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Investigation of the breakage of hard and soft components under high compression: HPGR application

Hakan Benzer, Namık A. Aydogan *, Hakan Dündar

Hacettepe University, Mining Engineering Department, 06800 Ankara, Turkey

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ABSTRACT

In the cement industry, high pressure grinding rolls (HPGR) has been used since 1985. At the first applications, this equipment has been installed in the existing cement grinding circuits as an open circuit precrusher in order to crush clinker especially. The cement factories produce different type of cement by using basically clinker, gypsum and additives like limestone and trass. The additives generally are not precrushed before ball mill circuits.

In this study, three different mixed feeds were prepared with clinker, gypsum, limestone and trass to evaluate the performance of an industrial scale open circuit HPGR. The results of the tests show that due to the stress concentrates on soft and fractured material, the performance of HPGR becomes worse when the relatively hard material (clinker) is fed together with soft and weak materials (i.e. gypsum, limestone, trass). In addition to the industrial tests, the piston die tests have been also performed with narrow size fractions of the mixed and unmixed materials.

1. Introduction

Schönert (1979) has shown that the most energy efficient method of comminuting particles is to compress them between two plates. Compressing a particle bed between two counter rotating rolls was achieved by the invention of the high pressure grinding rolls (HPGR) (Schönert, 1988). The first commercial application of HPGR was in 1985 and its success resulted in increasing numbers of applications since then, particularly in the cement industry (Kellerwessel, 1990). The proven success in the cement industry has been attracting the mineral industry's attention for many years. As a result of this, the number of HPGR applications in mineral processing plants is increasing rapidly (Thompsen, 1997; Kellerwessel, 1993; Sergeant, 1995).

Crushing and grinding are unit operation consuming high energy, and ores fed to comminution section may be highly variable and heterogonous due to ore formations and mining operations, therefore performance of comminution sections can be frequently change. For operating and modeling of grinding systems fed heterogonous material, understanding of what the effect of feeding soft and hard material together on the system and how they interact with each other during comminution is important.

Some studies have been performed to evaluate mineral mixture behavior in laboratory ball mills (Gardner and Rogers, 1975; Kuper and Fuerstenau, 1989). Additionally, some tests using quartz (hard material) and limestone (soft material) in a laboratory HPGR have been carried out, and the results of these tests have shown that the fraction of the energy consumed by the softer component increases as the ratio of the hard component in the feed is increased (Abouzeid and Fuerstenau, 2000, 2009).

This paper is concerned with the performance of the compressed bed crushing of pure and mixed minerals in an industrial high pressure grinding rolls (HPGR) and a piston die, and individual behavior of the particles in mixed and unmixed bed. In this way, the performance of HPGR used for mixed and unmixed materials feed in the cement industry was evaluated; at the same time this paper shows the way to understate the crushing behavior of HPGR applications in the mineral industry.

2. Sampling and experimental studies

In order to evaluate the effect of mixed feed on the performance of an industrial scale open circuit HPGR with partial recycling (in this type open circuit HPGR application, all HPGR discharge is divided into two part with a simple splitter and one of them is fed back to the HPGR in order to improve particle bed between rolls. Amount of it is arranged according to power draw, operating pressure, vibration and tonnage of the HPGR, Fig. 1), three different feeds were prepared with clinker, gypsum, limestone and trass. In addition to the industrial tests, the piston die tests have been also performed with narrow particle size fractions the mixed and non-mixed materials.

* Corresponding author.
E-mail address: aydogan@hacettepe.edu.tr (N.A. Aydogan).

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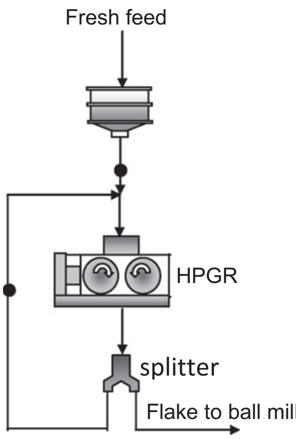

Fig. 1. Simplified flow sheet and sampling points of the sampled HPGR circuit.

