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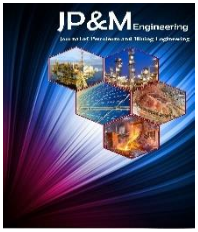

Grindability of Quartz under Compressive and Impact Forces

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Abstract

The main forces responsible for brittle material fracture in all conventional size reduction units are compression, impact, and attrition. The first two types of forces are the most effective ones in size reduction of rocks. The contributions of each of these forces differ from one size reduction machine to the other. These facts necessitate the urgent need to evaluate the breakage behaviour of the material under each of these acting forces to help choosing the appropriate comminution unit for a certain purpose. This paper presents a comparative study between the grindabiltiy of quartz by compression and impact forces as two different modes of size reduction in mineral comminution. The compression tests are carried out in a piston die, and the impact tests are performed using a stamp mill. Two quartz size fractions, (-6.3+4.75mm) and (-2.36+1.7mm) at sample weights of 150 and 100 grams were used for comparison of the behaviour of quartz under the two different modes of material disintegration forces. The obtained results showed that the cumulative weight of the product size distributions is reasonably normalizable with respect to the median particle size, X_{50}, for both compression and impact modes. The specific energy expended is inversely proportional to the median size of the products, and the reduction ratios (RR), X_{50f}/X_{50p}, are directly proportional to the applied forces in both grinding modes, and hence, to the specific energy expended. However, under the studied conditions, there is superiority of grinding by impact force, particularly at the high energy levels, over compression grinding in terms of reduction ratios and the fineness of the ground product. Analysis of the results points to conclusions concerning the choice of grinding equipment ensuring the most beneficial course of the size reduction process for a specific job.

Keywords

Confined bed; compression; impact; Piston die; Quartz

Introduction

It is well known that comminution is an energy intensive operation among the different processes involved in the mineral industry [1]. The mechanisms of comminution are not clearly understood and need further investigations. There are several conflicting views on how a brittle material is disintegrated under the combined forces acting on it within a size reduction machine [2-10]. The problem related to this process is the fact that it is a random process, not only in occurrence from circumstance, but also in geometry, composition of the minerals, and the particle orientation at which the rocks are smashed. Napier-Munn et al. [2] and Wills and Napier-Munn [3], believed that there are only two mechanisms, namely, impact fracture and cleavage of particle under compression. Based on his experimental results, Kwade [4] proposed three possible mechanisms; compression, impact fracture alongside attrition within the tumbling mills. These three mechanisms of comminution can be summarized as: Abrasion occurs when local low intensity stresses are applied, and the result is fine particles (aspirates) taken from the surface of the mother particle and particles of size close to the size of the mother particle. Cleavage of particles occurs when slow and relatively intense stresses are applied (compression) which produces fragments of size 50-80% of the initial particle size. Impact fracture is a result of rapid application of intense stresses (impact) which produces fragments of relatively small sizes with a relatively wide particle size distribution [8]. Other researchers [5-11], explored the mechanism in terms of the shape of the particles of the products and its consequence on the mineral liberation.

Breakage of particles in comminution processes can occur in a variety of ways depending on the material characteristics such as mineral composition, ore texture and grain size, and the breakage mechanism within the comminution device. In general, the mechanisms involved in mineral breakage during comminution, will depend on the material to be crushed and the machine used. The force modes acting to break brittle particles can be purely impact, such as in the Barmac machine and the Hammer mill, combination of compression and attrition, such as jaw crushers and HPGRs(High Pressure Grinding Rolls), or combination of all the acting forces, such as in tumbling mills [5, 11-19].

The breakage mechanisms which take place depend on the level of energy applied and the rate of its application. When the overall stress applied on the particle exceeds some critical value, impact fracture occurs resulting in disintegration of particles into many progenies which are all significantly smaller than the parent size [20-24]. Attrition, on the other hand, occurs when the stress applied is small such that the critical value is only exceeded locally, along the surface of the particle [21]. Impact crushing can be performed in two different modes, either by crushing media falling on the particle as in ball mill, or by letting the particle to move at a high relative speed falling against a surface as in hammer mill [22]. Testing by impact has the advantage that the impact energy can be calculated easily. The energy is transferred from the drop weight directly to the particle. The particles take up the energy necessary for breakage only. If the crushing medium has energy more than this, the surplus energy can cause secondary and tertiary crushing of the fragments from the primary crushing [22-23]. Also testing by controlled compression, such as pressing the particle bed in a piston die system, the energy is transferred to the material bed directly, dissipated as bed compression (to break coarse particles) and particle/particle friction (to generate fine aspirates) [25]. Many researchers have studied the breakage of single particle under impact for obtaining a greater understanding of this important mode of grinding, among them Krogh [21], Narayanan et al. [26] and Kapur et al. [27].

