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Horizontal roller mill (Horomill®) application versus hybrid HPGR/ball milling in finish grinding of cement

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A R T I C L E I N F O

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A B S T R A C T

Industrial scale Horomill® and hybrid HPGR/two-compartment ball mill applications at puzzolanic portland cement production were presented with emphasis on the general operational characteristics of the circuit configurations, size reduction and energy efficiencies of the Horomill® and two-compartment ball mill grinding conditions. Horomill® circuit configuration indicated to have advantages in terms of production of high strength cement as compared to Hybrid HPGR/two-compartment ball milling, depending on the classification performance of the separators influencing the circuit performance.

1. Introduction

Conventionally multi-compartment ball mills are used in finish grinding of cement. However, they are relatively inefficient at size reduction and have high energy consumption, so it is increasingly common to find grinding technologies such as High Pressure Grinding Rolls (HPGR), vertical mills and Horomill® in cement plants. As recorded in the literature, Horomills® mechanically combine many elements of a ball mill such as cylindrical shell on hydrodynamic shoes, drive gear rim, and a HPGR such as roller and bearings. As compared to ball mills, noise generated is lower and they are smaller, more compact mills beside the other recorded advantages (Cordonnier, 1994).

They were introduced in 1993 at Buzzi Unicem's Trino plant in Italy with the purpose of reducing energy costs. Details of the operating principle of Horomill® as compared to HPGR and vertical roller mills are given by Cordonnier (1994) and Buzzi (1997). The energy saving of this mill is claimed to be similar to that of HPGR and 30–50% lower than a ball mill (Cordonnier, 1994). In raw material grinding up to 20% moisture content, 50% energy reduction (Marchal, 1995) and savings in capital costs of between 12% and 15% could be achieved compared to ball mills (Buzzi, 1997). A view of an industrial Horomill® at Tepetzingo plant is given in Fig. 1.

This study presents the size reduction efficiencies and specific energy consumptions of an industrial scale Horomill® and Hybrid HPGR/two-compartment ball milling with emphasis on the general operational characteristics of the circuit configurations.

Fig. 1. Horomill®.

2. Circuit descriptions and sampling

Simplified flowsheets of the investigated circuits are given in Figs. 2 and 3. Streams sampled in steady state conditions of the circuits are shown on each flowsheet. As given in Fig. 2 the Horomill®

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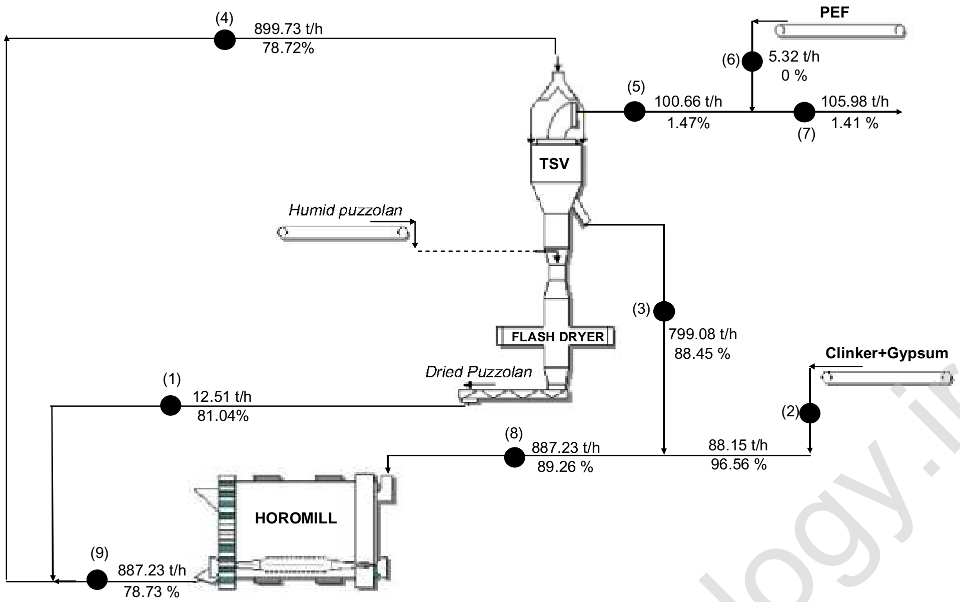

Fig. 2. Horomill® grinding circuit. Sampled streams: (1) dried puzzolan feed; (2) circuit fresh feed (clinker + gypsum); (3) TSV® separator coarse; (4) TSV® separator feed; (5) TSV® separator fine; (6) PEF (electrofilter dust); (7) final product; (8) Horomill® feed; and (9) Horomill® discharge.

