratory ball mills were also done using collected samples to determine breakage distribution function of feed to HPGR units. Selection function was estimated based on PSDs of HPGR feed and product samples using NGOTC program.

A comparison between HPGR measured and predicted product PSDs proved validity of modelling and simulation approach. Several simulation trials were performed to find the best settings of main input variables including applied roll pressure, roll gap and rolls rotational speed which showed that their optimal values are 180 bar, 0.01300 m and 2 m/s, respectively. Plant implementation of these settings for one of the HPGR units showed a 22% decrease in d80 of product. The optimization study indicates that production capacity can be increased from 150 t/h to 180 t/h with a Blain fineness of 3000 cm²/g.

Keywords: optimization, HPGR, cinker, simulation, Abyek Cement Plant

Introduction

Abyek cement plant is located at north-west of Tehran, Iran and produces around 12500 t/d Portland cement. It consists of four clinker grinding lines, each one equipped with a two-compartment tube ball mill in closed circuit with an air separator. The final cement powder produced at this plant has an average Blain fineness of 3000 cm²/g. In 2011, according to a retrofit expansion plan, two new identical HPGR units were installed on line No. 3 and line No. 4 before the ball mills. The HPGR units are operated in open circuits under the same condition. However, since start-up time, the grinding performance of these HPGR circuits had been unsatisfactory. The design goal behind installing HPGR units was to increase throughput of ball milling operation from current 100 t/h to 190 t/h. Nevertheless, practically, a throughput between 140 t/h to 150 t/h has been achieved so far in spite of various circuit adjustments. These numbers depend on quality and grinding ability of output clinker of the kiln and change continuously. Therefore, in this research, it was decided to optimize the HPGR circuit based on simulation approach. The HPGR module of BMCS program (Hasanzadeh and Farzanegan, 2011) was used in this study to simulate and optimize HPGR circuit.

Mathematical modelling of HPGR grinding has been discussed by several researchers (Daniel & Morrell, 2004; Aydoğan et al., 2006; Torres & Casali, 2009). Currently, there are reliable HPGR models that can be used confidently to simulate their performance which have been implemented in mineral processing simulators such as JKSimMet (Napier-Munn et al., 1996), MODSIM (King, 2001) and BMCS. The HPGR model which has been used in this research is due to Torres and Casali (2009) which has been coded in BMCS program. The HPGR model proposed by Torres and Casali is based on the model developed by Daniel and Morrell, 2004 involves three sub-models.

Throughput is not constant and changes with respect to the angle α as shown in Figure 1. The throughput at extrusion zone (α = 0) is regarded as HPGR capacity and can be calculated using Eq.(1):

$$G_S = 3600 \delta s_0 L U \quad (1)$$

where G_s (m) is throughput, S_0 (m) is the minimum distance between the rolls, L (m) is length

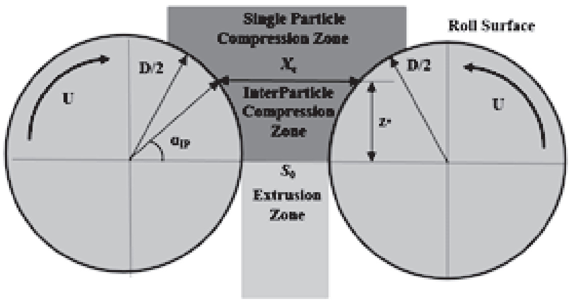

Fig. 1. HPGR Model

Rys. 1. Model prasy HPGR

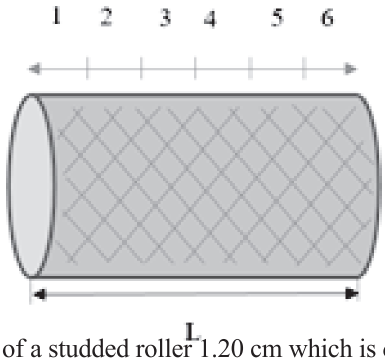

Fig. 2. View of a studded roller 1.20 cm which is divided into six parts 20 cm

Rys. 2. Widok rolek 1.20 cm podzielonych na sześć części 20 cm

of the roll, δ (t/m³) is density of ore in output area and U (m/s) is perimeter velocity of rolls.