The current paper attempts to correlate the grinding characteristics of quartz, in different size fractions, when ground at various loads in a confined piston die and impact mill. The correlation includes the effect of the grinding mode on the size distribution of the product material, the specific energy expended, the reduction ratio, and the production rate of fines.

Experimental Work

Material, Equipment and Procedure

- Material: The feed mineral used in this study was quartz collected from Sapaloga, North Khartoum, Sudan. The sample was prepared by stage-crushing, in a laboratory jaw crusher followed by a roll crusher, down to minus 10 mm particle size. The crushed sample was sieved to produce an enough stock of different size fractions. Two of these fractions, namely, (-6.3+4.75mm) and (-2.36+1.7mm), at 150 gm and 100gm sample were used for testing.
- a) Compression Tests. A cell assembly, a piston die arrangement, was used to crush the quartz samples, see Figure 1. A sample of certain weight was ground under a set of bed pressures ranging from 20 to 200 kN to generate a reasonable range of specific breakage energy inputs in the piston die. The assembly was loaded in a laboratory compression machine equipped with a load cell. The piston having a diameter of 5.5 cm was snugly fitted into the die, 5.55 cm diameter, to make a fully confined particle bed. The particle beds were compressed at a slow rate of loading which varies with the applied load {3 mm/s at the lowest load (20 kN), and 1 mm/s at the highest load (200 kN)} up to the desired maximum force level. Piston displacements were measured at the end of the unloading cycle using a Vernier caliper. The loading time was measured using a digital stopwatch from the start to the desired load. After load is released, the comminuted bed was discharged and soaked in water to disperse the agglomerated fines. The dispersed sample was then subjected to standard wet-dry sieve analysis.

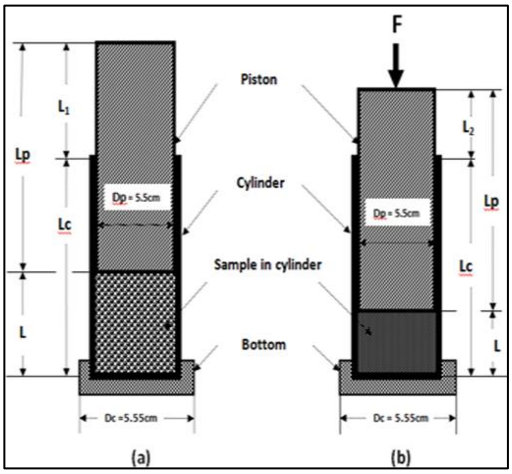


Figure 1 The piston die assembly: a) before loading and b) after loading [25].

