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Comparative Studies on the Grindability of Some Ore Minerals

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Abstract

Comminution tests are a vital element in the proper design of mineral processing plants. Several grindability tests have been developed over the years for different applications and each test has its strengths and weaknesses. Among test methodologies considered, is the universally accepted high-pressure grinding roller (HPGR) test procedures based on small-scale tests. The present work has been carried out to compare the grinding characteristics of different ore minerals. It was observed that all tested minerals, (quartz, chromite, marble, hematite, magnesite, dolomite) showed a general similar trend while being compressed. Moreover, because those minerals have wide differences in their mineralogical, physical, and mechanical properties they have different comminution behaviour under compression. The consumed energy as well as the reduction ratios are affected by the mineral hardness. The percentage product at a certain cut-size was found to be proportional to the expended energy for each mineral. A convenient grindability index under compression has been suggested as the specific productivity, in ton/kWh. This index is quite sensitive to the material hardness.

Introduction

Size reduction is the most fundamental and standard unit operation in most mineral industries. It is the process in which ores are reduced through crushing and grinding circuits. Size reduction operations remain by far the largest energy consumer in the mineral industry. It causes significant energy consumption and affects the subsequent processing operations. Hence, it has been revealed that comminution accounts for 30- 70% of all energy used in the mining industry [1-2]. It has been reported that about 3-4% of the world's electrical energy is consumed by grinding [3] and approximately 50-80% of the total energy consumption in a mineral processing plant is utilized by comminution equipment [4] rendering comminution an energy-intensive process.

It was recognized that different ores respond differently to comminution methods depending on the ore characteristics in terms of the mineral composition, mechanical properties, texture, and particle feed size [5-8]. In addition, the breakage mechanism within a comminution machine is another factor that can significantly affect how particles respond to size reduction [9]. Ores are comminuted using conventional crushing and grinding methods but the role of material properties on the grindability of these materials using the conventional machines is not yet fully investigated. Some studies [10-14] have been reported in the literature which revealed that grindability of minerals is greatly influenced by their characteristics. A detailed analysis of physical aspects of comminution for a better understanding of grinding characteristics of mineral matters was proposed. Compressive strength and hardness are the key factors that dictate the breakage characteristics of mineral materials during grinding. Other mineral properties, such as bulk density and porosity, also play a significant role during minerals grinding [15]. It is also reported in the literature that fracture propagation is significantly impacted by material density [16-17]. The present research work aims at gaining a fundamental understanding of how the different ore minerals break under compression in terms of size distribution produced and specific energy consumed. It also aims to approach the ambiguous definition of mineral grindability.

Experimental

The minerals samples used in this study were collected in the form of large lumps (≥ 20 cm) from different Sudanese states. The samples were prepared by stage-crushing, in a laboratory jaw crusher followed by a roll crusher, down to minus 10 mm particle size. The crushed samples were sieved to produce two size fractions namely -6.3+4.75 mm and -2.36+1.7 mm used for comparing the results of the size effect. Sample weight used for each experiment was fixed at 150 grams. A cell assembly given in Figure 1, a piston die arrangement was used to grind the mineral samples by compression. The detailed experimental work was illustrated elsewhere [14].

Results and Discussions

Mineral Compressibility (Piston Displacement)

As shown in Figure 2, for all tested minerals the piston displacement is in direct function with the applied load where the displacement is consistently reduced as the material size fraction is reduced, i.e., the displacement is larger in the case of the coarser fractions than in the case of finer fractions. The displacement, curves exhibit a definite trend in compressed bed according to the apparent bed porosities of the given minerals tested, where the compressibility increases with increasing bed porosity. The bed porosity for both fractions was found close to each other. Figure 3 shows a histogram of the piston displacement versus the apparent porosity of the given minerals. At an applied load of 100 kN, for the size fraction -6.3+4.75 mm, soft minerals such as dolomite, magnesite and marble are compacted on large bed thicknesses of about, 1.74, 1.7 and 1.65cm, respectively against hard minerals such as hematite, quartz and chromite of small bed thickness of about 1.6, 1.42 and 1.13 cm, respectively. Results for size fraction (-2.36+1.7 mm) showed the same trend.