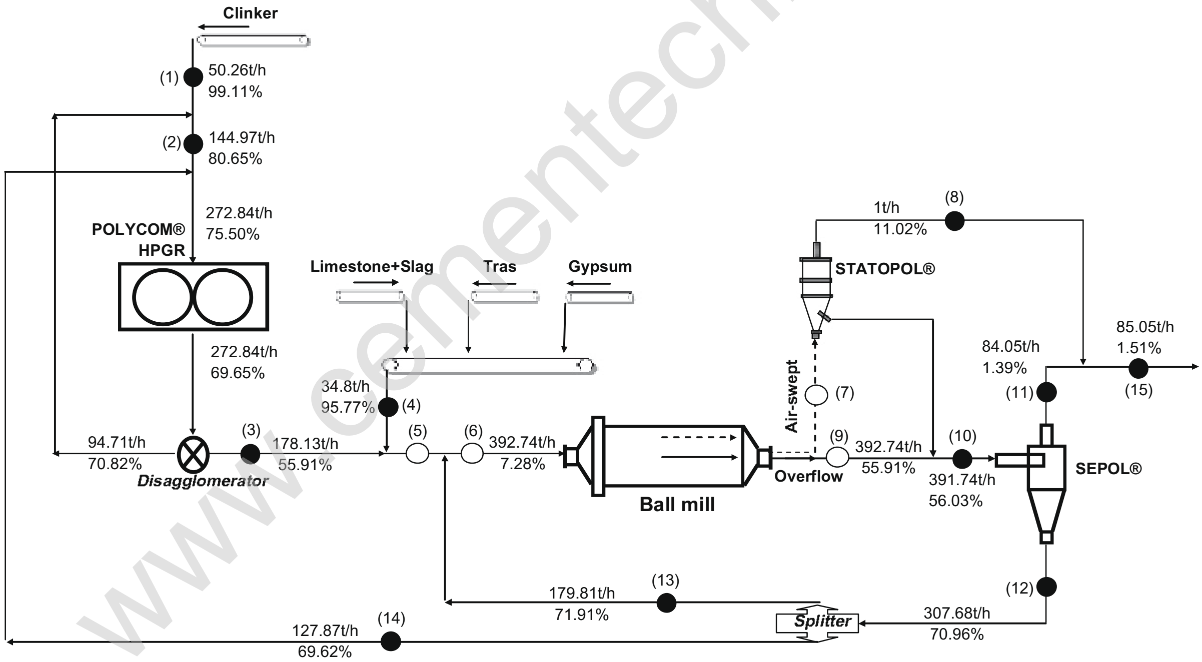

Fig. 3. Hybrid HPGR/two-compartment ball mill grinding circuit. Sampled/not sampled streams: (1) clinker feed; (2) clinker + HPGR discharge rejected to HPGR; (3) HPGR discharge rejected to ball mill; (4) total additive feed (Gypsum + Tras + Limestone + Slag); (5) ball mill circuit fresh feed (not sampled); (6) mill feed (not sampled); (7) air-swept material which forms the static separator feed (not sampled); (8) static separator fine; (9) mill discharge or overflow (not sampled); (10) dynamic separator feed; (11) dynamic separator fine; (12) dynamic separator reject; (13) dynamic separator coarse rejected to ball mill; (14) dynamic separator coarse rejected to HPGR; and (15) final product.

is operating in closed circuit with a TSV® high efficiency separator whereas in the Hybrid HPGR/two-compartment ball mill grinding circuit given in Fig. 3, air-swept material through the mill is classified in a static separator (STATOPOL®) and the coarse product is rejected to mill overflow for further classification in a SEPOL® dynamic separator. During the sampling surveys, the grinding circuits were operated at puzzolanic portland cement production types to achieve cement standards of CPP 30R in the Horomill® circuit and CEM IV/B 32.5R in the hybrid HPGR/two-compartment ball mill circuit. Basic design parameters of the grinding and classification equipments in the investigated circuits are given in Tables 1 and 2.