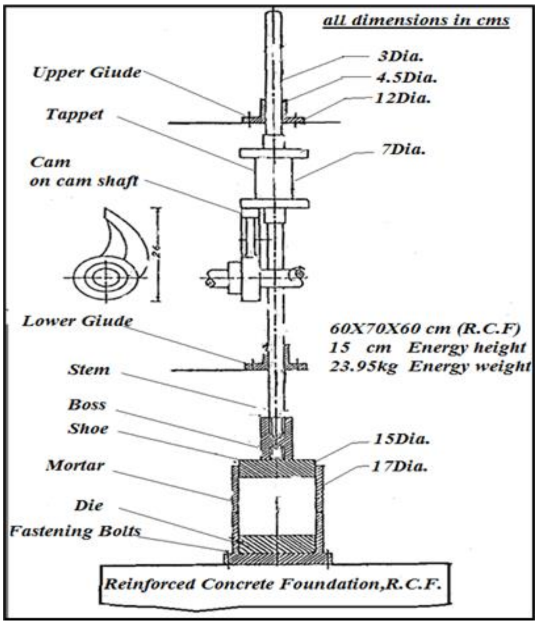


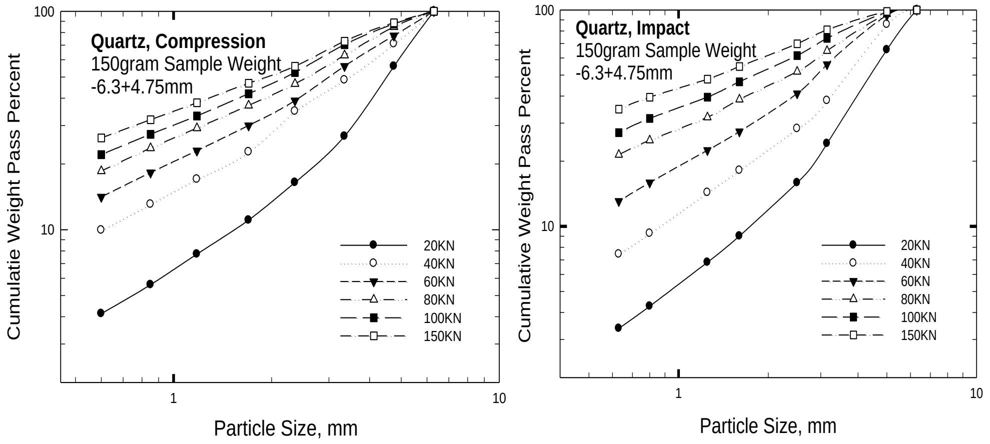
Figure 2 Sectional elevation through stamp mill [28]

- b) Impact Tests. The stamp mill [28] (Mining Department, Assiut University) Figure 2 was used to execute the tests sample weights of 150, and 100 grams of quartz. The sample was put on the bottom of the mortar to form a layer, which is subjected to the impact force equal to the dropping weight of23.95kg. The number of drops equivalent to the desired forces of 20, 40, 60, 80, 100, and 150 kN were calculated when the dropping weight was falling freely from a fixed height of 15cm. The quartz sample was stirred and remixed every five drops. At the end of test, the ground sample was collected, and wet-dry screened on an assembly of a laboratory sieve set (from 10 mm down to 0.212 mm) for 15 minutes. The sieved fractions were separately collected.

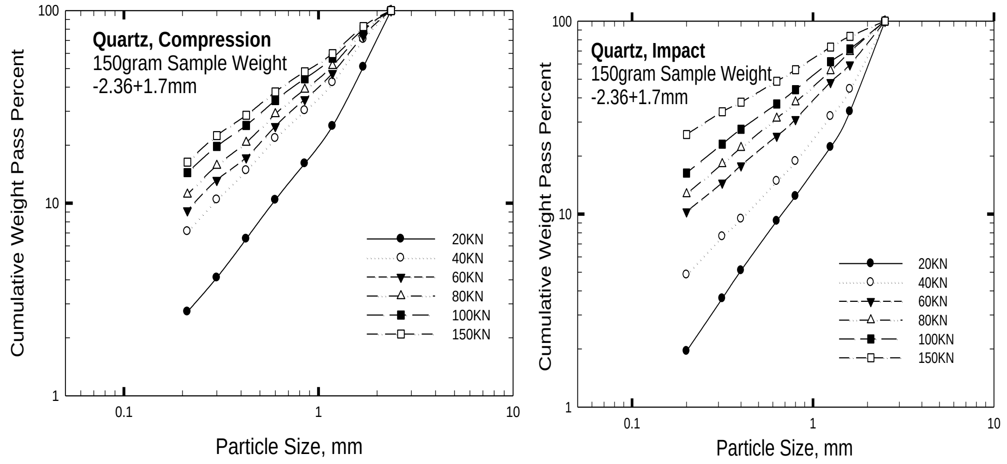
Results and Discussion

The Size Distribution of the Comminuted Product

The size distribution of the products from both compression and impact forces using piston die and stamp mill are different from those obtained from ball mills or high-pressure grinding rolls (HPGR) as stated previously [25]. They are fanning out, in straight lines, from the feed size towards the finer sizes at all applied loads (energy levels) for all size fractions tested (Figure 3). The slope of the size distributions produced by both compression and impact forces are functions of the applied loads (energy levels).



(a)Size fraction -6.3+4.75mm(impact) (a)Size fraction -6.3+4.75mm (compression)



(b)Size fraction -2.36+1.75mm(impact) (b)Size fraction -2.36+1.75mm(compression)

Figure 3 Product size distributions due to compression and impact for size fractions: a) -6.3+4.75mm and b) -2.36+1.7mm, (150gram weight).