P the total power draw (kW) is calculated based on Eq. (2):

$$P = 2F\sin\left(\frac{\alpha_{IP}}{2}\right)U \tag{2}$$

where F is compression force and α_{IP} is angle of particle bed compression zone.

Since the high pressure exerted along the roll varies and changes like a parabola, it is necessary to divide the roll length into several blocks. In each block a special compressional force is exerted related to pressure curve. Therefore, each block has a specific consumption power and a specific grinding kinetics. The total length of the roll is equal to 1.2 m which was divided into six parts each 20 cm and each part was considered separately as shown in Figure 2.

Parts 1 and 6 relate to end parts of the roll, parts 2 and 5 are middle parts and parts 3 and 4 are central parts.

The energy-based selection function, SiE,in each block is calculated using Eq. (3):

$$S_i^E = \frac{H_K}{p_k} S_{i,k} \tag{3}$$

where H_k is the mass hold up in part k, p_k is power draw for part k and $S_{i,k}$ is selection function for ith size and part k.

Materials and methods

Representative clinker samples were collected from HPGR circuit at various locations as shown in Figure 3 under two different operating conditions.

HPGR unit at line 4 was chosen for sampling. Samples were taken from HPGR input and output streams, approximately 200 kg for each stream. In laboratory, representative samples of both HPGR input and output streams were prepared by mixing samples from primary increments. The screening tests were performed to obtain particle size distributions of feed and product of HPGR circuit which are essential data for simulation calibration. After initial preparations and obtaining single-sized samples, tumbling grinding tests were done to determine clinker breakage function. Data and grinding times are introduced to BFDS program (Yousefi et al., 2005). The final breakage function will be determined by fitting (Broadbent and Callcott, 1956) relationship Eq. (4) to cumulative breakage function found by various methods included in the program:

$$B = \Phi R^{\gamma} + (1-\Phi)R^{\beta} \tag{4}$$

Selection function and clinker breakage function along with other necessary data were entered into BMCS program. Required data are: diameter and length of the roll in terms of m, pressure of the rolls in terms of bar, ore density and superficial density of the feed in terms of t/m³, number of blocks for the pressure exerted to the rolls, downward speed of the particles m/s, minimum distance between the rolls m, rotation velocity of the rolls 1/m, density of the output material t/m³, percentage of the residual weight of particles on each sieve level in feed and product and initial tonnage of the instrument that is 150 t/h and it is constant during the simulation and optimization. This program performs a simulation based on input data and predicts the d_{80} of feed and product and simulates specific consumption energy and energy necessary to rotate the unit.

Results and discussion

Based on grinding test data, breakage function of clinker samples was calculated using three

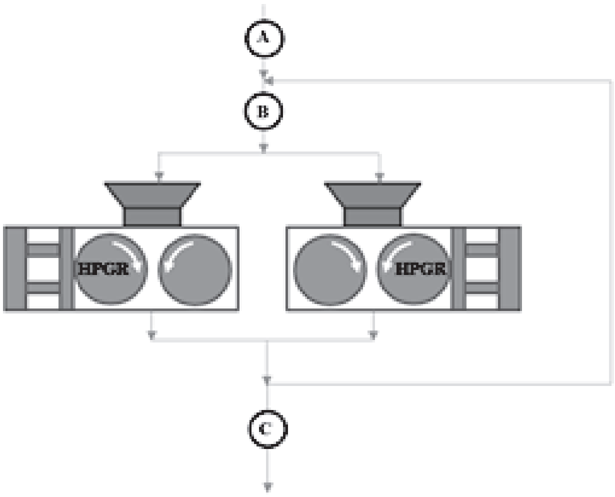

Fig. 3. Simplified flowsheet of HPGR and sampling points

Rys. 3. Uproszczony schemat prasy HPGR i miejsca pobierania próbek

methods. The breakage function for 12500 μm initial size is given in Figure 4 (a). It was found that clinker breakage function is normalizable. For subsequent simulations, the final breakage function was obtained by fitting B&C model (Eq. (4)) to calculated breakage function values. The optimal values obtained for model parameters namely, Φ, γ and β were equal to 0.04666, 0.0468 and 5.2209, respectively.

