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Article

Use of Uniform-Sized Balls to Improve the Manufacturing of $CaCO_3$ in Ball Mills

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Abstract: Building materials, such as $CaCO_3$ and dolomite, are widely used in industry and have to be crushed to a pre-determined size before they can be used as filling material. Ball mills are normally used to accomplish this. In this study, the effect of using balls that have a uniform size, rather than varying diameters, was investigated to determine their influence on powder digestion. The present study has formulated a new approach to overcome this common challenge faced by the industry.

Keywords: ball mill; digestion; powder/ball ratio; $CaCO_3$; dolomite; material.

1. Introduction

Powder digestion in a steel ball mill is one of the oldest and most well-known methods of manufacturing powder [1]. In addition, this method can be used to further grind powder manufactured by other techniques. In this method, the material to be digested is placed in a ball mill and the material's particle size is calculated. Then, once the mill is turned on, the balls begin to move (Fig. 1).

Ball mills are industrial equipment inside which particles of micrometer and millimeter sizes are digested (Fig. 2) [2]. However, it is not always clear exactly which material has been ground in the mill or how it was ground. The process depends on two parameters: the number of crushing collisions per unit time and the energy released by the collisions. In order for a material to be ground in a mill,

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the particles of that material have to be trapped and crushed between two balls or between a ball and the mill's wall [3]. Also, the energy density must be sufficient for the particles to be crushed.

The number of particles caught between two balls depends on the concentration of solids in the suspension and the size of the particles in the feed. The particle size can be expressed as the ratio of the diameter of the active volume between two balls to the average distance between two particles in the suspension (Fig. 3) [4].

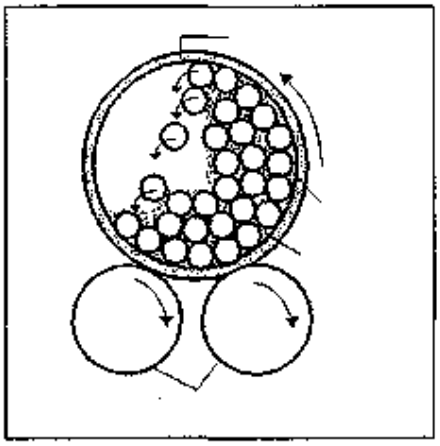


Figure 1 . Digestion in mill with balls.

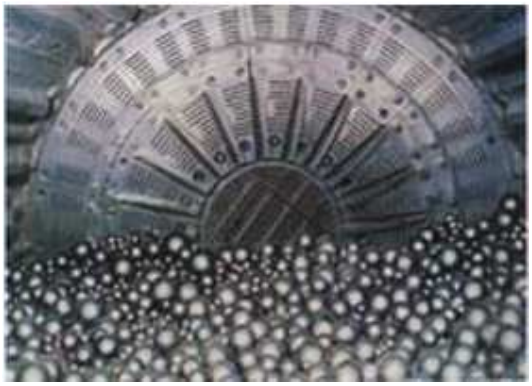


Figure 2. View of the inside of a mill containing balls.

If the particles to be digested are brittle, they will be ground into a very fine powder when trapped between two colliding surfaces [5]. Non-brittle particles, on the other hand, change their shape when trapped between two colliding surfaces. If there are mostly brittle particles in the mill, the material is ground into a fine powder (Fig. 4). Increasing the ambient temperature of the air shortens the digestion time and ensures that a fine powder is produced [6]. Under a given set of conditions, the productivity of a mill is determined by the average ball crushing speed and the average number of collisions a ball undergoes in the mill [7].

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Using a very low rotation speed during digestion forces the balls to move around inside the mill. Under high rotation speeds, the balls stop moving randomly and are pushed to the wall because of the centrifugal force. The ball's volume should be approximately half of the mill's volume, and the amount of material to be digested should be approximately 25% of the mill's volume [8]. Although cylindrical mills are widely used for digesting $CaCO_3$ materials, they rotate at a low speed and the digestion time is long [9]. In order to decrease digestion time, specific ball diameter to mill volume ratios are needed. In this study, the relationship between uniform ball size in cylindrical ball mills, digestion speed and particle size were investigated, and an improved method was developed.