Table 1
The design parameters of the sampled HPGR.

Roller diameter (mm)	1400
Roller length (mm)	660
Roller speed (m/s)	1.59
Motor power (kW)	840

Table 2
Operational parameters of the industrial scale tests.

Test	Feed	Fresh feed (t/h)	Circulating load (t/h)	Operating pressure (bar)	Mean gap (mm)	Motor power (kW)
1	Clinker (90%), limestone (5%), gypsum (5%)	234	40	94	10.2	774
2	Clinker (65%), limestone (5%), gypsum (5%), trass (25%)	218	40	91	10.4	721
3	Clinker (100%)	213	80	98	13.2	797

The design parameters of the HPGR on which the industrial tests were performed are given in Table 1.

In the cement grinding plant, the HPGR which the tests were performed on is normally operating as precrusher to prepare clinker feed to a ball mill circuit. On the other hand the cement industry produces different type of cement by adding different materials like limestone and trass. The additives are also fed to grinding circuit due to the cement type. In this grinding circuit, under normal operational conditions, the additives (limestone and trass) are directly fed to the ball mill. Three industrial scale tests (whose conditions are given in Table 2) were carried out with clinker and additives in order to evaluate the multi component breakage behavior of the HPGR.

In addition to these industrial tests, some piston die tests (summarized in Table 3) were also performed to understand the behavior of mix material bed under high compression.

3. Results and discussions

For each industrial test, particle size distributions of fresh feed and product are given in Fig. 2. It is clear from the Fig. 2 that

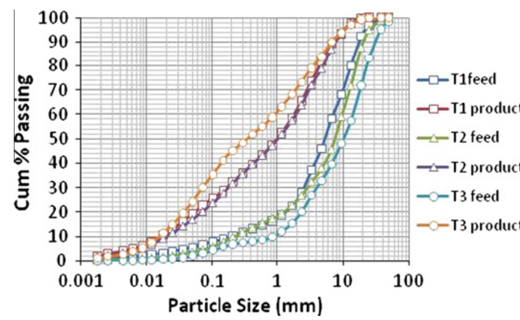

Fig. 2. Particle size distributions of HPGR fresh feed and product.

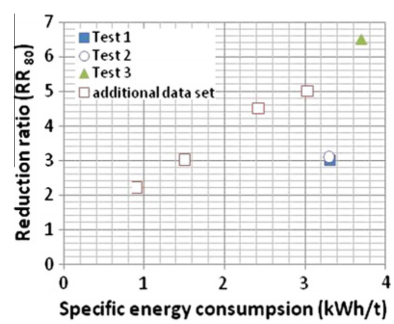

Fig. 3. Specific energy consumption–reduction ratio of the sampled HPGR.

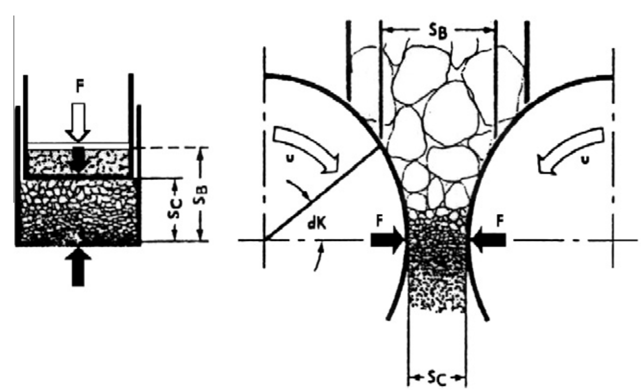

Fig. 4. Batch and continuous particle bed breakage mechanisms.

Table 3
Piston die test procedure.

