XVI International Mineral Processing
and Recycling Conference
28-30 May 2025, Belgrade, Serbia

DOI: 10.5937/IMPRC25632T Original research article

INVESTIGATION OF ULTRA-FINE GRINDING OF AGGLOMERATED BASALT DUST

Paweł Tomach[1#], 0000-0001-6133-642X,
Jacek Feliks[1], 0000-0002-5653-1674,
Marta Łuczak[2], 0009-0007-3209-3589,
Grzegorz Fabijański[2], 0009-0003-1963-0811,
[1]AGH University of Krakow, Kraków, Poland
[2]Trzuskawica S.A., Sitkówka, Poland

ABSTRACT – This paper presents preliminary results of experimental research on ultra-fine grinding of agglomerated basalt dust using a laboratory vibratory mill. The main objective was to maximize the fraction of particles smaller than 10 µm. A series of tests were performed using various combinations of grinding media (12.0 mm, 17.5 mm, and a 50/50 mix), different grinding durations, and grinding additives. The effects of ultrasonic disintegration during particle size analysis were also investigated to assess agglomeration. The most favorable outcome was achieved with a mixed set of grinding balls (Ø12.0 mm and Ø17.5 mm) combined with 0.4% propylene glycol. This configuration led to a significant increase in the sub-10 µm fraction from 25.4% in the feed material up to 70.5% after 60 minutes of grinding. Despite the challenges associated with the high initial moisture content of the raw material and the tendency for particle agglomeration during dry grinding, the results demonstrate the high potential of vibratory mills for the efficient production of fine basalt powder suitable for environmental and agricultural applications.

Keywords: Ultra-Fine Grinding, Basalt Dust, Vibratory Mill, Grinding Additives, Particle Size Distribution.

INTRODUCTION

In the face of increasing challenges related to environmental degradation, the need for sustainable development, and the growing importance of recycling, ultra-fine grinding of mineral raw materials with high application potential is gaining significance. One such material is basalt with a particle size below 10 µm, whose unique physicochemical properties offer a wide range of applications across various fields [1–3].

Ultra-fine grinding enables the production of materials with a large specific surface area. In the case of basalt, this results in increased reactivity and, consequently, enhanced availability of mineral components, making the resulting basalt powder an attractive additive in agriculture, construction (e.g., concrete admixtures), and environmental protection applications [1,4]. However, achieving such fine particle sizes requires the selection of an appropriate type of mill [5] and the optimization of technological process parameters.

[#] corresponding author: tomach@agh.edu.pl

EXPERIMENTAL

In order to select the basic technological parameters for the grinding process and for laboratory testing in vibratory mills (i.e., chamber filling ratio, type of grinding media, and feed quantity), it was necessary to determine three key physical properties of the ground material: moisture content, loose bulk density, and particle size distribution. The material subjected to grinding was basalt dust (below 300 µm) originating from the dedusting station of a mineral processing plant. It had been stored without roofing, which led to significant moisture absorption and resulted in the formation of a slurry-like mass. The high moisture content caused agglomeration and solidification of the material into lumps with maximum dimensions reaching 80–100 mm. The appearance of the material before and after drying is shown in Figure 1.

Moisture Content

The moisture content of the material was determined by drying a prepared sample in a laboratory dryer at a temperature of 110°C until complete dryness was achieved. Based on the measurements, the moisture content of the received material was determined to be 16.6% ±0.1.

Figure 1 Fine basalt dust before and after drying

Bulk Density

The loose bulk density was determined in accordance with the PN-EN 1097–3:2000 standard, which is commonly used in aggregate testing. The bulk density of the dried material, calculated as the average of four measurements, was 1.10 ± 0.02 kg/dm³.

Feed Particle Size Distribution

The particle size distribution of the fine basalt dust was determined after drying and disintegration of the agglomerated material using an impact (paddle) crusher. The grain size distribution of both the feed and the milled products was analyzed using a laser diffraction method with the Malvern Mastersizer 3000, applying wet measurement with the "Hydro EV" dispersion unit. The particle size distribution of the feed material for the grinding process is presented in Figure 2.