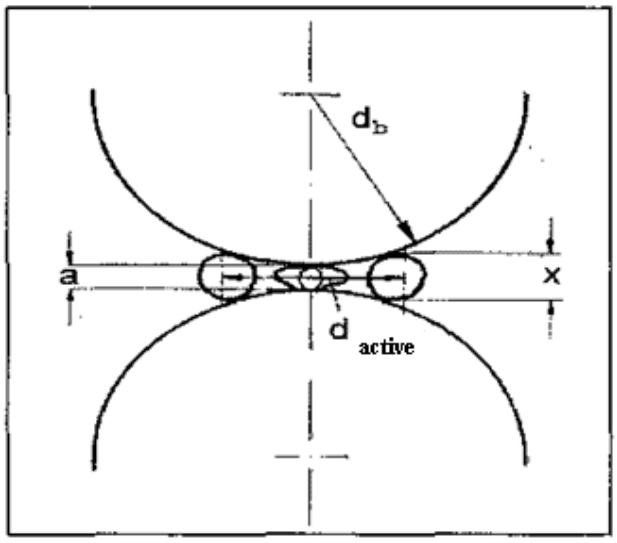
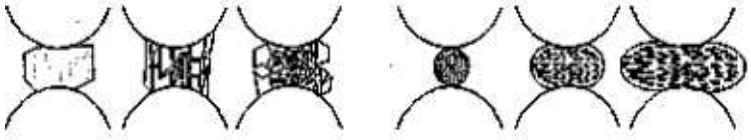


Figure 3. Active volume.



Brittle particles Elastic particles

Figure 4. Influence of crushing during digestion.

2. Design and Construction of Ball Mill with Uniform Ball Size

A cylindrical ball mill was built and powered by an electrical motor with an 18 rpm axle. The axle speed can be raised to 20, 25, and 30 rpm using a graded belt hoop. The cylinder that activates digestion was placed on two separate pressured oil pumps. The mill's inner surface was made from Cr-Ni stainless steel, and another seamless material was used around the outside of the cylinder. During

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mill operation, the oil pumps were cooled by water. The water-cooling systems can be used to prevent reactions that may occur due to the heat generated during the mill operation.

3. Materials and Methods

3.1. Experimental Conditions and Materials

3.1.1. Digestion

The average diameter of the balls used in the $CaCO_3$ digestion system was 55 mm. The rotation speed was adjusted to 18 rpm and the experimental digestion time was 1, 5 and 10 h, respectively. The powder/ball weight ratios were 1:5, 1:10, 1:20 and 1:40, respectively. To achieve a 1:10 powder/ball ratio, 100 g of $CaCO_3$ and a 1000 g steel ball were placed in the mill. Similarly, for a 1:40 powder/ball ratio, 50 g of $CaCO_3$ and a 2000 g steel ball were used.

Size analysis of the digested $CaCO_3$ powder was conducted using a Malvern Mastersizer E laser powder particle measuring device. As shown in Table 1, the average powder particle diameter was d = 0.5 mm, and for values of d = 0.1 and 0.9 mm, the digested $CaCO_3$ powder particle quantities were 10% and 90%, respectively. The effects of the digestion time on the particle size for powder/ball mass ratios of 1:40, 1:20, 1:10, and 1:5 are shown in Figs. 5-8, respectively.

The following formula was used to analyze the particle size in the powder [10]:

$$(d_{active} / y) = (3\sqrt{(6\times c_v)/\pi}) \times \sqrt{(2\times(1-a^{o})\times(R_b/x)+1-(a^{o})^2})$$

where a^{o} : a/x; c_v : solid particle concentration, % volume; a: minimum distance between two balls, m; R_b: ball diameter, m; x: powder particle size, m.

4. Results and Discussion

The effect of the powder particle size in terms of the powder/ball mass ratio is shown in Figs. 9-11 for 10, 5, and 1 h digestion time. Notably, the color of the powder changed to nearly black for 1:20 powder/ball ratio after a long digestion time. To decrease the pressure in the mill, an air hole used for material loading was opened. From Table 1, it is observed that the smallest average $CaCO_3$ powder particle size was obtained in test 4 with a 1:20 powder/ball ratio and 10 h digestion time, and the average powder size was 0.1 mm. Here, 10% of the particles are smaller than 0.05 mm, and 90% of the particles are smaller than 0.283 mm. As the digestion time increases and moves to the left of the total dispersion curve, the powder size becomes smaller.