	Individual unmixed material bed breakage test procedure			Mixed material bed breakage test procedure		
	Clinker, limestone, trass			Clinker (50%), limestone (50%)	Clinker (50%), trass (50%)	Trass (50%), limestone (50%)
Fraction (kN)	100	300	800	300	300	300
−13.2 + 11.2 (mm)	×	×	×	×	×	×
−9.5 + 8 (mm)	×	×	×	×	×	×
−5.6 + 4.75 (mm)	×	×	×	×	×	×

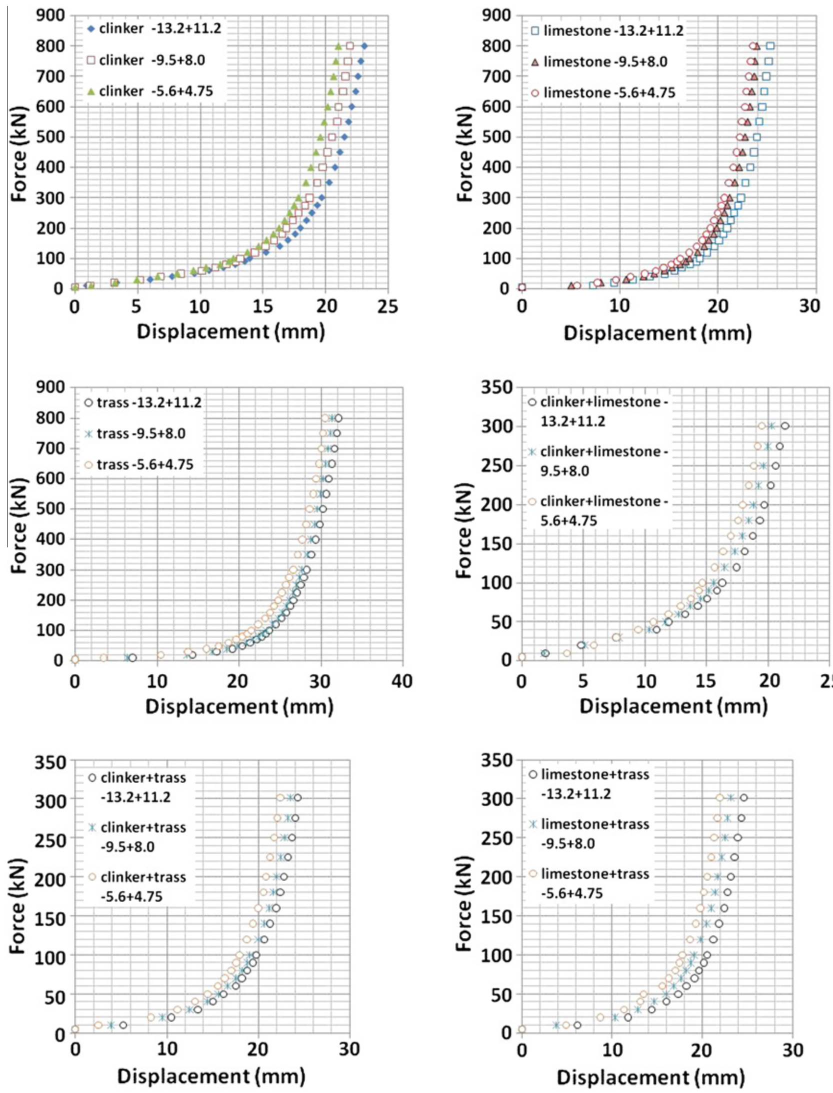

Fig. 5. Particle size effect on displacement for clinker, limestone, trass and mix materials in particle bed breakage.