In the context of sampling studies conducted around Hybrid HPGR/two-compartment ball mill circuit, following the circuit sampling, the ball mill was crash-stopped and samples were collected inside the mill at approximately 1 m intervals towards the intermediate and discharge diaphragms. Particle size distributions of the samples were determined by sieving and laser sizing techniques. Sizing procedure is summarised in Appendix A. Mass balance module of the JKSimMet software was used to calculate the

Table 1
Design parameters of Horomill® and TSV® separator.

Horomill®	
Effective diameter (m)	3.64
Roller diameter (m)	1.82
Roller/track width (m)	1.365
Installed power (kW)	2500
Operating power (kW)	2126.31
Mill shell speed (rpm)	35.9
Nominal pressure at cylinder (bar)	220
Type of motor	Slip ring
TSV® (DN 4000/SD6)	
Diameter (m)	4
Rotor diameter (m)	2.79
Nominal rotor diameter (m)	1.65
Rotor (kW)	62
Rotor speed$_{(min-max)}$ (rpm)	70–210
Nominal gas flow rate (m^3/h)	165,000
Nominal rotational speed (rpm)	135
Installed motor power (kW)	132
Operating motor power (kW)	88.58
Mass volumetric (kg/m^3)	0.8
Dynamic viscosity (kg/ms)	2×10^{-5}

Table 2
Design parameters of HPGR, two-compartment ball mill and SEPOL® separator.

HPGR	
Roll diameter (mm)	1400
Roll length (mm)	800
Roll velocity (rpm)	21.6
Maximum capacity (t/h)	350
Installed motor power (kW)	450
Operating motor power (kW)	409
Maximum current (Amper)	53.9
Velocity of motors (rpm)	1447
Two-compartment ball mill	
Effective diameter (m)	3.84
Compartment-1 length (m)	3.19
Compartment-2 length (m)	5.18
Compartment-1 ball load (%)	31
Compartment-2 ball load (%)	32
Compartment-1 ball size$_{(max-min)}$ (mm)	80–50
Compartment-2 ball size$_{(max-min)}$ (mm)	50–17
Mill rotational speed (rpm)	15.7
Critical speed (%)	73
Installed motor power (kW)	1671
Operating motor power (kW)	1951
SEPOL® separator (SVZ 250/4)	
Rotor diameter (mm)	2500
Installed motor power (kW)	250
Operating motor power (kW)	64
Maximum current (Amper)	448
Motor speed (rpm)	1470
Circulation fan	990
Circulation fan capacity (Nm^3/h)	111,000
Circulation fan motor power (kW)	260
Circulation fan current$_{(max)}$ (Amper)	31.5
Circulation fan rotational speed (rpm)	985

statistically adjusted tonnage flow rates (t/h) and fineness as given by 0.045 mm residue for each stream.

3. Results and discussions

Comparisons of Horomill® and ball mill feed and discharge size distributions are presented in Figs. 4 and 5. Mill feed size distributions of both grinding systems were recorded to be the same in the size range of –25 to +3.35 mm (Fig. 4). Depending on the differences both in operational characteristics and discharge mechanism of the two grinding systems, particles coarser than 0.841 mm were found to not exist in the ball mill discharge stream as compared to the Horomilling case.

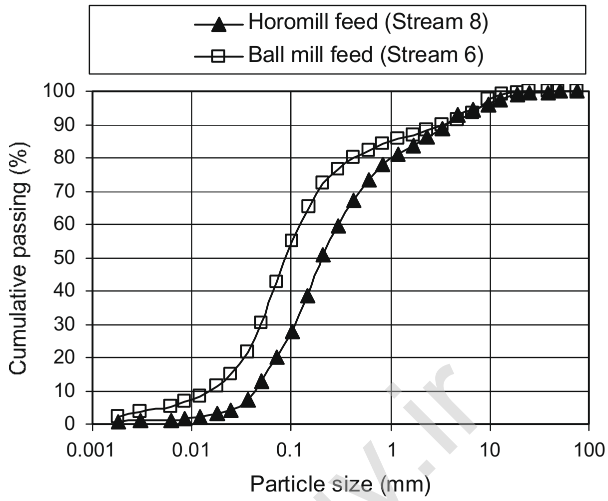

Fig. 4. Mill feed size distributions.