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Table 1. $CaCO_3$ powder particle sizes for different digesting conditions

Test No.	Powder/Ball	Digestion time (h)	d_{active} / y (0.05 mm)	d_{active} / y (0.1 mm)	d_{active} / y (0.9 mm)
1	1:40	10	0.228	0.080	0.521
2	1:40	5	0.239	0.085	0.524
3	1:40	1	0.318	0.090	0.857
4	1:20	10	0.150	0.051	0.285
5	1:20	5	0.259	0.076	0.791
6	1:20	1	0.306	0.081	0.761
7	1:10	10	0.219	0.071	0.551
8	1:10	5	0.273	0.080	0.878
9	1:10	1	0.463	0.094	1.351
10	1:5	10	0.328	0.085	0.956
11	1:5	5	0.359	0.088	1.218
12	1:5	1	0.576	0.091	1.637

When the influence of powder particle size on powder/ball mass ratios was investigated, it was observed that the 1:20 powder/ball ratio was the critical value for the loading conditions in this study (Fig. 9-11). However, it was observed that a sufficiently small powder particle size was also achieved after 60% total dispersion values for 5 h and under 1:40 powder/ball ratio conditions. Under these conditions, the average powder size is closer to the size obtained by the 1:20 ratio. The frequency curve for 1 h digestion almost coincides with the total frequency curves for powders produced by 1:20 and 1:40 ratios (Fig. 10). For a digestion time of 10 h, the powder size corresponding to a powder/ball ratio of 1:20 was smaller than that corresponding to a powder/ball ratio of 1:40 (Fig. 9). Thus, a 1:40 powder/ball ratio did not ensure an advantage under the present these loading conditions.

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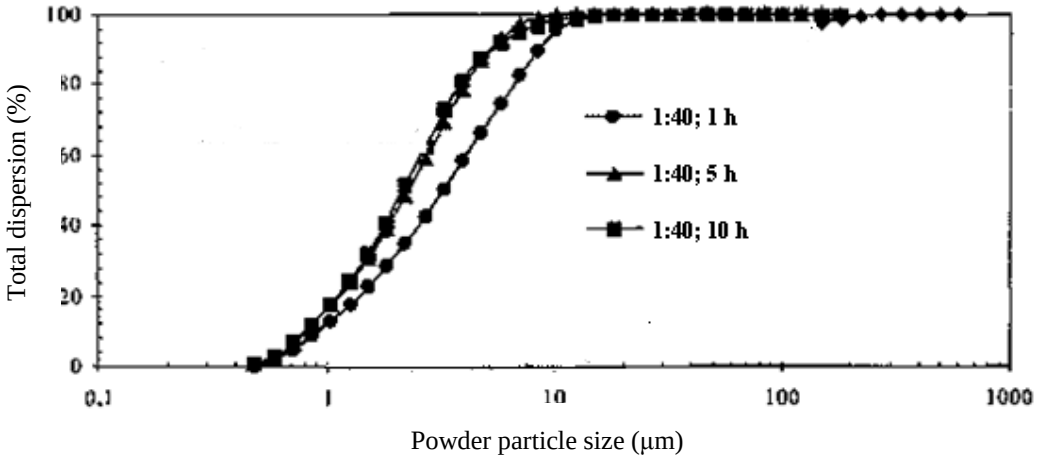


Figure 5. Powder size vs. digestion time. (1:40 powder/ball ratio)

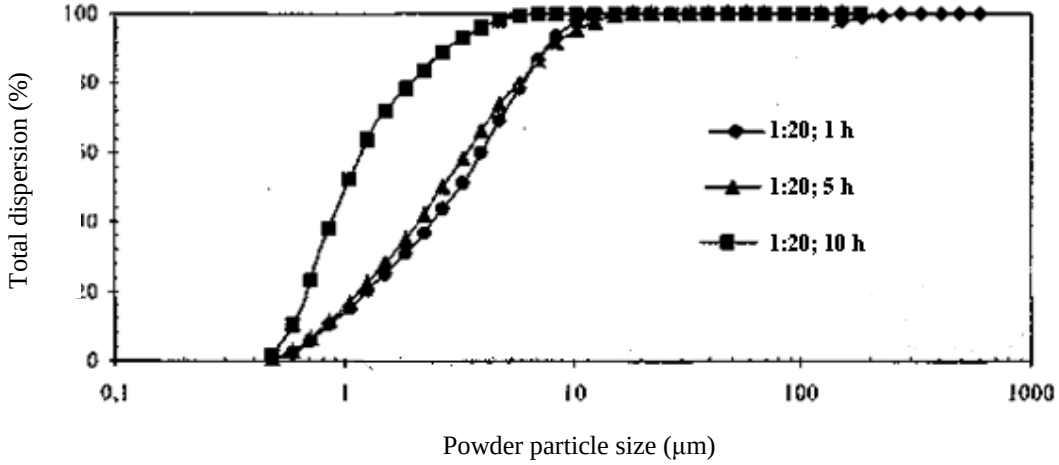


Figure 6. Powder particle size vs. total dispersion (1:20 powder/ball ratio)

