

2nd International Conference on Sustainable Materials Processing and Manufacturing
(SMPM 2019)

Effect of media shape on particle breakage in a batch ball mill: Lessons learnt from Population Balance Model and Attainable Region technique

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Abstract

The batch grinding equation and the Attainable region technique tools were used in evaluating data obtained from the breakage of quartz ore in a laboratory batch ball mill. Using the same milling conditions and grinding equipment, test results were evaluated through the breakage distributions of different size fractions. Results prove that mixing different grinding media increases volume of grinding zones and that translates to an improvement in grinding kinetics and amount of required PSD. The tools are valuable and practical ways of evaluating the breakage of materials on the size fractional base and results of which can be used in the mathematical modelling and optimising of ball milling unit operations.

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Peer-review under responsibility of the organizing committee of SMPM 2019.

Keywords: Attainable region (AR), Population balance model, Media shape, Optimisation,

1. Introduction

Comminution is a vital unit process that is performed in the processing of mineral ores. The ore is slowly reduced in size in tumbling mills to produce material of the preferred size class. This is done to expose, or to free, the valuable mineral from the gangue material before the product is sent to downstream recovery processes. The unit process is energy intensive and any potential savings is of paramount importance as it inspires the efforts for optimisation of size reduction processes.

A lot of literature exists that has been dedicated to describe the milling unit operation and the Attainable region technique (AR).

Some key aspects of population balance model and AR will be considered.

1.1. The population balance model

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A number of researchers have used the model [1-3]. It is also known as the batch grinding equation and is made up of the specific rate of breakage (S_i), the primary distribution breakage (b_{ij}) functions and a residence time distribution function. For a simulation of a ball mill to be successful, operation using laboratory scale results in a relationship of these functions and design of mill and operating variables should be well defined. The tool is centered on first order kinetics and the two functions give a size-mass balance equation for fully mixed batch milling operations. The modelling aspect allows us to construct a simulation model which can easily predict the particle size distribution in terms of the design of mill and the conditions of operation

1.2. Attainable Region technique

The AR is a graphical technique that is equipment-independent and has been applied in the area of comminution to describe the size reduction processes [4]. A complete AR analysis involves a description of the set of all possible outputs for a system [5]. There exist some similarities between the size reduction process and chemical reaction engineering and this suggests that comminution processes can be studied using the AR approach with a mill being considered as basically a reactor system where large feed particles are transformed into smaller product particles. The work already done by different researchers described the construction and application of AR method to optimize size reduction processes done under different operating conditions with different objectives [6-15].

1.3 Media shape

Apart from being relatively wasteful of energy, tumbling mills are also inefficient with regard to mineral liberation because of the indiscriminate nature of the grinding force. Accordingly, researchers have made efforts to study the effects of media in an attempt to improve the grinding process [16-19] and have come up with interesting results. Studies on media efficiency have concentrated on comparing their effects on the breakage distribution function and the selection function ignoring other parameters defining mill performance such as downstream processes. The aim of this investigation intends to add value to the understanding of the breakage of the materials as well as to better comprehend optimum conditions required for the downstream processing of mineral ores. Two different tools are applied to the batch grinding data to understand kinetics and maximise the liberation of value material in downstream recovery processes.

2. Materials and Methods

A quartz ore obtained from a local mine in Johannesburg South Africa was used in the experimental work. A mono sized feed fraction of between 2360 and 1700 μ m was prepared and used for all the tests. Spheres, cubes and eclipsoids made of cast iron (Figure 1) were prepared and used as grinding media.



Figure 1: Photographs of cubes, spheres and eclipsoids and mixture of grinding media shapes used for the batch tests [19]

Grinding experiments were done in a laboratory batch mill with diameter 0.282m, length 0.302m and milling conditions in Table 1. During all the tests, mill feeds were constant, (1941g). The sample to be milled was loaded in the mill with the media of appropriate size and weight. The feed material was then ground batch wise using media charges for selected periods (3, 5, 15, 30, 60 and 90 minutes) and a full product size distribution done on the product after each time interval.

Table 1: Milling conditions for experiments on the ore

Mill speed	Operational speed (Φ)	75% of critical
Media		Dimensions
	Balls	30 mm
	Cubes	32mm
	Eclipsoids	40mm* 40mm
	Mix Ball and cubes (B-C1)	50% B 50% C
	Mix Ball and cubes (B-C2)	75% B 25% C
	Mix Ball and Eclipsoids (B-E)	50% B 50% E
Material	Feed size μm	2360-1700

For the use of the AR, the particle size distribution is usually divided into three or more size classes. For easier use of the tool we selected three sizes classes. This allows us to select the feed material, the intermediate and fine size class. The three size classes were chosen as: Size class 1: Material between 2360 μm and 1700 μm , Size class 2: Between 150 μm and 75 μm , Size class 3: Everything less than 75 μm .