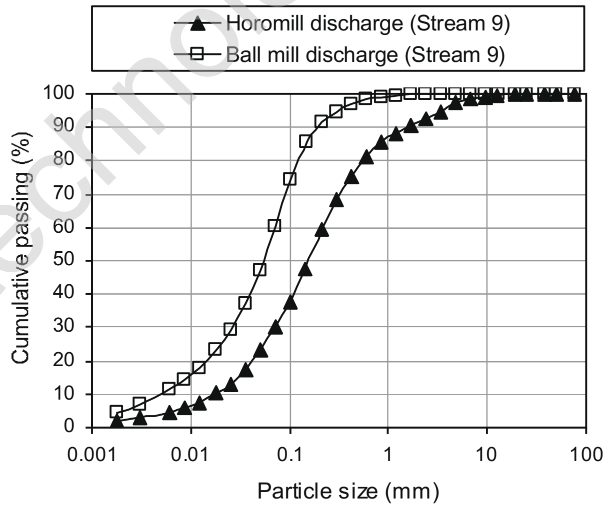

Fig. 5. Mill discharge size distributions.

Comparison of the final product size distributions measured by laser sizing technique is given in Fig. 6. It should be mentioned that, 0.045 mm residue per cent values of the distributions obtained from laser sizing are within the range of cement fineness specifications determined by screening. The two circuit configurations were found to produce similar final cement size distributions, which could be linked to the classification performance of the separator systems, however, slightly coarser in the size range of (–0.036 to +0.003) mm in the ball milling circuit. This could have an effect on the hydration property of cement which is expected to influence the strength of concrete as the strength specifications of final cement (higher in ball milling circuit) in both circuits are different. As indicated in the study of Celik (2009), particle size distribution has recorded effects in hydration. Thus Horomill® grinding could have advantages in production of cement with higher strength specifications at lower specific energy consumption figures. Classification performance of TSV® and SEPOL® air separators are compared with the performance curve parameters in Fig. 10 given in Appendix B. The specific energy consumptions for the HPGR and ball mill were determined based on the mill throughput rate and circuit capacity as 1.5 kWh/ton and 23 kWh/ton respectively during production, and of the Horomill to be 20.1 kWh/ton.

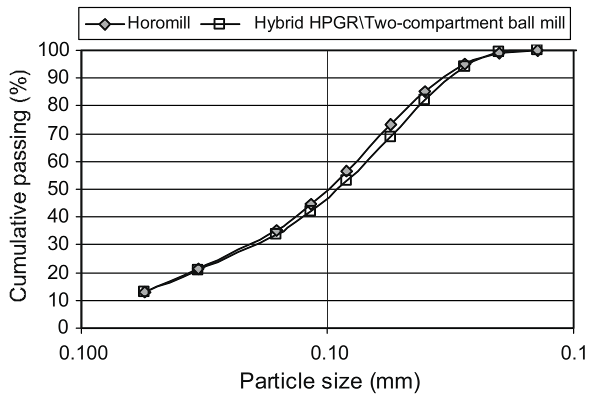

Fig. 6. Final product size distribution comparison.