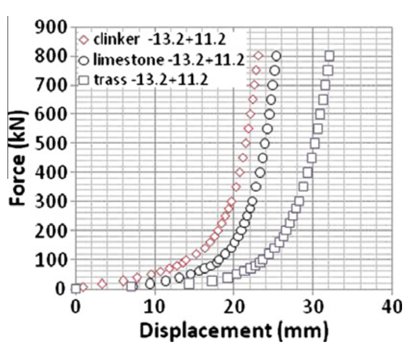

Fig. 6. Material type effect on displacement for clinker, limestone and trass in particle bed breakage.

although the feed of Test 3 is coarser than others, its product is the finest.

In order to evaluate the results of tests, the relation between specific energy consumption and reduction ratio (RR_{80}) is given in Fig. 3. In this figure, a data set collected from different sampling survey is used for showing the trend of RR_{80} of same HPGR with clinker feed. The graph clearly shows that the performance of the HPGR changed under different feed condition. When the HPGR was fed with clinker and relatively soft material together, its grinding performance decreased compared to clinker grinding.

Fig. 3 shows that the results of the additional data set and Test 3 are on the same trend as well.

Because of some operational conditions and mechanical problems like different material feeding, vibration of the HPGR and feeding system oscillation, the industrial tests could not performed under same conditions. Total HPGR tonnage is very important operational parameter and affects the operational gap and pressure of the equipment. Under same pressure set value of hydraulic system condition, total HPGR feed tonnage increases the operational pressure and gap (Aydogan, 2006). During all tests, the hydraulic pressure was set as 100 bars, but depends on the HPGR total feed tonnages, the operational pressures were not obtained at same value. Some parameters like pressure, gap, and total HPGR feed tonnage are very important operational parameters affect the performance of HPGR. In the other hand, the additional data set collected under different operating conditions from same HPGR (Fig. 3) shows that clinker grinding performance is higher than mix grinding.

Because of some differences among the industrial tests conditions, it is not easy to explain the industrial tests' results. Hence,

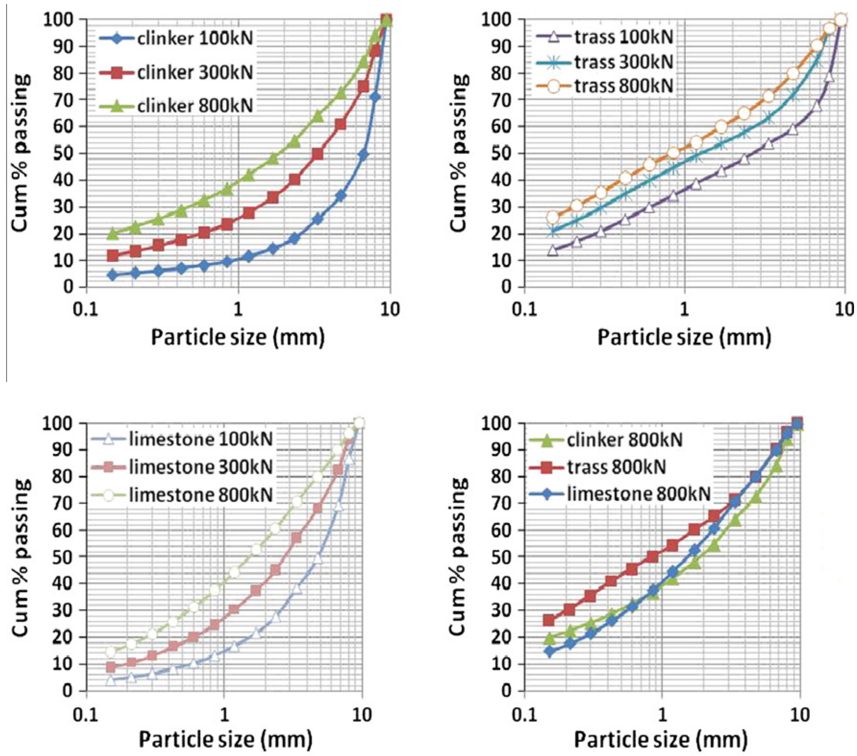

Fig. 7. Particle size distributions of the particle bed breakage test's products for −9.5 + 8.0 mm fraction.