3. Results and Discussion

Figure 2 shows a variation of specific rate of breakage and the particle size for all grinding policies. Results show that mixtures offer higher rates of breakage in abnormal region. It is also observed that on adding spheres to cubes, a noticeable increase in breakage rates compared to cubes alone is attained. The authors suggested that further investigations must be done to determine the proportion of cubes in the mixture. Instead of using spheres it is possible to obtain optimal ball to cube mix ratio and use it for size reduction process. On evaluating the selection function for all selected size classes it was noted that breakage function to be normalisable. The rate of conversion of feed to required product is a function of milling conditions and ore properties (i.e. selection function and breakage function). They further established that spheres are most effective and the cubes being the less efficient. Eclipsoids were also effective as the ball especially performing better than balls for coarser material.

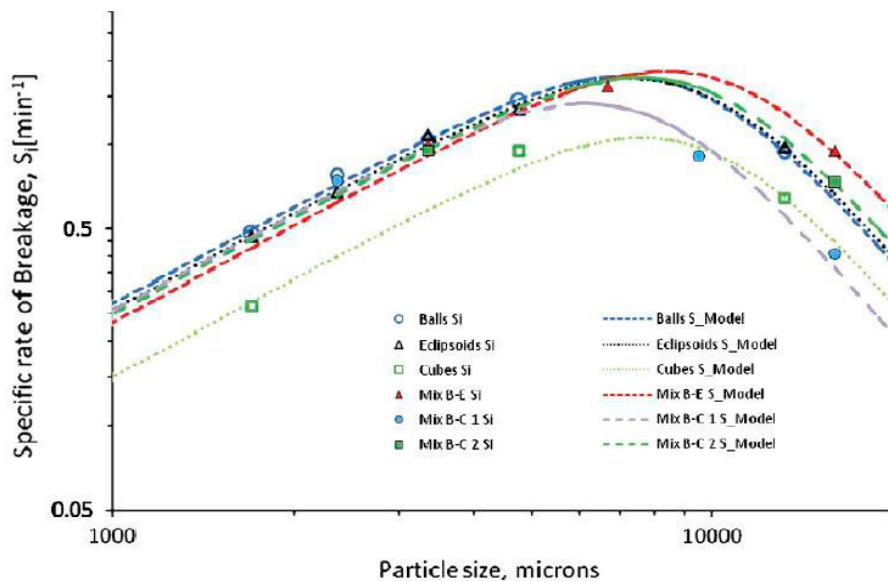


Figure 2: Variation of the specific rate of breakage with particle size for different grinding media and their mixtures [19]

Figure 2 shows that the breakage rates for all media shapes are highest at the initial periods of milling but as time progresses and material in the mill gets depleted, cubes seem to be failing to produce a finer size class. This could be due to the reduced probability of particle capture between the cube to cube impacts. Figure 3(a) also reveals that use of cubes alone as a grinding

media will not achieve the objective of higher grinding rates and finer material production. Different combinations of grinding media shapes improve the production of finer material.

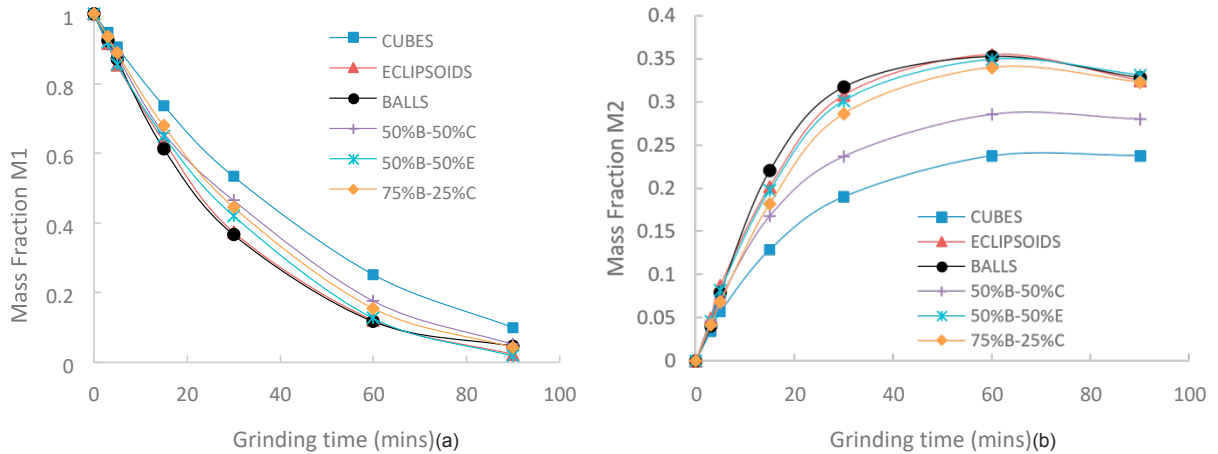


Figure 3: Mass fraction of silica material obtained versus grinding time (a) M1 vs. time (b) M2 vs. time