3.1. Size reduction efficiency

3.1.1. Horomill® circuit

A comparison of the Horomill® feed and discharge size distributions is given in Fig. 7. Size distributions indicated a higher size reduction ratio (size reduction efficiency) for particles coarser than 0.3 mm which was physically characterised by the ratio of 80% material passing size of Horomill® feed to the discharge [$F80_{mill\ feed}/P80_{mill\ discharge} = 2$]. However size reduction efficiency was decreased in the size range of (−0.3 to +0.1) mm and characterised by the ratio of 50% material passing size [$F50_{mill\ feed}/P50_{mill\ discharge} = 1.4$] and found to increase again in the fine size ranges (<0.1 mm) as characterised by the 20% material passing size [$F20_{mill\ feed}/P20_{mill\ discharge} = 2$]. The observed size reduction behaviour could be a characteristic feature of bed breakage conditions which is expected to be affected by the high recycling load condition [Recycling $Factor_{operational} = TSV_{coarse}/TSV_{fine} = 7.9$]. Operation of the Horomill® at high recycling load condition which was not the case in conventional closed circuit two-compartment ball milling is to maintain the optimum operational conditions such as material bed thickness in the grinding zone as recorded to be 2–3 times compared to the HPGR (Cordonnier, 1994). Efficient grinding conditions may have been promoted by the addition of puzzolan to the separator feed in addition to the operational conditions of TSV® air separator. Operational features and details related to the classification efficiency of TSV® high efficiency air separators are given by Duhamel et al. (1997).

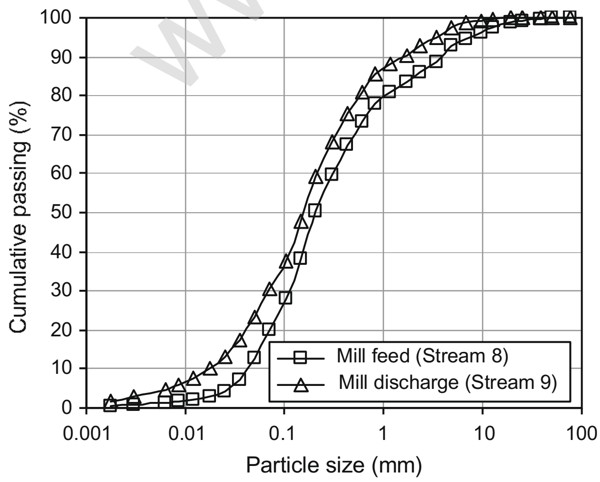

Fig. 7. Characteristic particle size distributions around Horomill®.

3.1.2. Hybrid HPGR/two-compartment ball milling circuit

In the two-compartment ball milling case, size reduction efficiency in compartment-1 and compartment-2 was evaluated individually based on the *intermediate diaphragm screening effect* assumption stated by Benzer (2000), Benzer et al. (2001). According to this assumption, material rejected from the intermediate diaphragm is expected to accumulate approximately at the last meter of the compartment length. Thus, any accumulation effect related to the diaphragm screening performance would be expected to result in a coarser size distribution at the last meter of the intermediate and discharge diaphragms as compared to the size distributions at the end of the compartments. Particle size distributions of inside-mill samples and mill feed (calculated by mass balancing), representing the size reduction progress in each grinding compartment with a schematic top view of sampling locations are shown in Fig. 8.

Size distributions of mill feed and the sample collected in compartment-1 at a length of 2 m (Fig. 8) indicated a higher level of size reduction for particles coarser than 0.3 mm and characterised by the 90% passing particle size [$F90_{mill\ feed}/P90_{compartment\text{-}1(2\ m)} = 7.8$]. However, the characteristic size reduction consistency; as discussed for the size reduction efficiencies of particles coarser than 0.3 mm, in the size range of −0.3 to +0.1 mm, and finer than 0.1 mm for Horomilling case; was not observed, as the efficiency varied in the indicated size ranges. Due to the higher size reduction in the coarse size ranges (>0.425 mm) and screening effect of the intermediate diaphragm, size distributions at a length of 2 and 3.2 m were found to be similar which is contrary to the "intermediate diaphragm screening effect assumption" used in the evaluation.

In compartment-2 size distributions at the 4.1 and 5.2 m indicated an accumulation of particles coarser than 3.35 mm. The accumulation amount is small and recorded as 4.3% at the 4.1 m and 6.5% at the 5.2 m of the compartment thus was found to not exist at the inlet of the compartment at the sampling conditions. Such an accumulation problem could be observed in cement mills due to the mill feed grindability or breakage characteristics and is discussed for the single particle impact breakage characteristics of mill feed and accumulated clinker particles by Genc et al. (2008). The amount of accumulation (4.3%) at the 4.1 m is discarded to demonstrate the effect on size reduction and presented in Fig. 9.

