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Analysis of grinding media effect on specific breakage rate function of particles in a full-scale open circuit three-compartment cement ball mill

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ABSTRACT

A full-scale three-compartment FLSmidth® cement grinding ball mill with dimensions of Ø3.5 × *L*10 operating in open circuit was sampled to analyse the grinding media effect on specific breakage rate function of particles. Size reduction performance of the ball mill was evaluated with respect to the applied grinding media size. Samples from the circuit and inside the mill were collected. Mass balance of the circuit was done using JKSimMet Steady State Mineral Processing Simulator. Specific discharge and breakage rate functions of particles were estimated using perfect mixing modeling approach (Whiten, 1972) on the basis of the proposed open circuit three-compartment ball mill model structure (Genç and Benzer, 2015). Maximum specific breakage rate was related to maximum grinding media size in the grinding compartments. An exponential correlation was found to exist between maximum grinding media size and maximum specific breakage rate. Relationship between maximum grinding media size and maximum particle size was also fitted to an exponential function. Findings indicated that, grinding performance of cylpebs applied in the third compartment did not improved the size reduction performance as compared to the grinding performance of the first and second compartment.

1. Introduction

Cement is produced by intergrinding of clinker and additive materials such as gypsum (∼3–5%), trass, limestone, and slag in multi-compartment ball mills. Multi-compartment ball mills can have a single, two or three grinding compartments where coarse grinding is achieved in the first compartment. Second and third compartments are for fine grinding. The third compartment of the mill constitutes the finest media size distribution. Steel balls and cylpebs are widely applied grinding media types in cement grinding mills. Cylpebs are slightly tapered cylindrical grinding media with length equalling diameter, and all the edges being radiused (Shi, 2004). It was claimed that, cylpebs provide 25% more grinding media surface area for size reduction for a given charge volume (Doering international). The grinding performance of the cylpebs is expected to be higher when compared with the steel balls (Shi, 2004).

Cement grinding is energy intensive process. 2% of the total electrical energy produced in the world is consumed in the grinding stage of cement production as stated by Norholm (1995). In this respect, even a slight reduction in grinding energy consumption can reduce the operating costs in a significant amount. Best way for optimization of the power consumption per ton of cement raw material or cement produced is to build up reliable comprehensive mathematical models of the grinding mills so that simulations can be done to predict the performance of the circuit when operational or design characteristics of the equipments are changed (Genç, 2015). Effects of design and operational parameters of multi-compartment ball mills used in the cement industry on grinding performance was extensively studied by Genç (2008). Perfect mixing modeling approach was proposed by Whiten (1972) to model ball mills. This model requires the estimation of breakage, specific discharge rate (d) and specific breakage rate (r) functions. Estimated specific breakage rates should be related to design and operational parameters of the ball mill so that, simulations can be done (Napier-Munn et al., 2005). Grinding media size is one of important operational parameter in estimation of the mill product using simulation methodology. A few studies were reported concerning the relation between breakage rate and ball size derived from full-scale mill data in the literature. Napier-Munn et al. (2005) reported that, X_m size could be related to the maximum ball diameter (B_{max}) by Eq. (1).

$$X_m = K * B_{max}^2 \quad (1)$$

where K is the maximum breakage rate factor. The value of K was found to be equal to $4.4 * 10^{-4}$. They also stated that, normalized

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Nomenclature

i	particle size fraction i	a	single column step triangular breakage function matrix
j	particle size fraction j	s_i	mass of size fraction i (ton)
f_i	mass flowrate of mill feed (ton/h)	Q	volumetric feed rate (m^3/h)
p_i	mass flowrate of mill discharge (ton/h)	D	mill diameter (m)
r_i	specific breakage rate of size fraction i (h^{-1})	L	mill length (m)
d_i	specific discharge rate of size fraction i (h^{-1})	r/d^*	ratio of breakage rate to normalized discharge rate
d_i^*	normalized discharge rate of size fraction i		

discharge rate dependent breakage rate parameter (r/d^*) could be scaled according to the ball area by Eq. (2) for particles smaller than X_m. b_{FIT} corresponds to the original mill ball area and b_{SIM} corresponds to the ball area of the predicted mill in Eq. (2).