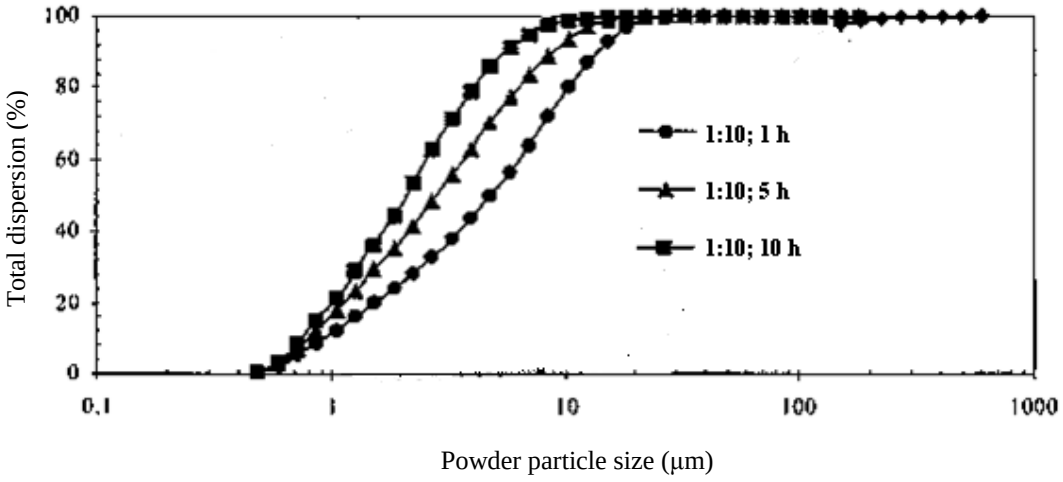


Figure 7. Powder particle size vs. total dispersion. (1:10 powder/ball ratio)

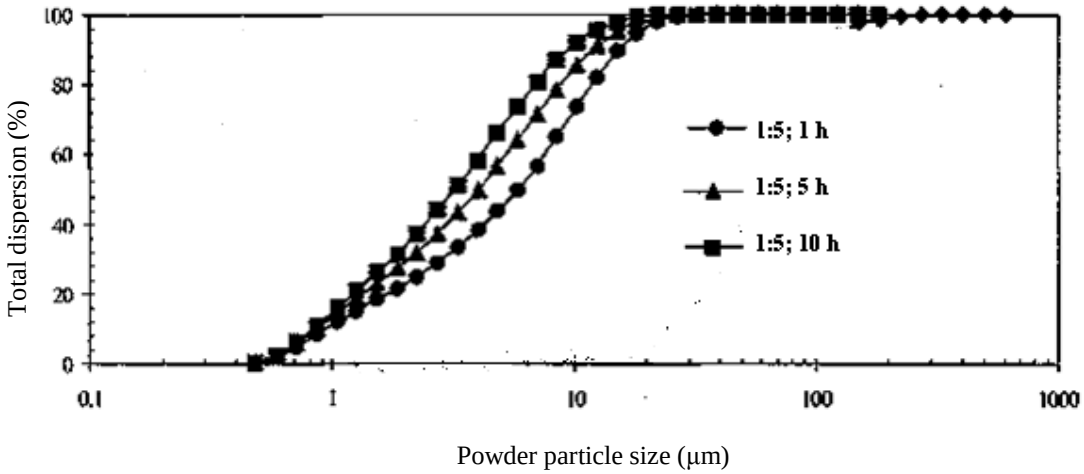


Figure 8. Powder particle size vs. total dispersion. (1:5 powder/ball ratio)