The product at any load, e.g., 100 kN, is distinctly finer in the impact mode than that in the compression mode for all size fractions tested as shown in Figure 4. Moreover, all the distributions are reasonably normalizable with respect to the median size, X50, as shown in Figure .5. This means that quartz is behaving the same behavior in the confined piston die as well as in stamp mill under all applied loads for all size fractions tested.

Specific Energy Consumption

As expected, the specific energy consumed for grinding the different size fractions increased as the applied load increased. There is a similar trend of the specific energy consumed by compression and impact as a function of the applied load as shown in Figure 6. At any applied load, the specific energy expended is higher for the coarser size fraction than that for the finer size fractions. An explanation for this behaviour is that the displacement is larger in the case of the coarser sizes than the finer sizes.

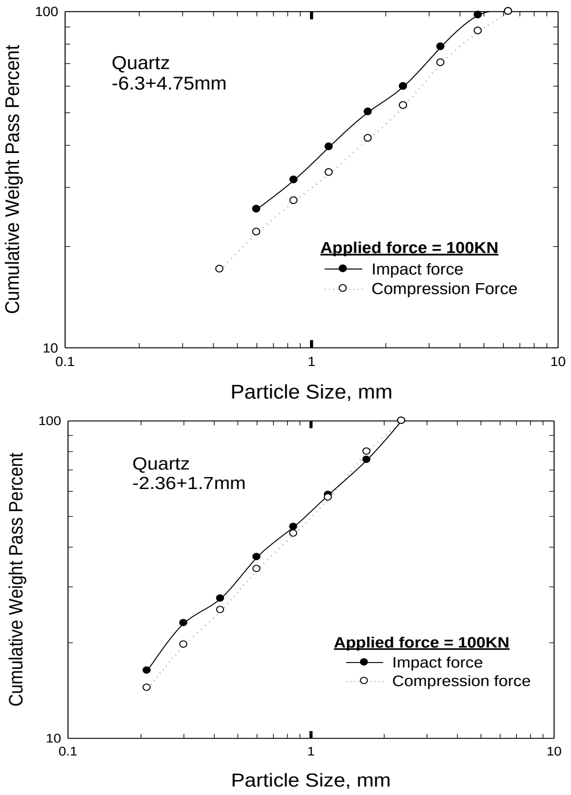


Figure 4 Size distributions of feed sizes-6.3 + 4.75 mm and-2.36 + 1.7 mm ground under compression and impact modes of forces at a force of 100 kN.

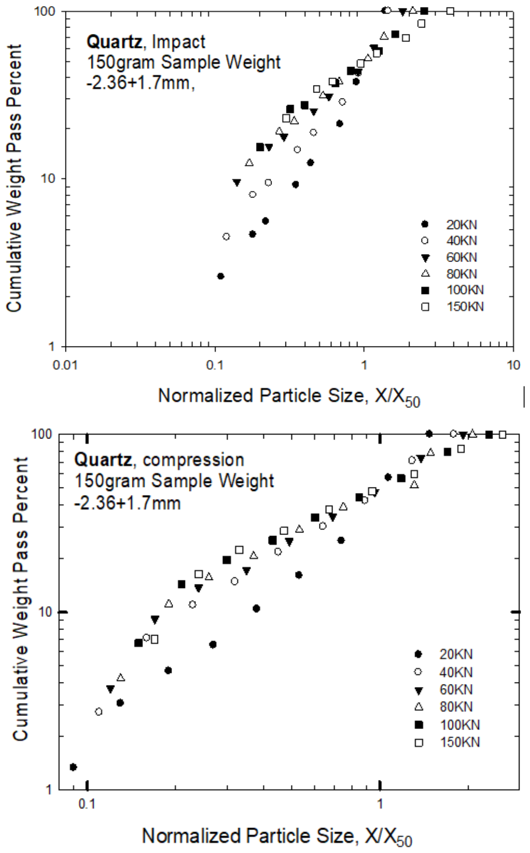


Figure 5 Normalized size distributions for all size fractions at various loads, 150gram weight (compression, impact)