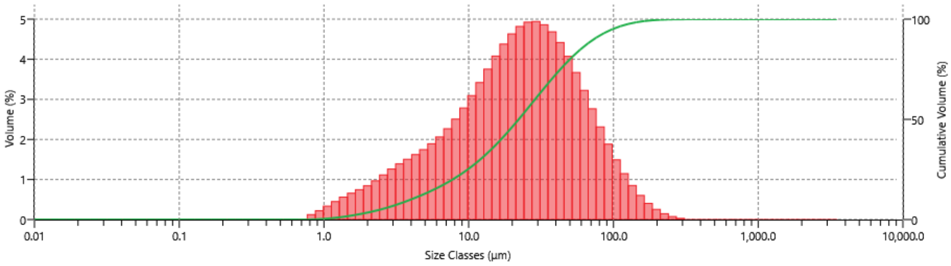

Figure 2 Particle size distribution of basalt before grinding

Vibratory Mill Test Stand

Experimental grinding tests were carried out using a laboratory-scale vibratory mill operating in batch mode. A schematic view of the vibratory mill test stand is presented in Figure 3 [6]. The main technical parameters of the test stand are summarized in Table 1.

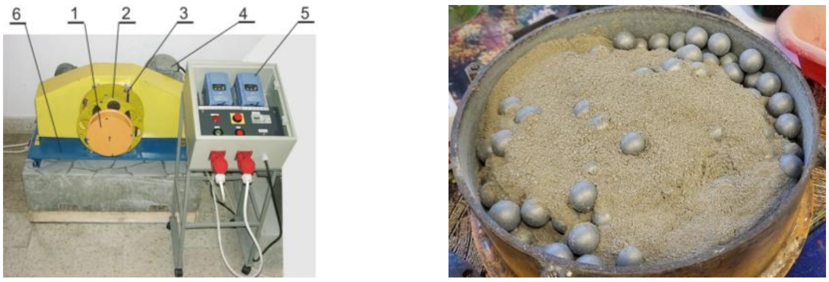

Figure 3 Laboratory vibratory mill test stand and view of the chamber interior with the ground material: 1 – chamber, 2 – chamber holder plate, 3 – drive module, 4 – vibrator motor, 5 – control and power system, 6 – supporting structure

Table 1 Basic parameters of the vibratory mill test stand

Parameter Name	Unit	Value
Amplitude of chamber vibrations	mm	3÷14
Frequency of chamber vibrations	Hz	4÷18
Filling degree of the chamber	%	10÷90
Power of vibrator drive motor	kW	3,5

Method and Implementation of Grinding Process Research in a Vibratory Mill

A steel chamber with a diameter of 0.21 m and a smooth lining was chosen for the experiments. These diameters and linings are typical of the smallest industrial vibratory mills. Steel balls were used as working elements. The grinding process was conducted dry, in an air environment. During the grinding, attempts were made to apply two grinding process activators, namely: ethylene glycol and propylene glycol.

The following mill operating parameters were adopted:

– Chamber vibration frequency: 16 Hz;

- Vibration amplitude: 6 mm – circular,
- Steel chamber with an internal diameter of 210 mm and a working volume of 2.2 dm³.

The ultra-fine grinding trials were conducted for the following technological variants:

a) Grinding set A1: Ø 17.5 mm;
b) Grinding set A1: Ø 17.5 mm with the use of a grinding activator (propylene glycol);
c) Grinding set A2: Ø 12.0 mm with the use of a grinding activator (ethylene glycol);
d) Grinding set A3: mixture of Ø 12.0 mm and Ø 17.5 mm (50/50) with the use of a grinding activator (propylene glycol).

RESULTS AND DISCUSSION

a) Grinding set A1: Ø17.5 mm

In order to determine the grinding kinetics, for the first technological variant, grinding times of t: 2.5, 5.0, 10.0, and 20.0 minutes were adopted.

The results of the granulometric parameters of the grinding products for this technological variant are presented in Table 2.

Table 2 Grinding results for test BD-A1

Sample Symbol	Grinding Time, [min]	Control Grain Size, [µm]			Class 0÷63µm, [%]	Class 0÷10µm, [%]
		d10	d50	d90		
Feed: BD-Nadawa	0	3,97	22,1	73,2	86,52	25,41
BD-A1-t2.5	2,5	3,51	19,7	59,8	91,11	27,98
BD-A1-t5.0	5,0	3,28	17,5	53,5	93,47	31,80
BD-A1-t10.0	10,0	2,70	15,0	44,1	96,95	36,79
BD-A1-t20.0	20,0	2,52	13,8	40,3	98,09	39,07

During grinding, excessive coating (coating of the grinding elements and chamber with the ground material) was observed, which led to a slowdown in the grinding process, especially after exceeding the grinding time of 10 minutes. Therefore, in the next experiment, it was decided to conduct the test using a grinding activator – polypropylene glycol.

b) Grinding set A1: Ø17.5 mm with the use of a grinding activator (propylene glycol)

The grinding activator (propylene glycol), which is intended to prevent excessive agglomeration of finely ground particles, was added to the chamber in an amount of 0.2% by mass. After 20 minutes of grinding, excessive agglomeration of the ground material was observed, so it was decided to increase the glycol amount by an additional 0.2% (BD-A1-G0.2x2).