Figure 4 (b) shows selection function of particles at different locations of the rolls. The reason why parts 1 and 6 have higher selection functions compared to parts 2 and 5 and parts 3 and 4 is that in these locations of the rolls coarser particles are ground in compare with other locations. It seems that coarse particles will be pushed towards the edges of rolls under chock feeding and continuous vibration during high pressure grinding. Besides, considering that coarse particles have a higher instability than that of smaller particles, they are accumulated at the feed column peripheral and will be ground there. Obtained model parameters were averaged and their mean was chosen as input data to BMCS program.

To describe energy-based selection function, the functional expression given in Eq. (5) is used (Herbst and Fuerstenau, 1968).

$$\ln\left(\frac{s_i^E}{s_1^E}\right) = \zeta_1 \ln\left(\frac{\overline{x_i}}{\overline{\overline{x_1}}}\right) + \zeta_2\left(\ln\left(\frac{\overline{x_i}}{\overline{\overline{x_1}}}\right)\right)^2 \quad (5)$$

In which, ζ1, ζ2, ζ3 and S1E are model parameters. These parameters are calculated using selection function values obtained from NGOTC program.

Figure 5 shows cumulative and noncumulative plots with base values. As it can be concluded from this figure, feed and product consists of two statistical populations, one population of coarse particles with a mode around 10000 μm and one population with a mode around 35 μm.

Results obtained by BMCS program were compared to results obtained from plant sampling measurements and Torres and Casali model. To do this, firstly, specific consumption power and power needed to rotate the rolls predicted by BMCS program was compared with values obtained from Torres and Casali model. Results of comparison is presented in Table 1.

This program simulated the particle size distributions of total feed and ground product of high pressure grinding rolls. To be sure of validity of simulation process and output data of the program, predicted data were compared with data measured by sieve analysis. Figure 6 shows the cumulative plots of HPGR feed and product particle size distributions.

It can be concluded that the simulated results for HPGR feed and product particle size distributions are very close to the real measurements. Hence, it is clear that predicted d80 of both streams are also close to their measured d80, too. As a result, validity of simulation and tests are verified.

In order to optimize HPGR operation, several operating parameters which were supposed to have a high impact on operating efficiency were identified and considered. Accordingly, three parameters including roll pressure, roll gap and rolls speed were selected as variables to be optimized. The parameters were allowed to be changed within the specified range permitted by equipment manufacturer. At first, the effect of each parameter

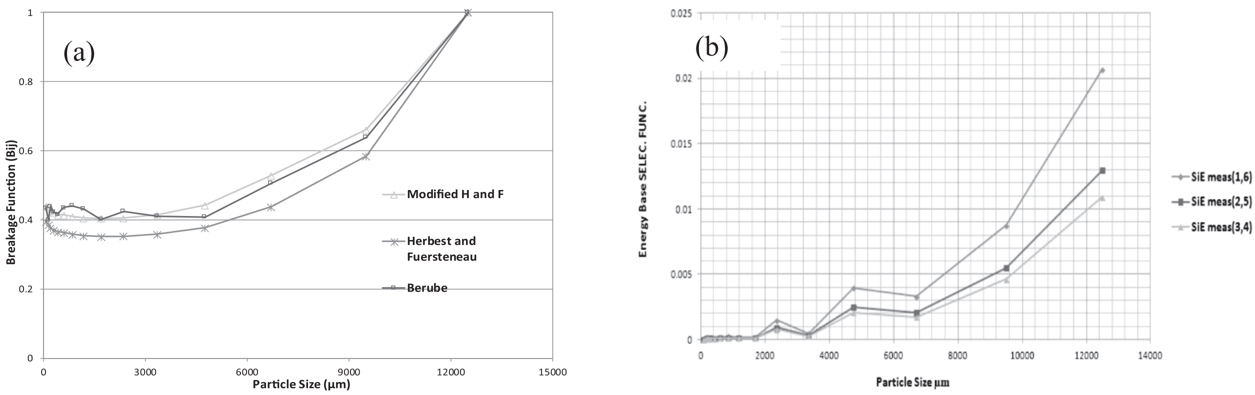

Fig. 4. (a) breakage function for 12500 μm initial size (b) selection function

Rys. 4. (a) funkcja rozdrabniania dla wielkości nadawy 12500 μm (b) funkcja selekcji