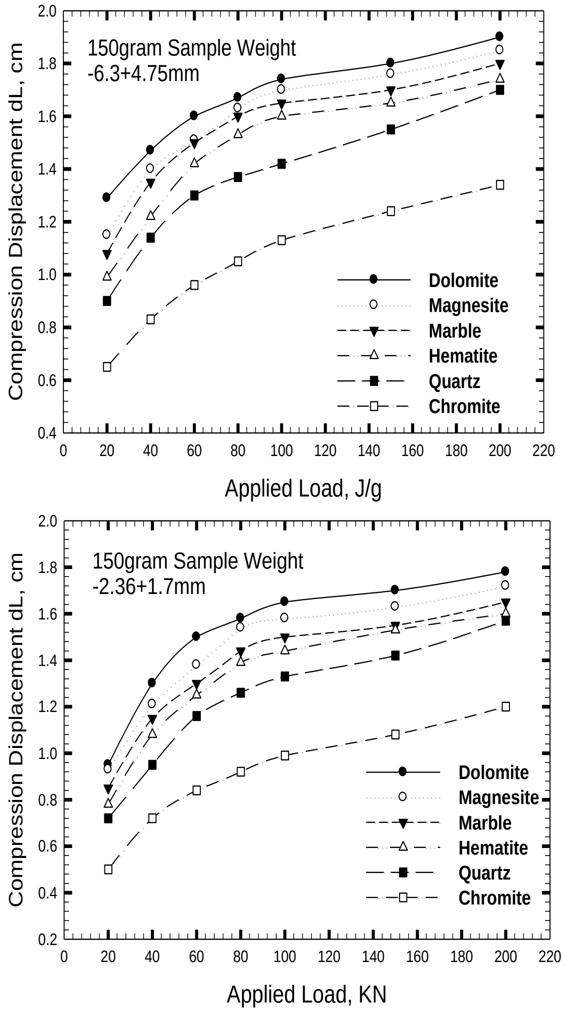

Figure 2 The piston displacement as a function of the applied load, for size fractions (-6.3+4.75 &-2.36+1.7 mm) at 150 grams of various minerals.

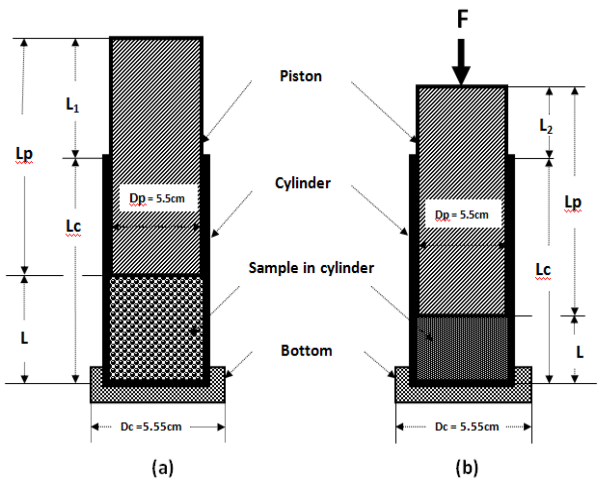

Figure 1 The piston-die assembly: Dp diameter of piston (5.5 cm), Dc diameter of cylinder (5.55 cm), Lp length of piston (12.5 cm), Lc length of cylinder (11.55 cm), L1 measure length of the piston before compression), L2 measure length of piston after compression).