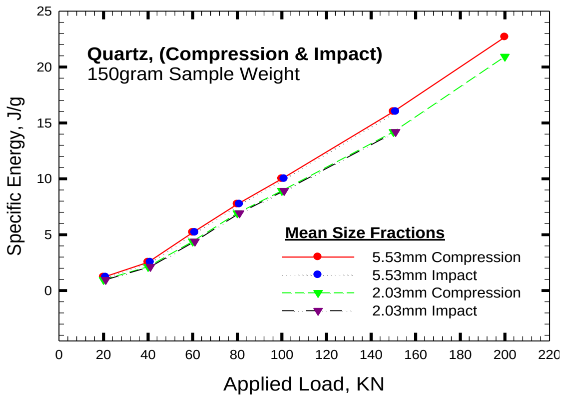


Figure 6 The specific energy consumption as a function of applied loads for different size fractions, sample weight is 150 grams.

The Reduction Ration of the Products

The reduction ratio, X50f/X50p, as a function of the specific energy consumed for the breakage of some of the size fractions used in this study is shown in Figures. 7 and 8 for 150, 100 g material samples. As expected, the slope of the relationship increases as the size fraction increases, i.e., the coarser size is more easily crushed by compression as well as by impact than the finer sizes. However, apparently, it is observed that grinding by impact is markedly more efficient than grinding by compression, which disagrees with the results reported by Herbst [29] who stated that compression has the highest efficiency, followed by impact. The main reason for this contradiction is that the surface area of the used Stamp mill cylinder (on which grinding action takes place) is 176.70 cm^2 while that of the used piston die is 23.76 cm^2. Thus, the effective grinding area in the case of impact was more than seven times that of compression. Moreover, the superiority of impact mode of grinding over that of compression could be attributed to the shock waves produced in all directions by impact that move through the mineral particles. Another reason is that in the case of compression, a portion of the supplied energy is expended in particle/particle friction producing some fines by attrition and abrasion rather than breaking the particles through inter-particle breakage. Another observation is that in the case of the fine fraction, the reduction ratio at low energy levels is higher for compression than that for impact at both material loads (100 g and 150 g).Which could be explained as follows: at low energy levels the compression force acted as pulverizer for fine particles whereas the impact forces just make cracks or fractures through coarse particles. In addition, when the thickness of the quartz bed was decreased the grinding efficiency was more pronounced through impact rather than compression as illustrated in Figure 9.

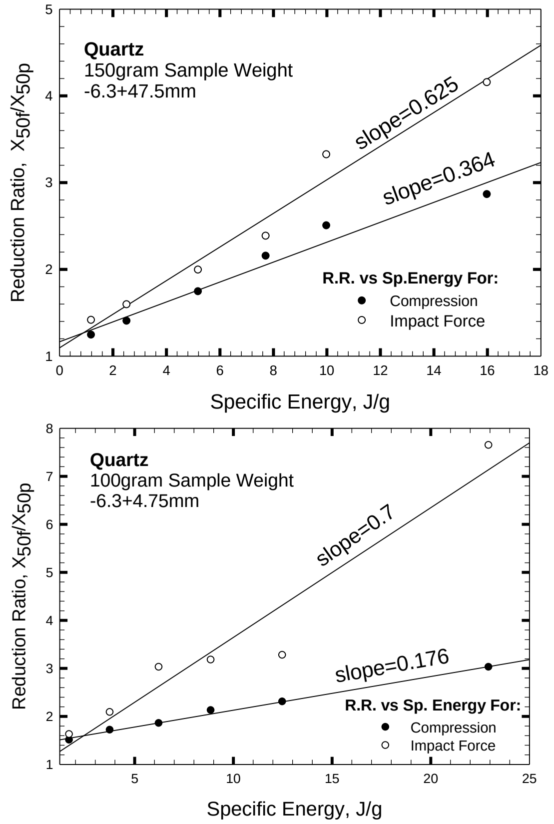


Figure 7 Reduction ratio versus specific energy applied for particle size (-6.3+4.75mm, the feed weights are 100 &150grams.