As can be observed from Fig. 9, size distribution corresponding to the 4.1 m sample is similar below 0.15 mm when the accumulation is discarded. When excluding the accumulation, size reduction efficiency was found to remain consistent in both conditions for particles in the size range of −0.119 to +0.030 mm characterised by 50% passing size [$F50_{compartment\text{-}2(inlet)}/P50_{compartment\text{-}2\ (L\,=\,4.1\ m)} = 1.5$] and for particles in the size range of −0.030 to +0.010 mm based on 20% passing size [$F20_{compartment\text{-}2(inlet)}/P20_{compartment\text{-}2\ (L\,=\,4.1\ m)} = 1.7$]. On the otherhand, due to the accumulation effect at the coarse size ranges (>0.119) the consistency in size reduction efficiency observed in Horomilling case could not have been observed although the size distribution without accumulation effect indicated the similar consistency as characterised by the 80% passing size [$F80_{compartment\text{-}2(inlet)}/P80_{compartment\text{-}2\ (L\,=\,4.1\ m)} = 1.7$].

Another characteristic feature which can be observed in the second compartments of cement mills is the progressive fineness decrease towards the last meter of the compartment due to the coarse particle accumulation and probable blockage at the discharge diaphragm as the size distribution at the 5.2 m was found to be coarser than the one at the 4.1 m.

Size distributions at the last meter of both compartments indicated that the assumption considered in the evaluation of the size reduction efficiency is highly dependent on the operational characteristics of the mill such as grindability or breakage characteristics (raw meal, kiln, cooling and pre-crushing conditions), mill feed size distribution (pre-crushing and air classifier performance), diaphragm screening performance (blockage of diaphragm with

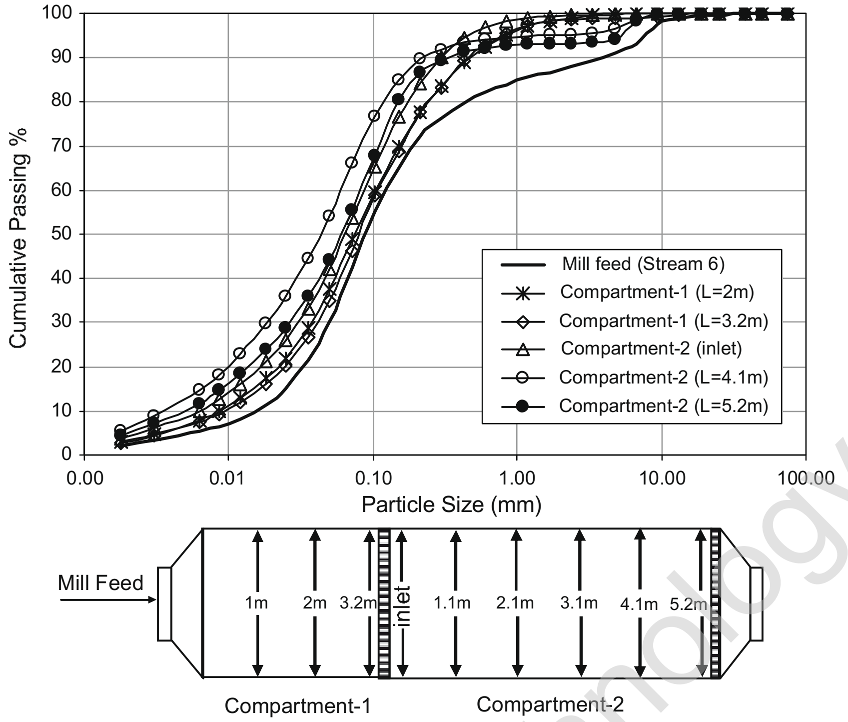

Fig. 8. Size reduction progress and sampling locations in two-compartment ball mill.