Specific Energy Consumption

The specific energy expended on the various minerals at 100 kN as a function of their Vickers Micro-hardness (VH) is illustrated in Figure 4. It can be noticed from this figure that the specific energy expended increased with decreasing the micro-hardness value of the tested minerals. This behaviour may be attributed to the difficulty of crack propagation with increasing material hardness. This effect is not significant in the case of the soft minerals where the VH is less than 400. Correlating Figures 2 and 3, one notices that the hard minerals are less in their bed porosity than the soft minerals. This means that there is a combined effect of the minerals hardness and the energy expended on the material breakage. This concludes that this combined effect is not a sensitive measure for the differences in mineral grindabilities.

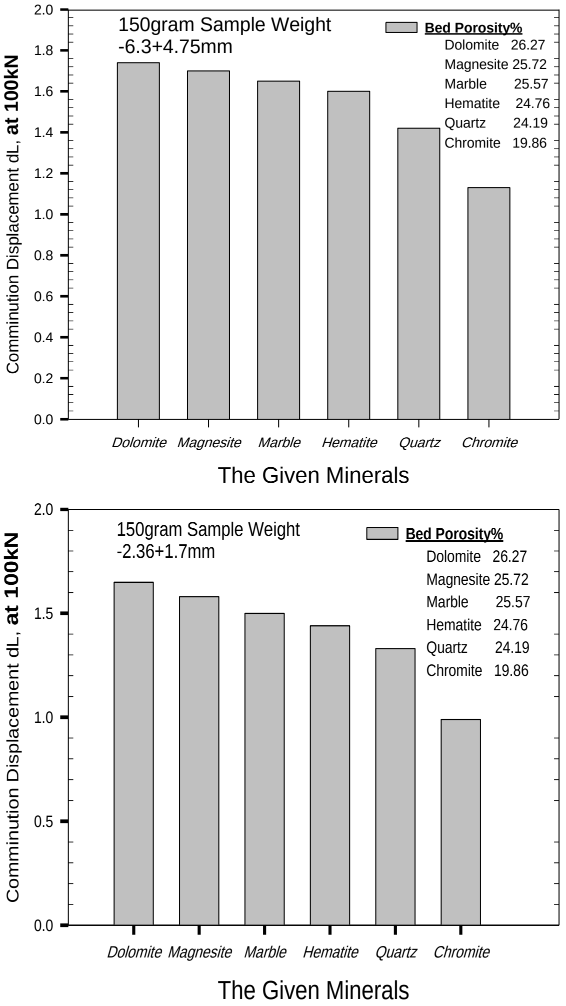

Figure 3 Histogram of piston displacement versus apparent porosity of the given minerals, for size fractions (-6.3+4.75 & -2.36+1.7 mm).

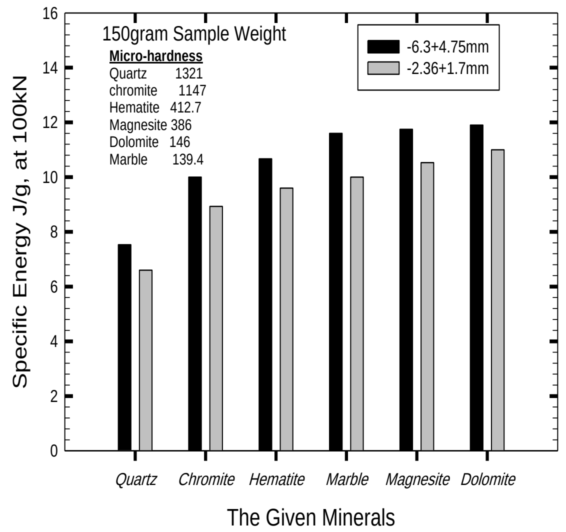

Figure 4 The specific energy consumed at an applied load of 100 kN as a function of the minerals' Micro-Hardness (VH) value.