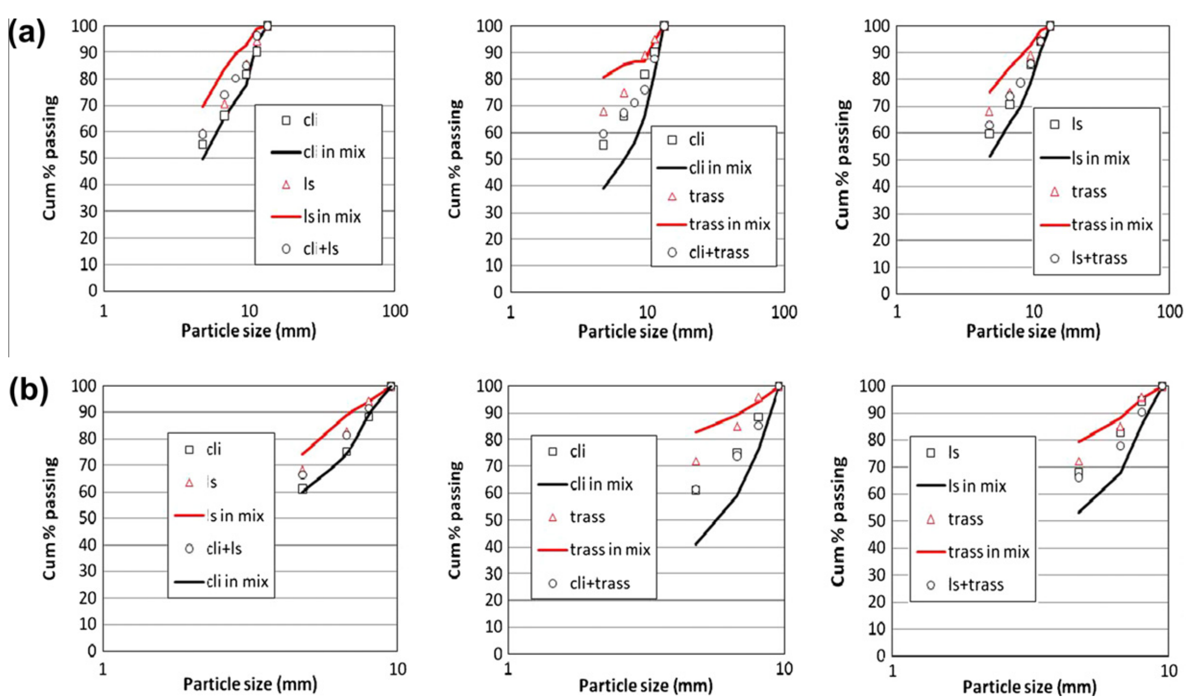

Fig. 8. Particle size distributions of the products for −13.2 + 11.2 mm (a) and −9.5 + 8.0 mm (b) mixed and unmixed materials under 300 kN compression force condition in particle bed breakage tests.

to support these results, some laboratory tests were also performed by piston and die. In order to understand the particle bed breakage behavior under high pressure of HPGR (continuous process), piston and die tests (a batch process) can be used. Batch and continuous particle bed breakage mechanisms under high pressure compression are illustrated in Fig. 4 (Seebach and Knocbloch, 1987).

In order to evaluate the breakage behavior of the materials (clinker, limestone, trass and mixed), piston die test summarized in Table 3 were conducted on three different narrowed particle fraction, −13.2 + 11.2 mm, −9.5 + 8.0 mm and −5.6 + 4.75 mm. Each test material was 500 g, and while three test force levels (100, 300, 800 kN) were used for clinker, limestone and trass, for mix materials one level (300 kN) was used.