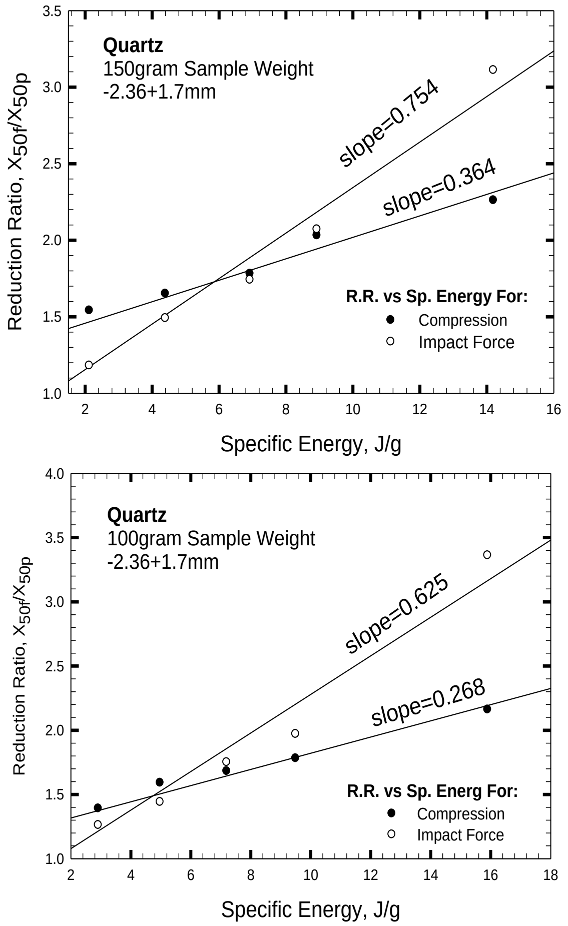


Figure 8 Reduction ratio versus specific energy applied for particle size -2.36+1.7mm), the feed weights are 100 and 150grams.

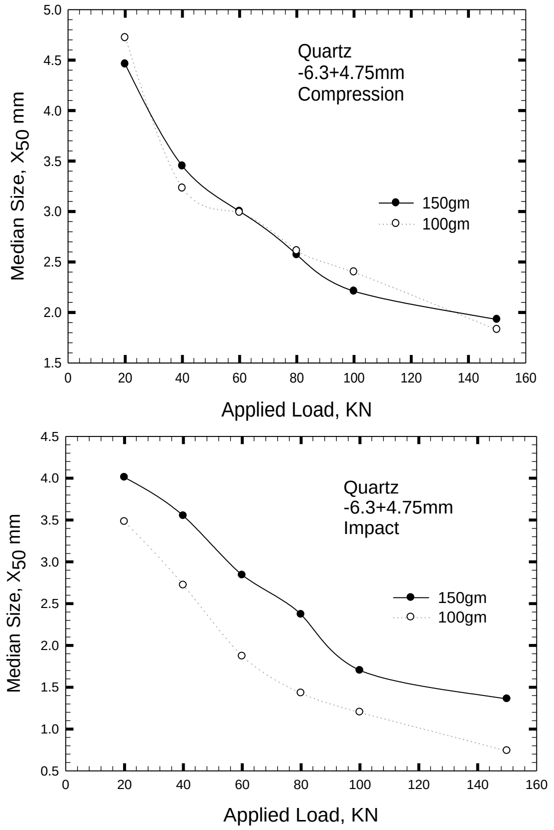


Figure 9 The effect of bed thickness on grinding efficiency for compression and impact modes of grinding

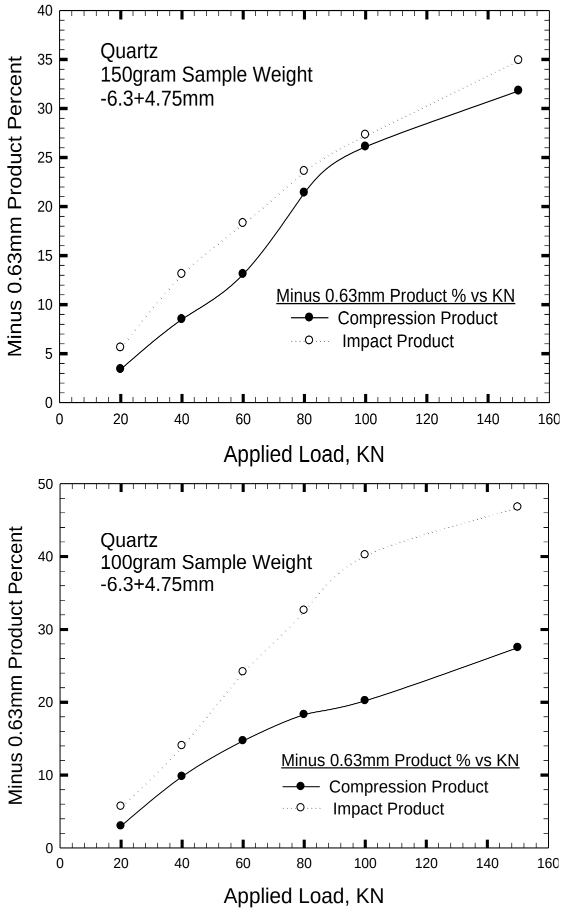


Figure 10 Minus 0.63mm produced by compression & impact for feed size fraction: -6.3+4.75mm, the feed weights are 100 &150grams.