The Reduction Ratio of Minerals

Figure 5 shows the reduction ratio, X_{50f}/X_{50p}, as a function of the specific energy expended by compression mode of grinding for two size fractions (-6.3+4.75 & -2.36 +1.7 mm) of each mineral sample. This figure shows that, the hard minerals such as quartz and chromite, have low grindabilities (low values of the reduction ratio) and the soft minerals such as marble, dolomite and magnesite have higher grindabilities (high values of the reduction ratio), which break into finer products with widely dispersed size distributions [18]. The reduction ratios for the two size fractions of the different minerals follow strictly the measured values of the VH tests, i.e., the values of the slope of the reduction ratio curves (X_{50f}/X_{50p}) versus the specific energy consumed and the micro-hardness of the minerals are inversely proportional to each other. This means that as the hardness increases, the reduction ratio decreases, which is logical. Figure 6 shows a relationship between the reduction ratio values of those minerals and the energy consumption for their comminution. Although the reduction ratios of these minerals follow their hardness, it is not quite sensitive for the minerals with high hardness values, e.g., quartz, and chromite.

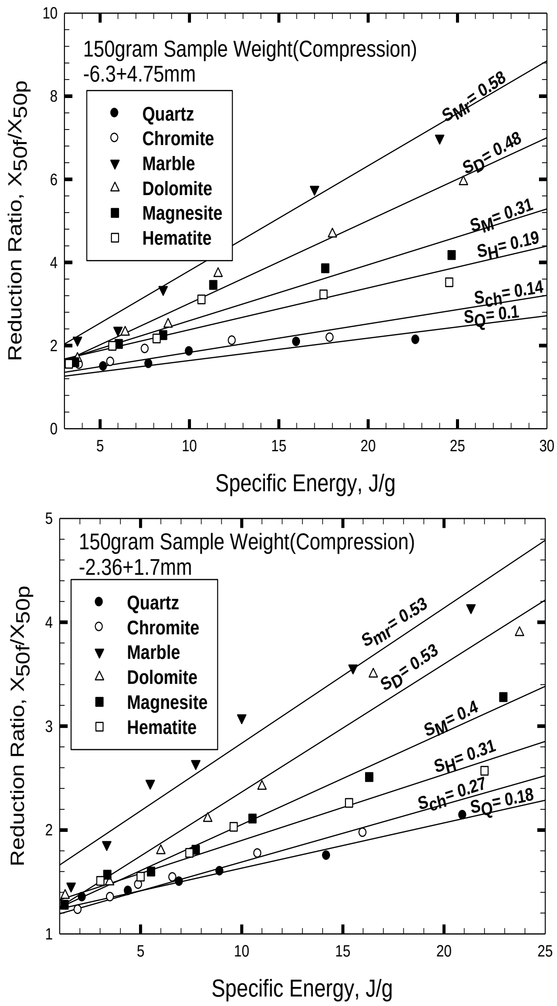

Figure 5 Reduction ratio as a function of specific comminution energy: feed size fractions (-6.3+4.75mm and -2.36+1.7 mm), for quartz, chromite, marble, dolomite, magnesite and hematite broken in the compression mode.

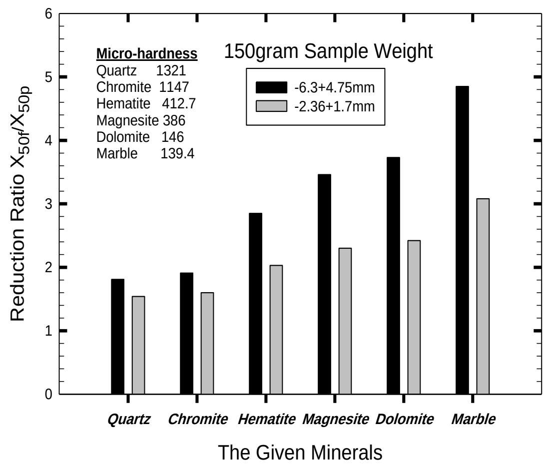

Figure 6 Reduction ratio for feed size fractions (-6.3+4.75 & -2.36 +1.7mm) of the tested minerals.

