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The specific selection function effect on clinker grinding efficiency in a dry batch ball mill

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ABSTRACT

Dry grinding experiments on cement clinker were carried out using a laboratory batch ball mill equipped with a torque measurement. The influence of the ball size distribution on the specific selection function can be approached by laboratory runs using mono-size balls. The breakage is more efficient with maximal specific selection functions at the initial size reduction stage. But, in terms of cement finish grinding all stages of grinding are determinant for the production of a required Blaine surface area (3500 cm^2/g). So, the choice of ball size according to a maximal specific selection function leads to an increase of the energy consumption. In addition, investigations on the mono-sized fractions and on the crude material (size minus 2.8 mm) demonstrate that the energy efficiency factor can be optimized using ball size corresponding to relatively low specific selection function.

1. Introduction

In the cement industry, the clinker grinding step consumes about one-third of the power required to produce 1 ton of cement. This refers to an average specific power consumption of 57 kWh/t (Seebach and Schneider, 1986) and specific carbon dioxide emissions intensity for electricity generation of 9.1 kg CO_2 per ton (Worrel et al., 2000). Considering these factors, a small gain in comminution efficiency can have not only a large impact on the operating cost of a plant, but also a reduction in greenhouse gas emission. Several investigators have presented convincing cases for the use of population balance models as an alternative to the Bond energy-size reduction equation for scale-up design (Herbst and Fuerstenau, 1980; Austin et al., 1984). The breakage process is characterized by two basic functions: a selection function that represents the fractional rate of breakage of particles in each size class; and a breakage function that gives the average size distribution of daughter fragments resulting from primary breakage event. Various laboratory studies, pilot plant works and full size plant observations showed that ball diameter, as an operating variables, can affect grinding efficiency at a given output fineness in ball milling. It is however known that there is a specific ball size which maximises the breakage rate of a given size fraction of a material (Austin et al., 1984; Gupta et al., 1985). Thus, a number of empirical relations have been proposed between the maximum specific rate of breakage and the ball diameter for the cement clinker (Deniz, 2003) and other solid materials (Kotake et al., 2002). However, finish grinding circuits in the cement industry are operated to produce a powder of 3500 cm^2/g Blaine surface area, taken as an index of the cement quality, and no attempt is made to produce a specified size distribution (Opoczky, 1977). So, the specific energy demand of this grinding process cannot be evaluated only by the size reduction analysis. The objective of the present study was to analyse the effect of the specific selection function, obtained from the grinding tests, which reflects the size reduction energy efficiency (Herbst and Lo, 1989), on the energy consumed to produce a desired Blaine surface area. In particular, we aim to correlate the specific selection functions, with the energy efficiency factor, defined by the production of 3500 cm^2/g surface area per unit of specific grinding energy.

2. Background

Considering a mass of material M in a ball mill to be divided into n narrow size intervals with maximum size x_1 and minimum size x_{n+1}, the ith size interval, bounded by x_1 above and x_{i+1} below, contains a mass fraction of material $m_i(t)$ at time t. When breakage is occurring in an efficient manner, the breakage of a given size fraction of material usually follows a first-order law. Since the mill hold up, M, is constant, this becomes:

$$\frac{\mathrm{d}m_i(t)}{\mathrm{d}t} = -S_i m_i(t) \quad (1)$$

Where S_i is proportionality constant and it is called the selection function for the ith size interval that denotes the fractional rate at

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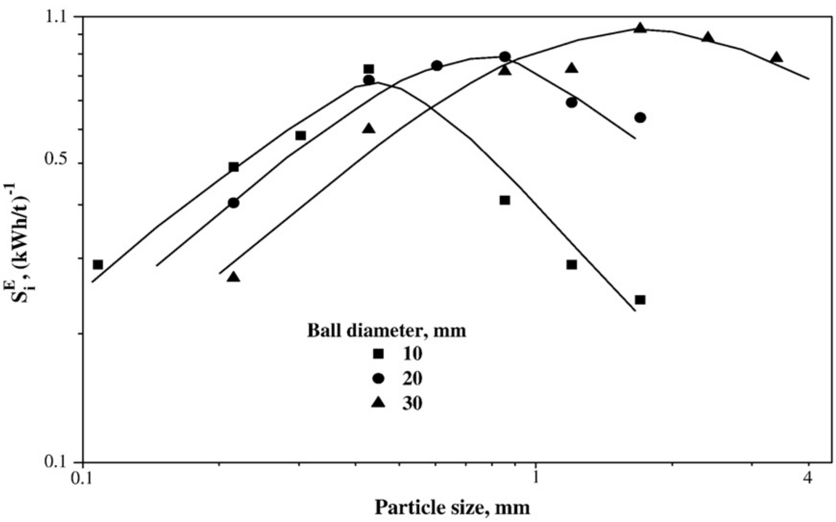