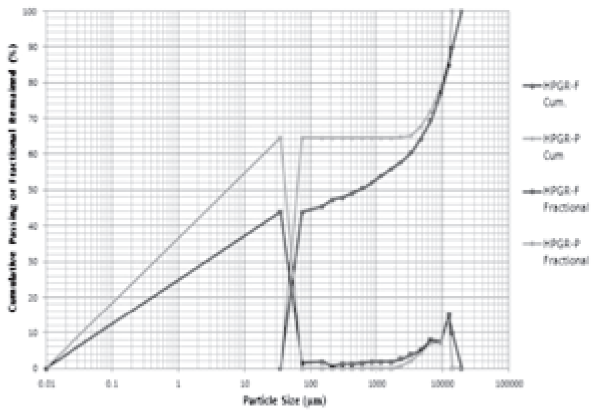

Fig. 5. Validation of simulation predictions

Rys. 5. Ocena symulacji

Tab. 1. Comparison between the data of BMCS from calculations with Torres and Casali model

Tab. 1. Porównanie danych BMCS z wyliczonymi z modelu Torresa i Casali

Parameter	Manual Calculation	Simulator Predictions	Error (%)
Specific power consumption (kWh/t)	3515.34	3553.48	1.08
Power (kW)	7.81	7.90	1.15

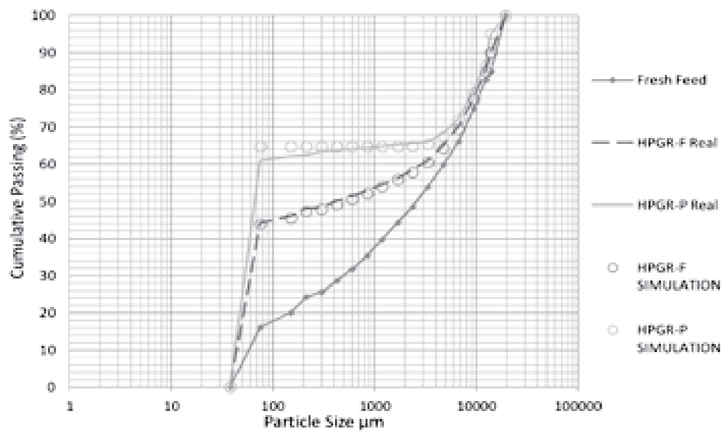

Fig. 6. Feed and product size distributions predicted by the BMCS program and measured by particle size analysis

Rys. 6. Wielkość ziaren nadawy i produktu wyliczonych w programie BMCS i wielkości zmierzone

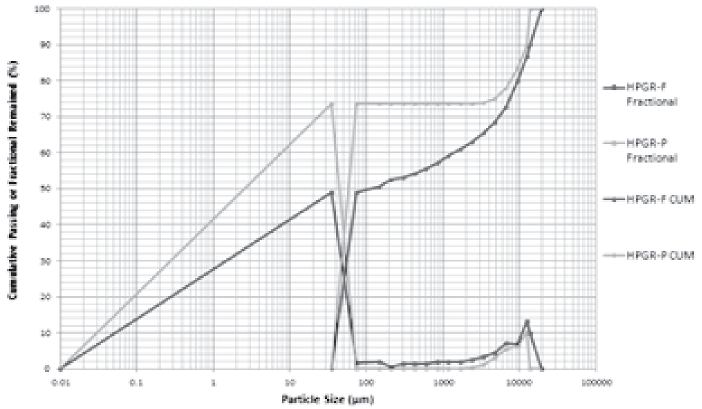

Fig. 7. Three parameters, pressure 180 bar, the distance between the rollers 0.013 m, rotation velocity of the rolls 2 m/s and 170 t/h tonnage

Rys. 7. Trzy parametry, ciśnienie 180 bar, odległość rolek 0.013 m, prędkość obrotowa rolek 2 m/s i wydajność 170 t/h