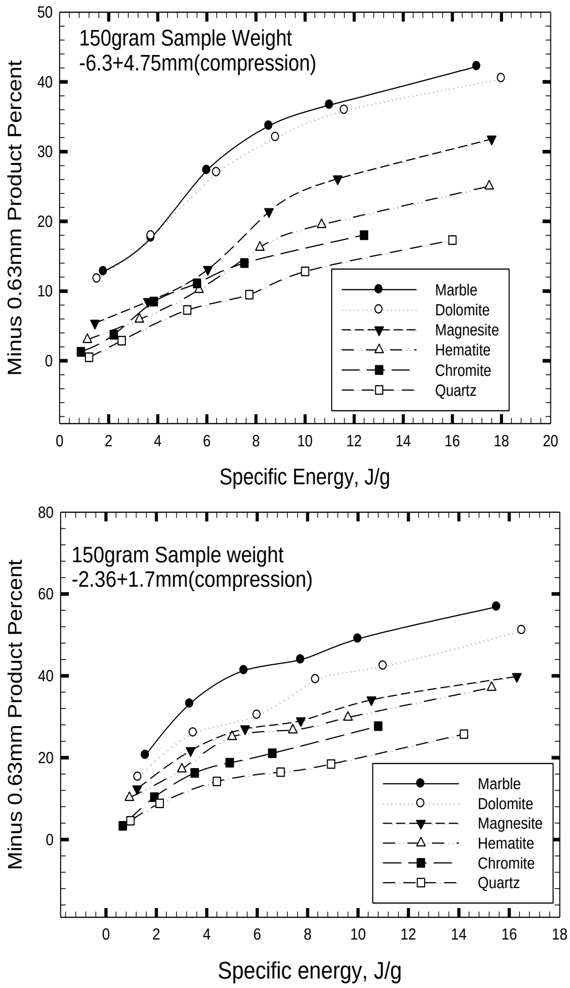

Figure 7 The product -0.63 mm percent, as a function of the specific energy, expended, size fraction (-6.3+4.75 and -2.36+1.7mm), in compression mode.

Percentage of Material Passing a Cut Size

Figure 7 shows the percentage fraction of minus 0.63 mm (product of -0.63 mm) for quartz, chromite, hematite, magnesite, dolomite, and marble tested by compression as a function of applied energy. The produced fine fraction increases as the specific energy increases for all the tested minerals. In addition, the fine product percent increases as the feed size decreases for all the tested minerals. The production of fines is markedly influenced by the different physical and mechanical characteristics of those minerals such as bed porosity, micro-hardness and particle size.

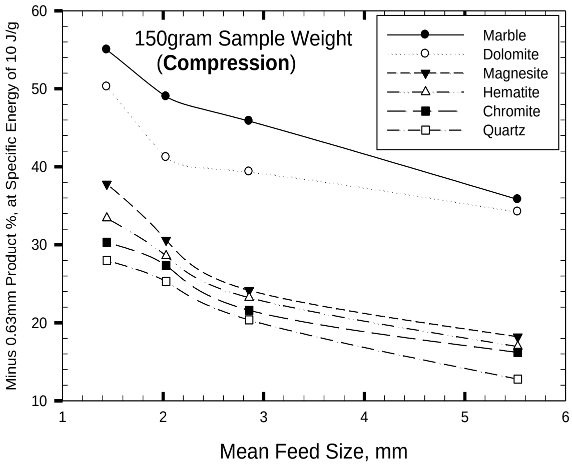

Figure 8 The product -0.63 mm percent, versus mean size feed size fractions, at specific energy of 10 J/g for the tested minerals, (Compression).