The results of the granulometric parameters of the grinding products for this technological variant are presented in Table 3. In this table, samples marked with blue color and the symbol "US" refer to the particle size analysis in which ultrasound was used—this was done to demonstrate the occurrence and breakdown of particle agglomerates.

Table 3 Grinding results for test y BD-A1-G

Sample Symbol	Grinding Time, [min]	Control Grain Size, [µm]			Class 0÷63µm, [%]	Class 0÷10µm, [%]
		d10	d50	d90		
Feed: BD-Nadawa	0	3,97	22,1	73,2	86,52	25,41
BD-A1-G0.2-10	10	2,75	14,9	44,5	96,59	36,76
BD-A1-G0.2-20	20	2,80	13,4	39,2	97,99	39,48
BD-A1-G0.2x2-30	30	2,22	11,1	33,8	99,19	46,44
BD-A1-G0.2x2-30+US2x60s	*30 US*	*2,11*	*10,2*	*32,1*	*99,41*	*49,45*
BD-A1-G0.2x2-30+US3x60s	*30 US*	*1,97*	*9,38*	*31,1*	*99,59*	*52,15*
BD-A1-G0.2x2-30+US4x60s	*30 US*	*1,90*	*8,98*	*31,3*	*99,41*	*53,51*

c) Grinding set A2: Ø12.0 mm with the use of a grinding activator (ethylene glycol)

In the next stage of the research, to examine the effect of grinding ball diameter on the grinding parameters, steel balls with a diameter of 12 mm were used as the grinding set. The experiment was conducted with a grinding activator – ethylene glycol. Based on the previous research results, grinding times of 20, 40, and 60 minutes were adopted for this trial. After 40 minutes of grinding, it was decided to add a commercial product called AEROSIL. The results of the granulometric parameters of the grinding products for these trials are presented in Table 4.

Table 4 Grinding results for experiment BD-A2-GE

Sample Symbol	Grinding Time, [min]	Control Grain Size, [µm]			Class 0÷63µm, [%]	Class 0÷10µm, [%]
		d10	d50	d90		
Feed: BD-Nadawa	*0*	*3,97*	*22,1*	*73,2*	*86,52*	*25,41*
BD-A2-GE0.2-20	20	2,90	13,9	32,5	100,00	36,60
BD-A2-GE0.2+.02-20+20	40	2,30	11,5	34,1	99,03	45,11
BD-A2-GE0.2+.02-20+20-US4x60s	*40 US*	*1,69*	*7,05*	*23,3*	*100,00*	*62,07*
BD-A2-GE0.4-T60-Aeo1	60	2,19	11,2	35,1	99,23	46,42
BD-A2-GE0.4-T60-Aeo1-US4x60	*60 US*	*1,56*	*6,64*	*21,6*	*100,00*	*63,48*
BD-A2-GE0.4-T60-Aeo1-US6x60	*60 US*	*1,49*	*6,33*	*21,1*	*100,00*	*64,63*
BD-A2-GE0.4-T60-Aeo1-US8x60	*60 US*	*1,43*	*5,94*	*19,7*	*100,00*	*66,65*

d) Grinding set A3: mixture of Ø12.0 mm and Ø17.5 mm (50/50) with the use of a grinding activator (propylene glycol)

In the next stage of the research, to examine the effect of grinding media diameter on the grinding parameters, a mixture of steel balls with diameters of 12.0 mm and 17.5 mm in a 50/50 mass ratio was used as the grinding set. Based on the previous research results, grinding times of 20, 40, and 60 minutes were adopted.

The results of the granulometric parameters of the grinding products for these trials are presented in Table 5.