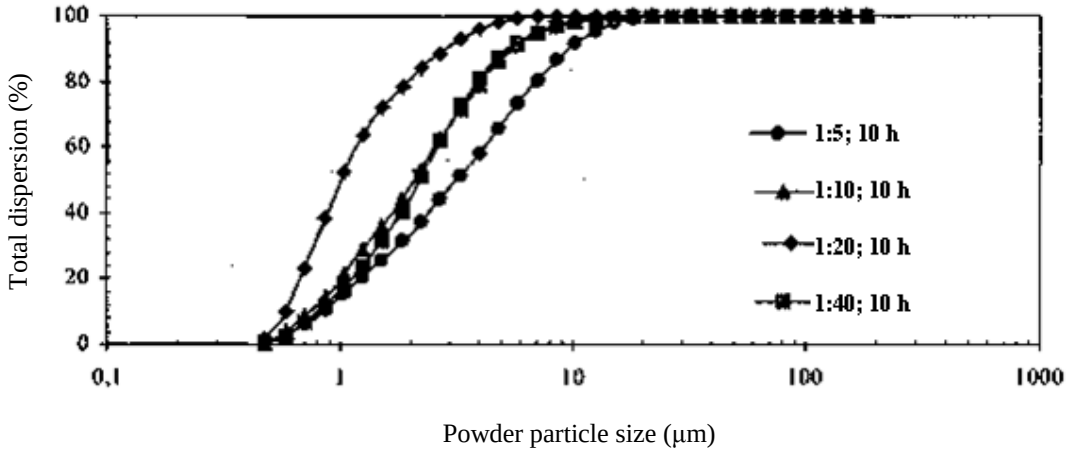


Figure 9. Powder particle size vs. total dispersion. (10 h)

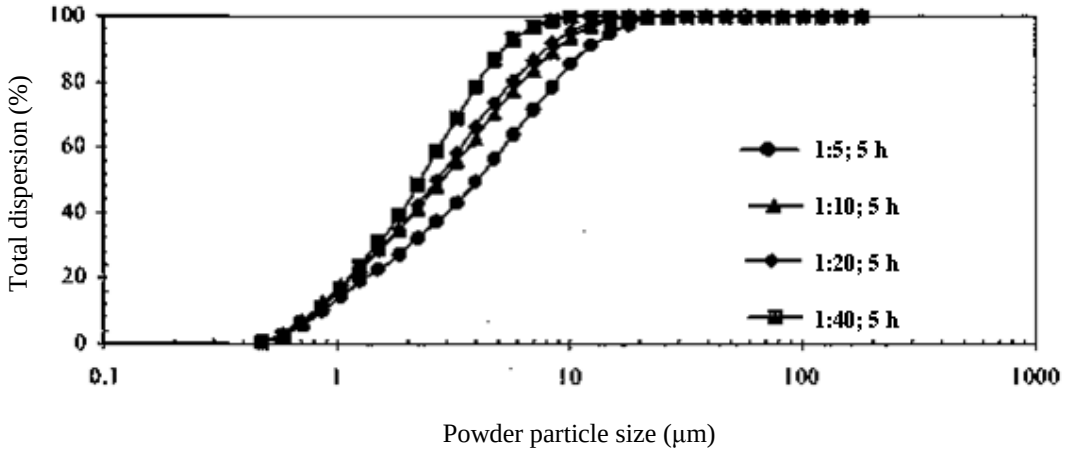


Figure 10. Powder particle size vs. total dispersion. (5 h)

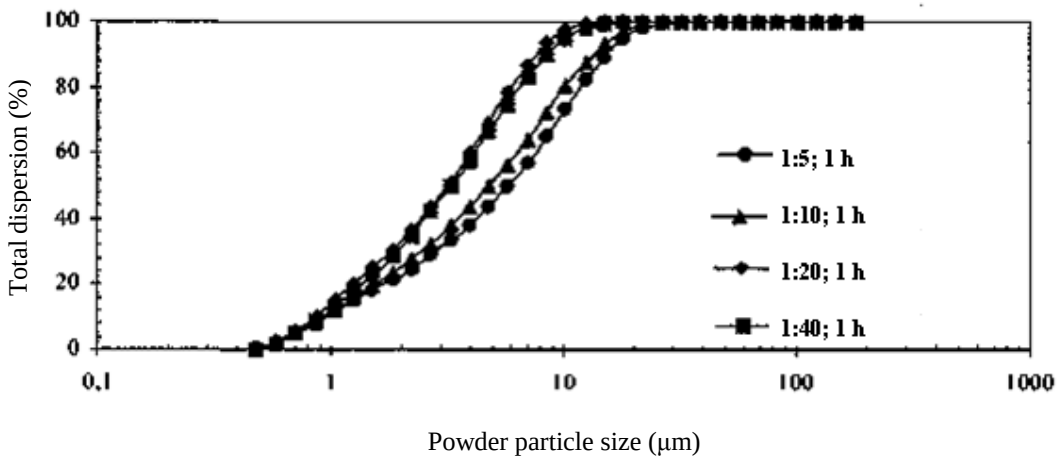


Figure 11. Powder particle size vs. total dispersion. (1 h)

4. Conclusions

In industries where filling materials are used as secondary raw materials, processing filling materials before their use is a challenge. In this study, we analyzed this challenge and concluded that uniform sized balls should be used in a ball mill for processing the raw material, and the average diameter of the balls used for digestion in a mill should be 55 mm.

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