Percentage of Fine Material (- 0.63 mm Size) Produced

The product material passing 0.63 mm was reported as a function of the specific energy consumed for the tested size fractions, Figure 10 and 11. The produced fine fraction increases as the specific energy increases for the tested size fractions. The product percent increases as the feed size decreases. This is because as the feed size approaches the cut size(0.63mm) at the same specific energy, more crushed material will pass the cut size. At higher energy levels, the rate of increase of the product percent decreases as a result of the rapid decrease of the unbroken material in the fine sizes at higher energy levels. Again the production of the -0.63 mm in the case of fine feed fraction is more by compression than by impact at low energy levels as was observed in the reduction ratio presentation, Which could be explained as follows: at low energy levels the compression force acted as pulverizer for fine particles whereas the impact force just makes cracks or fractures through fine particles.

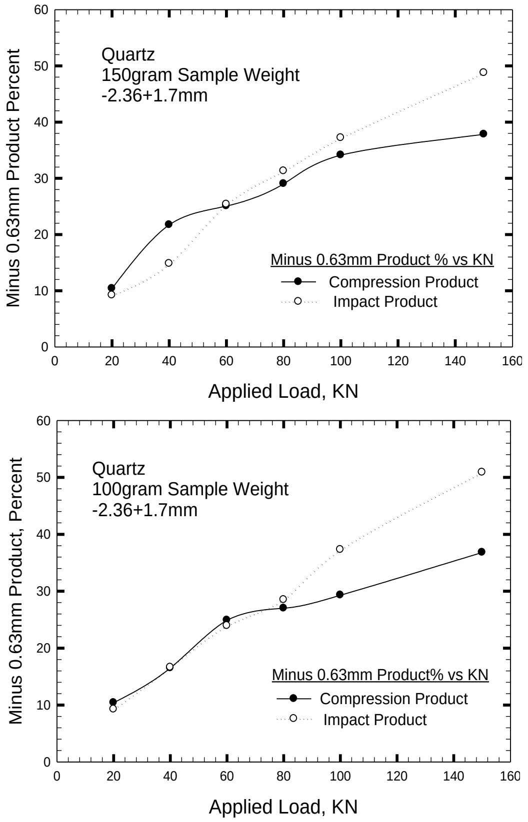


Figure 11 Minus 0.63mm produced by compression & impact for feed size fraction: -2.36+1.7mm, the feed weights are 100 &150grams.

Conclusions

In this investigation, comparison is made of the grinding performance of quartz under both compression and impact forces. Two size fractions (-6.3+4.75mm and -2.36+1.7mm) were used in this study. The applied load was varied from 20 to 200 kN. The results revealed the following conclusions:

- The size distributions of the ground product by both compression and impact forces differ from those of ball mills or HPGR. They fan out in straight lines from the feed size down to the fine size fraction for the various specific energy inputs. The size distributions follow similar criterion with respect to the median size, X50.
- The cumulative size distributions can be represented by simple linear relationships on log-log plots. The slope of the linear relationship is a function of the energy consumed for breaking the feed material.
- For both, compression and impact grinding modes the specific energy consumption was almost identical for certain size fraction tested, while increases with increasing the applied load.
- Under the studied conditions, the reduction ratio, X50f/X50p, occurred by impact grinding is higher than that of compression grinding, and for both grinding modes is in a reasonably linear function with the consumed specific energy.
- The impact grinding produced more fines than that of the compression in terms of the material passing a cut size (-0.63 mm) for the size fractions tested, which increases as a function of the specific energy consumption. The trend of the produced fines for both the grinding modes as a function of the energy expended follows the trend of the reduction ratio with the energy level.

Conflicts of interest

There are no conflicts to declare.

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