Table 5 Grinding results for experiment BD-A3-

Sample Symbol	Grinding Time, [min]	Control Grain Size, [µm]			Class 0÷63µm, [%]	Class 0÷10µm, [%]
		d10	d50	d90		
Feed: BD-Nadawa	*0*	*3,97*	*22,1*	*73,2*	*86,52*	*25,41*
BD-A3-GP0.4-20	20	2,42	11,8	37,9	98,38	44,56
BD-A3-GP0.4-20-US 8x60	*20 US*	*1,83*	*7,49*	*22,6*	*100,00*	*60,21*
BD-A3-GP0.4-40	40	2,24	11,6	33,1	99,86	44,90
BD-A3-GP0.4-40-US8x60	*40 US*	*1,61*	*6,64*	*19,3*	*100,00*	*63,99*
BD-A3-GP0.4-60	60	2,22	11,3	36,7	98,79	46,03
BD-A3-GP0.4-60-US8x60	*60 US*	*1,42*	*5,56*	*17,6*	*100,00*	*69,53*
BD-A3-GP0.4-60-US14x60	*60 US*	*1,34*	*5,24*	*17,0*	*100,00*	*70,87*

CONCLUSION

The conducted preliminary research on the ultra-fine grinding of basalt demonstrated a high potential of vibratory milling for this type of material – while maintaining standard mill operating parameters (vibration amplitude and frequency). Among the tested technological variants (grinding media sets and grinding activator), the most favorable was the grinding set A3, consisting of steel balls with diameters of 12.0 and 17.5 mm, used in combination with a grinding activator – polypropylene glycol – in the amount of 0.4% of the mass of the ground material.

For this variant, it was possible to increase the 0–10 µm grain size fraction from an initial content of 25.4% in the feed to:

- 60.2% - for a grinding time of 20 minutes;
- 64.0% - for a grinding time of 40 minutes;
- 70.5% - for a grinding time of 60 minutes;

Based on the conducted research, it can be concluded that ultra-fine grinding of basalt dust to achieve a very high content of the 0–10 µm grain size fraction is feasible in vibratory mills. However, it should be emphasized that dry grinding of material with such high initial moisture content may not be economically justified. Therefore, it is important to prevent exposure of materials intended for subsequent grinding to atmospheric conditions.

Considering the difficulties associated with the initial moisture content of the material and the specific challenges of ultra-fine dry grinding, the results obtained for fine basalt (BD) grinding can be considered satisfactory.

ACKNOWLEDGEMENT

The authors would like to express their gratitude to Trzuskawica S.A. Poland for financing the conducted research.

REFERENCES

1. Richardson, J.B. (2024) Basalt Rock Dust Amendment on Soil Health Properties and Inorganic Nutrients—Laboratory and Field Study at Two Organic Farm Soils in New England, USA. Agriculture, 15, 52. doi:10.3390/agriculture15010052.
2. Conceição, L.T., Silva, G.N., Holsback, H.M.S., Oliveira, C.D.F., Marcante, N.C., Martins, É.D.S., Santos, F.L.D.S., Santos, E.F. (2022) Potential of Basalt Dust to Improve Soil Fertility and Crop Nutrition. Journal of Agriculture and Food Research, 10, 100443. doi:10.1016/j.jafr.2022.100443.
3. Beerling, D.J., Leake, J.R., Long, S.P., Scholes, J.D., Ton, J., Nelson, P.N., Bird, M., Kantzas, E., Taylor, L.L., Sarkar, B., et al. (2018) Farming with Crops and Rocks to Address Global Climate, Food and Soil Security. Nature Plants, 4, 138–147. doi:10.1038/s41477-018-0108-y.
4. Dalmora, A.C., Ramos, C.G., Querol, X., Kautzmann, R.M., Oliveira, M.L.S., Taffarel, S.R., Moreno, T., Silva, L.F.O. (2016) Nanoparticulate Mineral Matter from Basalt Dust Wastes. Chemosphere, 144, 2013–2017. doi:10.1016/j.chemosphere.2015.10.047.
5. Sidor, J., Foszcz, D., Tomach, P., Krawczykowski, D. (2015) Młyny wysokoenergetyczne do mielenia rud i surowców mineralnych. Cuprum: Czasopismo Naukowo-Techniczne Górnictwa Rud, 2.
6. Tomach, P. (2024) The Influence of the Grinding Media Diameter on Grinding Efficiency in a Vibratory Ball Mill. Materials, 17, 2924. doi:10.3390/ma17122924.