Displacement–force graphs for clinker, limestone, trass and mix materials with 800 kN and 300 kN force level respectively are given in Fig. 5. Cumulative displacement and the applied force on the particle bed were measured concurrently by a linear variable displacement transducer (LVDT) and a force transducer respectively. This figure shows the effect of particle size on displacement behavior of particle bed under same compressing force is shown in Fig. 5. In order to illustrate the effect of material type, a displacement–force graph is given as an example in Fig. 6. All these graphs show that displacement behavior of particle bed under compression depends on particle size and material.

Product size distributions of −9.5 + 8.0 mm fraction for each force level are given in Fig. 7. The product size distributions from all these tests are systematically getting finer with increased force.

In order to evaluate the breakage behavior of the individual component in mixed feed, the fractions between −13.2 + 4.75 mm of products were separated by using the colour differences of the components and for each component product size distributions were determined individually. In Fig. 8, product size distributions of each material in mixed and unmixed feed are given. These graphs show that while soft materials in mix are much finer than its unmixed condition, hard materials are getting coarser. On the other hand, the overall products of the mixed feeds are among the products of each component under unmixed condition.

The findings of this research correlate to the work conducted by Abouzeid and Fuerstenau (2009).

4. Conclusion

In this paper, the performance evaluation of an open circuit HPGR operated with clinker and mixed feed (clinker plus additives) was presented. Under different specific energy consumption conditions, as the ratio of relatively soft and brittle material (trass) in the feed is increased, the fine product is getting coarser. This result was also supported with piston die tests. The result obtained from the mixture feed piston die test indicates that, when soft and hard materials are crushed together, soft and brittle particles were broken more effectively. These tests also show that displacement breakage behavior of particle bed under compression depends on particle size and material. The piston die tests indicate that mixture feed decreases the breakage of the hard material, thus particle size distribution of hard material in mixed feed is coarser than the product of individual breakage. Because this product is fed to next step grinding system, generally ball mill, the performance of the ball mill circuit is also affected inversely.

References

Abouzeid, A.-Z.M., Fuerstenau, D.W., 2000. Mixture grinding in the high-pressure roller mill. In: Proceedings of the XXI International Mineral Processing Congress, Rome, Italy, July 23–27, A4-60-68.

Abouzeid, A.-Z.M., Fuerstenau, D.W., 2009. Grinding of mineral mixtures in the high-pressure grinding rolls. International Journal of Mineral Processing 93, 59–65.

Aydogan, N.A., 2006, An investigation of the performance of high pressure grinding rolls in cement industry. Hacettepe University, PhD Thesis.

Gardner, R.P., Rogers, R.X., 1975. A two-component mechanistic approach for the comminution of material that exhibits heterogeneous breakage characteristics. Powder Technology 12, 247.

Kellerwessel, H., 1990. High-pressure material-bed comminution in practice. Translation ZKG 2 (90), 57–64.

Kellerwessel, H., 1993. High pressure particle bed comminution of mineral raw materials. Aufbereitungs Technik 5, 243–249.

Kuper, P.C., Fuerstenau, D.W., 1989. Simulation of locked-cycle grinding tests using multi-component feeds. Powder Technology 58, 39.

Schönert, K., 1979. Aspects of the Physics of Breakage Relevant to Comminution. Fourth Tewksbury Symposium, University of Melbourne, pp. 3.1–3.30.

Schönert, K., 1988. A first survey of grinding with high-compression roller mills. International Journal of Mineral Processing 22, 401–408.

Seebach, M.E., Knocbloch, O.R., 1987. High-pressure grinding rolls in industrial applications. Aufbereitungs Technik 10, 591–599.

Sergeant, P.J., 1995. The High-Compression Roller Mill – An Overview, Colloquium, Interactions Between Comminution and Downstream Processing, Mintek, Randburg, pp. 1–15.

Thompsen, L.G., 1997. Operational performance of grinding rolls at cyprus sierrita corporation. In: Kawatra, I.S. (Ed.), Comminution Practice. SME, Denver, pp. 107–110 (Chapter 15).