Figure 3(b) shows an A.R plot of the mass fraction of intermediate size class material against grinding time for different grinding media shapes. The region bounded by the curves and the x-axis is the wanted or attainable region within which lies solutions of the optimization question. The turning point of the plots give result to the solution of the optimization problem of the maximum amount of the intermediate size class material that can be obtained within the limits of the experimental conditions employed. The A.R plot shows that use of 100% balls or 100% eclipsoids will produce optimum amounts of the required size class material. The A.R method also shows that grinding media mixtures (50%B- 50%E and 75%B-25%C) also give relatively high amounts of the required material. This implies that if media cost and availability are limiting factors, then it is possible to select and mix what you have and still obtain relatively high values of the required size class material.

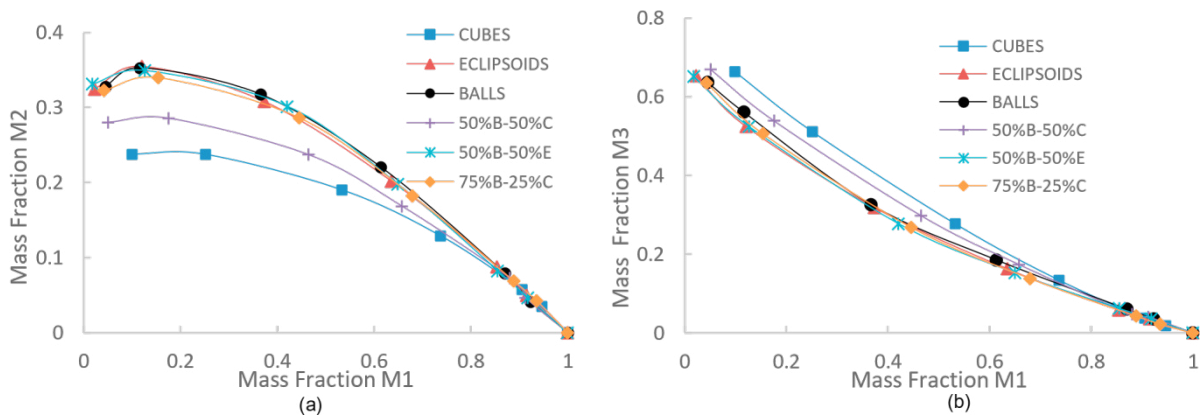


Figure 4: Attainable region plots for different media and mixing them (a) M2 vs. M1 (b) M3 vs. M1

Figure 4 (a) shows the A.R plot of the variation of mass fraction of material in the intermediate size class versus that in the feed size class obtained by milling with different shapes of grinding media. Similarly, the area bounded by each curve and the x axis is the wanted space termed the A.R and the turning point on each curve at the peak signifies an optimum solution for the maximum production of material in the intermediate size class. Figure 4(b) shows an A.R plot of the variation of mass fraction of material in the fines size class with that in the feed size class for milling done with different media shapes. The concurs with previous A.R plots in that the cubes produce less material in the finer size class while the balls and eclipsoids produce the maximum amount of fines. There are some size reduction industries where fines are a required product e.g the cement production industry. Hence the A.R plot can also be useful in such industries in formulating grinding media policies that give result to optimum production of material in the fines size class.

4. Conclusion

Milling tests were done using similar grinding conditions in order to compare the breakage behaviour of quartz in a batch ball mill using spheres, ellipsoids, cubes, and different mixtures of grinding media. The grinding media mass was kept constant and results showed that each media shape policy offers unique surface area and contact mechanisms during the size reduction process and this was attributed to differences in their geometry. The Attainable Region results show that the spheres and ellipsoids managed to offer high values of the required size class whilst cubes due to their geometry offered a coarser product compared to what was required. Using same grinding conditions as researchers [19] who demonstrate that using population balance model, it is possible to improve particle breakage by mixing different grinding media the AR shows that mixing can be done to get optimum amounts of material in the desired size class. The A.R results also make evident that each media policy can be applicable in its own unique industry to give optimum amounts of the required product.

Acknowledgement

The authors appreciate the National University of Science and Technology, Department of Chemical Engineering where the paper was put together.

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