Tab. 2. Results of simulation and optimizations

Tab. 2. Wyniki symulacji i optymalizacji

Simulation Run	Specific Power Consumption (kWh/t)	Power (kW)	Feed Size, d_{80} (µm)	Product Size, d_{80} (µm)	Relative Product Size d_{80} (%)
Base Case	7.900	3553.480	10568	9860	100.00
Pressure 160 bar	8.420	3790.380	10516	9762	99.00
Pressure 170 bar	8.950	4027.270	10460	9659	97.96
Pressure 180 bar	9.480	4267.170	10416	9571	97.06
Distance between the rolls 0.018 m	9.930	2774.990	10367	9480	96.14
Distance between the rolls 0.013 m	11.630	2348.540	10212	9184	93.14
Rotation velocity of the rolls 1.6 m/s	7.900	3953.250	10481	9696	98.33
Rotation velocity of the rolls 1.8 m/s	7.900	4447.410	10375	9492	96.26
Final Case	13.960	3919.130	9548	7718	78.27

was studied separately and finally simultaneous effect of all these parameters was considered. In final optimization, the distance between the rolls decreased to 0.013 m, rolls pressure was set to 180 bar and rotation velocity of grinding rolls increased to 2 m/s (Figure 7). Since during the sampling, the tonnage was 170 t/h, the same value was considered in all simulations.

Table 2 presents results of all simulations. It shows that minimum value of d_{80} in product belongs to final optimization which was predictable and improved 22% compared to the base condition. It is noted that for a final conclusion in addition to d80 of the product other parameters involved such as grinding ratio, the energy necessary to rotate the rolls and specific consumption energy must be considered as well. In the last phase of the research, the optimal condition predicted by the simulator was applied in real plant on line 4. With the constant Blain fineness of 3000 cm^2/g, capacity increased from 150 t/h to 180 t/h, showing correctness of simulation and optimization processes.

Conclusion

In this research, application of simulation-based approach to optimize high pressure grinding rolls circuit of Abyek cement plant was shown. Preliminary plant implementation of research results indicates that the efficiency of HPGR unit has been increased by adjusting operating and design condition according to BMCS circuit simulations findings. By applying optimized parameters and at a constant Blain fineness of 3000 cm^2/g, the capacity of high pressure grinding rolls of line number 4 increased from 150 t/h to 180 t/h.

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Optymalizacja układu mielenia klinkieru w prasach HPRG w zakładzie Abyek Cement Plant za pomoca programu Steady-State Process Simulations

Cementownia Abyek jest wyposażony w cztery linie mielenia klinkieru; każda linia składa się z dwóch młynów kulowch. Ostatnio w projekcie modernizacji, zainstalowano dwie prasy ciśnieniowe HPGR usytuowane w ciągu technologicznym przed młynem kulowym. Skuteczność HPGR ocenia się na podstawie założeń projektowych. Badania oparto na modelowaniu bilansu procesu rozdrabniania w prasie i symulacji procesu. Reprezentatywne próbki pobrano z nadawy i produktów rozdrabniania w HPGR, celem było okreslenie parametrów modelu - funkcję rozkładu spękań oraz funkcję rozdrobnienia. Badania analityczne przeprowadzono w celu określenia rozkładu wielkości ziaren każdej próbki i jego D80 jako wskaźnik wielkości ziaren. Określono również wielkość ziaren metodą analizy obrazu na szlifach pobranych próbek. Funkcja selekcji została określona za pomocą programu NGOTC.

Porównanie zmierzonych i przewidywanych wyników rozdrabniania w HPRG wykazało dokładnośc modelowania i symulacji. Liczne badania symulacyjne przeprowadzono w celu znalezienia optymalnych parametrów zmiennych wejściowych w tym ciśnienia i prędkości obrotowej. Badania wskazują, że optymalizacja zdolność produkcyjna może zostać zwiększona z 150 t/h do 180 t/h, z powierzchnią właściwą Blaina 3000 cm²/ g.

Słowa kluczowe: optymalizacja, HPRG, klinkier, symulacja, Abyek Cement Plant