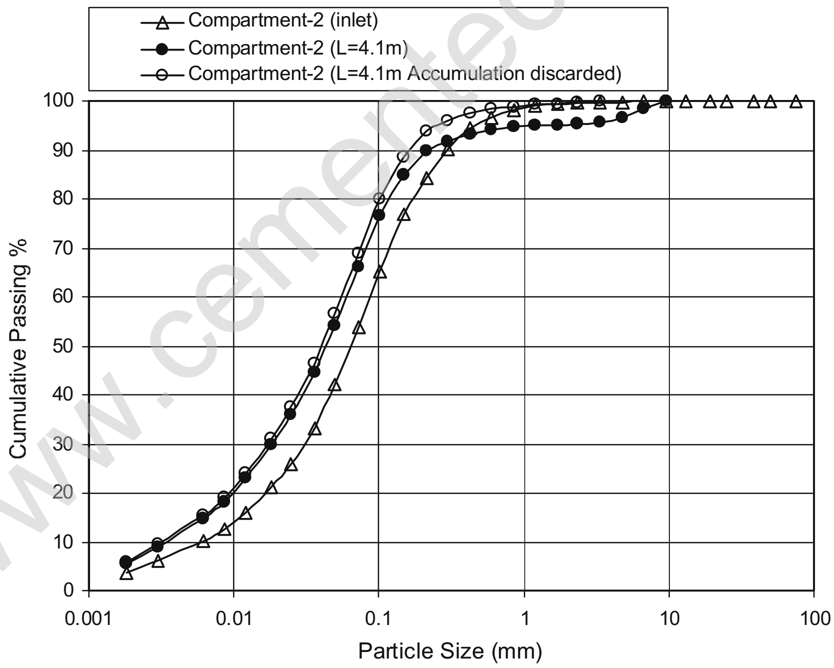

Fig. 9. Consistency in size reduction in compartment-2.

material or balls, crack formation on the diaphragm both affecting open area per cent), air flow rate (especially in air-swept type mills), liner and ball wear conditions which will influence the size reduction progress during grinding.

4. Conclusions

Data presented provides some useful insights into the operational and size reduction characteristics of Horomill® and Hybrid HPGR/two-compartment ball milling with indications that Horomill® application could produce high strength puzzolanic portland cement depending on the classification performance of the separator system at a higher production level.

The specific energy consumption figures indicated approximately 15% energy saving in Horomilling case. However, as recorded in the literature, it is difficult to make a direct comparison as the energy efficiency figures will vary depending on the Horomill®, HPGR, ball mill design, operational parameters and the circuit configuration. This thus the comparison suffers from the same limitations.

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Appendix A

A.1. Sizing methodology

Total amount of each sample was sieved on a 9.5 mm screen and screen oversize material which is +9.5 mm was then sized using a $\sqrt{2}$ sieve series. Representative amount of +150 μm sample was dry sieved and laser diffraction spectrometer on dry measurement mode was used to determine the size distribution of −150 μm sub-sample. Size distribution of each sample from the top size down to 1.8 μm was calculated using the sieving results obtained from the typical top size of 50.8 mm down to 150 μm and laser results obtained for the sub-sieve sample of −150 μm.

Appendix B

B.1. Performance of air separators

The presented values for the fish-hook is defined as the difference between the maximum percentage for the fines reporting to separator coarse product and the by-pass per cent. Classification performance of TSV® was found to be higher than SEPOL® as indicated by the higher slope of performance curve in addition to lower by-pass and fish-hook percentage.

Parameters	TSV®	SEPOL®
d50 (μm)	23.33	20.32
By-pass (%)	23.29	28.11
Fish-hook (%)	1.99	5.63

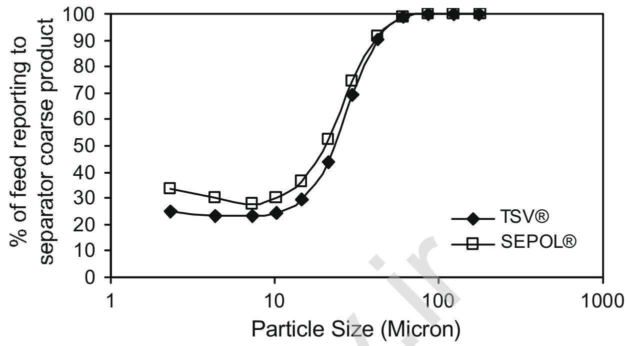

Fig. 10. Classification performance.

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