Fig. 1. Specific selection function versus particle size for various ball sizes.

which material is broken out of the ith size interval. Under conditions where grinding kinetics are directly proportional to the specific power input (net) to the mill (P/M), Herbst and Fuerstenau (1973) showed that the first order disappearance kinetic equation in the energy normalized form can be expressed by:

$$\frac{\mathrm{d}m_i(E)}{\mathrm{d}E} = -S_i^E m_i(E) \quad (2)$$

where E is the specific energy equal to the product of specific power by grinding time t. In Eq.(2), the specific selection function S_i^E is dependent of ball size (Lo and Herbst, 1986; Touil et al., 2003) and usually independent of mill design and operating conditions (Herbst and Fuerstenau, 1973; Malghan and Fuerstenau, 1976). It is extremely useful for computational simplification involved in tumbling mill simulation since the evolution of size distribution, resulting from size reduction stage, depends only on the ball size and the energy expended during the grinding step.

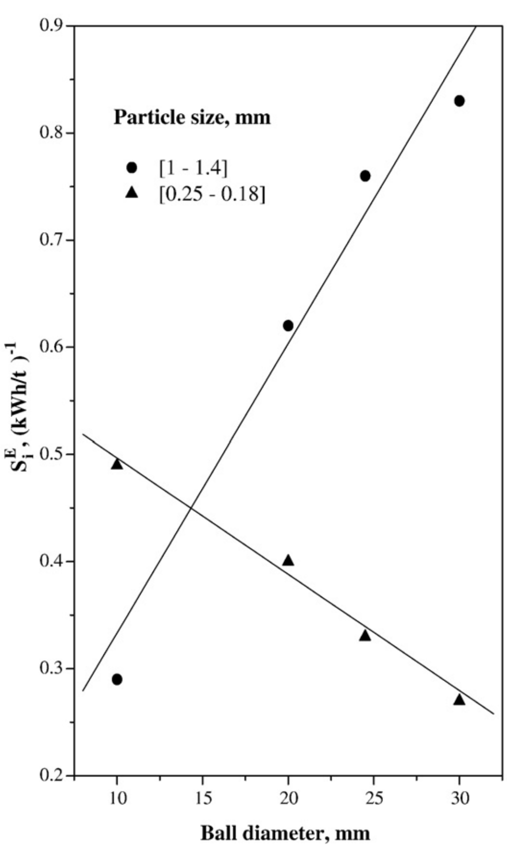

Fig. 2. Variation of specific selection function versus ball size.

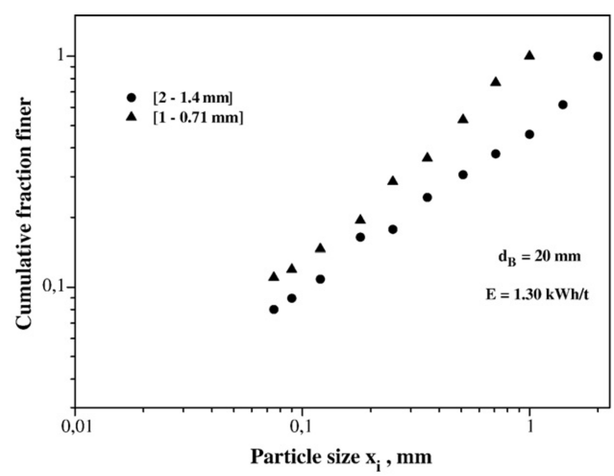

Fig. 3. Experimental product size distributions for the (2–1.4 mm) and (1–0.71 mm) initial size ground using the 20 mm size ball.

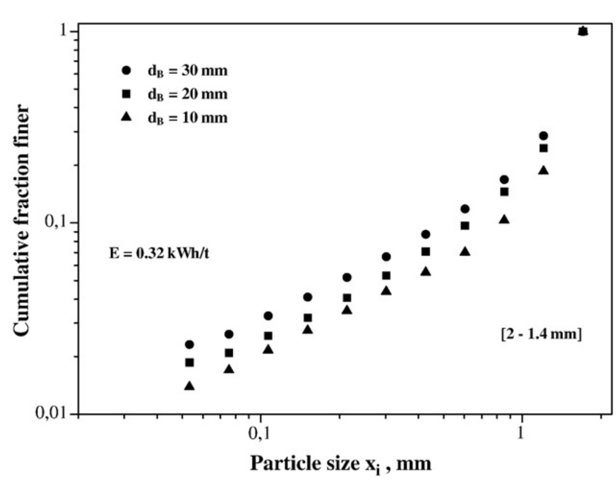

Fig. 4. Experimental product size distributions for the (2–1.4 mm) initial size ground using 10, 20 and 30 mm size balls.