$$\frac{r/d^*_{SIM}}{r/d^*_{FIT}} = \frac{b_{FIT}}{b_{SIM}} \quad (2)$$

Impact mechanism was assumed to be predominate for particles larger than X_m and r/d^* scale up relation was given by Eq. (3).

$$\frac{r/d^*_{SIM}}{r/d^*_{FIT}} = \left(\frac{b_{SIM}}{b_{FIT}}\right)^2 \quad (3)$$

However, particle size versus r/d relations may not always indicate the X_m size in the mill due to the discharge rate effect in r/d parameter. Established specific breakage rate versus particle size relationships proved that, X_m size can be absolutely determined when the discharge rate effect is eliminated (Genç, 2008).

An extensive pilot-scale experimental study was reported by Erdem and Ergün (2009) to establish the relationship between maximum ball diameter (D_b) and particle size (X_m). Perfect mixing mill model (Whiten, 1972) was used in their research. The resulting relationship is given in Eq. (4). Eq. (4) was proposed to scale the r/d^* functions to predict specific breakage rates (r) when the mill content (hold up) size distribution was measured at a constant discharge rate in a batch test.

$$X_m = 0.2971e^{0.0346(D_b)} \quad (4)$$

In this study, the approach was to relate maximum specific breakage rate (r_{max}) to maximum grinding media size in the grinding compartments to form a basis for modeling of multi-compartment dry grinding ball mills. An exponential correlation between maximum grinding media size and maximum specific breakage rate was found to exist. Relationship between maximum grinding media size and maximum particle size was also fitted to an exponential function. Size reduction performance in each grinding compartment was also evaluated with respect to the applied grinding media size. Findings indicated that, cylpebs applied in the third compartment did not improved the size reduction performance as compared to the grinding performance of the first and second compartment.

2. Methods

Plant and laboratory scale studies were performed to evaluate the size reduction performance of the open circuit three-compartment FLSmidth® ball mill. Ball mill design and operational characteristics are given in Table 1. Balls were applied in the first and second compartment whereas cylpebs in the third compartment as a grinding media. Grinding media size distributions in each compartment are given in Tables 2 and 3.

Table 1
Three-compartment FLSmidth® ball mill design and operational characteristics.

Design parameters	
Effective diameter (m)	3.5
Nominal diameter (m)	3.56
Mill length (m)	10
Compartment-1 length (m)	2.94
Compartment-2 length (m)	1.70
Compartment-3 length (m)	4.66
Mill power (kW)	1650
Mill rotational speed (rpm)	16.55
Critical speed%	73.20
Design ball filling% (Comp-1)	31.8
Design ball filling% (Comp-2)	31.8
Design ball filling% (Comp-3)	29.0
Operational parameters	
Clinker (t/h)	38.42
Calker (t/h)	1.86
Gypsum (t/h)	2.27
Total mill feed (t/h)	42.55
Moisture% (Clinker)	0.12
Moisture% (Limestone)	0.68
Moisture% (Gypsum)	1.80
Mill power (kW)	1558
Work index (kW h/t)	13.95
Specific energy consumption (kW h/t)	36.67

Table 2
Ball size distributions in the first and second compartments.

Ball size (mm)	Weight (%)	Cumulative weight (%)
Compartment-1		
90	8.33	100
80	22.91	91.67
70	26.71	68.77
60	19.97	42.06
50	22.09	22.09
Compartment-2		
50	32.91	100
40	32.96	67.09
30	34.14	34.14

2.1. Plant survey

Sampling survey was performed at the steady state condition of the circuit. Flowsheet of the circuit with the sampling points is given in Fig. 1. Samples were collected from around the circuit. Samples from inside of the mill along the long axis of the mill was collected after crash stopping of the mill. Photographs of the first, second and third compartment inside are given in Figs. 2–4. The first compartment was lined with lifter liners whereas second compartment with classifying liners. The third compartment was also lined with classifying liners in addition to the damming rings. Damming rings are used to assist grinding media size classification along the mill length in addition to the movement and mixing of the grinding media and to impede the material flow in the mill.