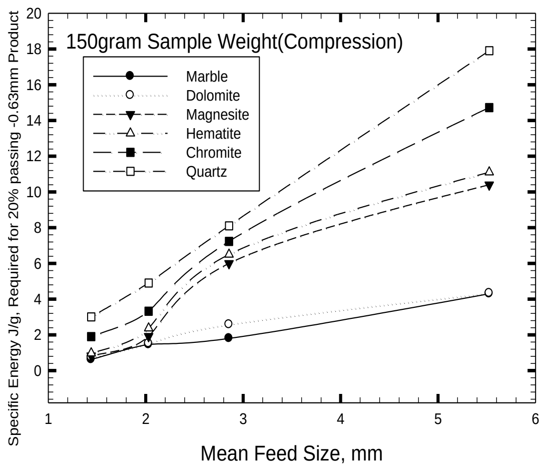

Figure 9 Mean feed size fractions versus specific energy, required for 20% passing product for the tested minerals (Compression).

Energy Consumed for Passing Certain Cut Size

Figure 8 shows the relationship between the percentage minus 0.63mm product and the mean feed size at a fixed specific energy (10 J/g), for the tested minerals. It shows that the generation of fines during grinding has a decreasing trend with increased mineral hardness. Figure 9 also shows that the size reduction is related to hardness as well as brittleness. The result shown in Figure 9 confirms the findings discussed in Figure 8. That is, more energy is needed to break harder and coarser sizes than to break softer and finer sizes down to a certain cut size. As an example, marble has the highest percentage of fine product whereas quartz has the lowest fine product percent. Figure 9 presents the relationship between the energy required for obtaining 20 percent minus 0.63 mm product in all the tested minerals versus the mean feed size fractions, using compressive force.

Relative Grindability of Minerals

Using the size fraction (-6.3+4.75 mm) of the tested minerals and the -0.8 mm as the product cut size, the productivity, in ton/kWh, for each mineral was calculated as a relative grindability indicator. These indicators are presented in Figure 10, which suggests that the productivity of minerals, at fixed grinding conditions, can be used as a granted relative grindability index under compression. This index differentiates clearly between the behaviour of the different minerals under compression even at small differences in their hardness such as the case of marble, dolomite and magnesite, or quartz, chromite, and hematite.

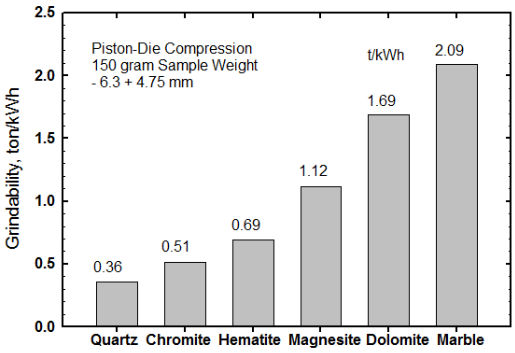

Figure 10 The specific productivity, grindability in ton/kWh, for the various minerals under investigation.

Conclusions

In this study, comminution tests using a piston-die set-up, have been carried out using six minerals different in their physical and mechanical properties in order to investigate their gindability characteristics under compression. The following conclusions may be drawn based on the obtained results:

- The mineral compressibility is a function of the bed porosity of the minerals.
- The reduction ratios of the minerals follow strictly the mineral hardness in all size fractions, but it is less sensitive in the case of hard rocks and reasonably sensitive in the case of soft rocks.
- The production of fines was markedly influenced by the different physical and mechanical properties of minerals such as bed porosity and hardness.
- The specific productivity, in tons/kWh, is a convenient parameter to differentiate between the minerals grindabilities. It is sensitive for the mineral hardness whether it is soft or hard. It can be called, with confidence, as a "mineral grindability index" under compression.

List of abbreviations

HPGR High-pressure grinding roller

t/kWh Productivity in tons per one Kwh of consumed energy

X_{50f}: Median size of the feed

X_{50p} Median size of the product

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Conflicts of interest

There are no conflicts to declare.

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