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The Properties of Mineral Additives Obtained by Collision Milling in Disintegrator

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Abstract. Mineral additives are materials which are used in wide range of industries including construction, cosmetics, agricultural and biotechnology. Such materials as plasters, paints, abrasives etc. are produced using mineral powders. Main qualities of mineral additives are purity of chemical composition, grading properties and shape factor. To obtain powder like material most common method is milling. One of most effective milling method for refining of brittle material is grinding by collision in disintegrator. One of advantage of this method is that high milling energy is transferred to the milling material in short period of time. In present research three types of mineral materials were treated in disintegrator with specific energy E_s applied 8.4 and 25.2 kWh/t: natural quartz sand 0.3/1mm, quartz-limestone 0.3/2.5mm sand and dolomite screenings 0/4mm. Results indicate that powder like material with d_{90} form 66 to 141 µm could be obtained at E_s 8.4 kWh/t while increase of E_s reduces d_{90} value to 48 to 72 µm and the milling efficiency was effected by the sand type.

Introduction

To obtain powder mineral additives often milling is used to reduce particle size distribution and morphology of obtained particles. Traditionally ball and planetary ball milling is applied, however, this method has its fair share of shortcomings: the difficult construction and high metal consumption, great wear of grinding parts, the product is exposed to intense heat, etc.

Grinding by collision is more effective method for refining of brittle material and an alternative for the mills that produce mineral supplements for construction mixtures could be the use of disintegrator technology where the material is milled not as a result of low-speed impact abrasion but rather as the result of a highly effective high-speed and high-intensity impact. [1]. The main kinetic parameter in the processing of a material in disintegrators is the specific energy of treatment E_s in kJ/kg or kWh/t, important both from the point of view of the grinding effect (grindability) and the economic aspect of the process. The rotation speed of grinding elements is regarded as one of the most important factors.

Unlike ball and planetary mills, disintegrator mills have a rather simple construction. Instead of many grinding details, it has two rotors with grinding elements, which revolve in opposite directions at high speed. A particle accelerated by the first rotor is sent into the opposing rotor. The relative velocity of the collision could occur at up to 200 m/s and beyond. The tensions generated in the particle during this impact may significantly surpass its tensile strength. The disintegration process is very short, and takes up a fraction of a second. During the disintegration of the particles a large amount of the new surface is formed, which has not had time to oxidise and is therefore extremely chemically active. Another benefit is the high quality of the blending of the processed components in the mixture, a process that could be performed simultaneously with the milling.

High-energy milling can be used to produce several different types of materials, including amorphous alloy powders, nanocrystalline powders, intermetallic powders, composite and nanocomposite powders, and nanopowders [2]. During high energy milling the mechanical activation of solids may appear, which results in enhanced reactivity of solids due to physicochemical changes induced by milling [3]. Nikashina et al. has reported that milling natural zeolites with energy rate below 0.5-0.7 kJ/g the dominant process is disintegration of zeolite particles and changes of bulk density while at higher energy milling amorphous phase prevails [4].

Gbureck et al reported that prolonged high-energy ball milling of β-tricalcium phosphate led to mechanically induced phase transformation from the crystalline to the amorphous state resulting with the thermodynamic solubility increase up to nine times and accelerated the normally slow reaction with water and such cements could reach compressive strength up to 50 MPa [5].

The high-energy ball milling of clay minerals resulted with changes of the size, morphology and structure and was followed by the change of the physico-chemical properties. The decrease of the particle size of the clay minerals resulted in significant increases in the specific surface area and cation exchange capacity values, and in the exposure of new, amphoteric surfaces, significantly changing the electrophoretic mobility while prolonged milling produced amorphous alumina-silicate aggregates [6]. Such mechanical activation could be applied in wide range of industries including construction industry where fine graded amorphous mineral materials could be used as supplementary cementitious materials or pozzolanic materials to increase the strength of cement based composites [7].

In current study the effect of natural quartz, dolomite and quartz-dolomite sand milling by collision in disintegration at different energy rates was researched. The morphology of obtained particles was observed and grading analysis performed.

Experimental Methods

Semi-industrial disintegrator milling system DSL-115 with direct operating system was used for collision milling of washed 0.3/1mm natural quartz sand (QS), washed 0.3/2.5mm natural quartz and limestone mixed sand (MS) and 0/4mm dolomite screenings obtained from crushing and washing dolomite rocks (DS). DSL-115 is given in Fig. 1 and it consist of control panel (I), feeding system (II), two electrical motors (III), rotors (IV) and output channel (V). Maximum size of feed material – 12 mm, maximum diameter of rotors – 480mm, nominal power 9.5 kW. Two treatment regimes with specific energy E_s 8.4 and 25.2 kWh/t were applied, which was realized by number of times sand was disintegrated through the milling system (1 and 3 times respectively). The chemical composition, physical and mechanical properties of tested sands is given in Table 1 and Table 2.

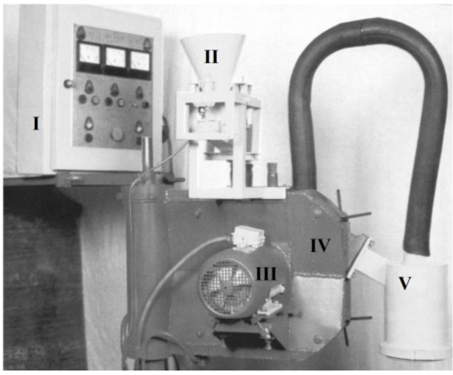

Fig. 1. Semi-industrial disintegrator milling system DSL-115 with direct operating system

Table 1. Chemical composition of selected sand

Chemical component	Content, wt.%		
	QS	MS	DS
SiO_2	96.8	72.5	1.2
Al_2O_3	1.42	5.18	0.3
Fe_2O_3	0.34	1.15	1.32
CaO	0.32	14.6	22.1
MgO	0.17	2.16	11.8
Na_2O	-	1.16	-
K_2O	-	2.78	-
SO_3	-	0.23	-
LOI, 1000°C	0.33	5.6	63.3

QS main component is SiO_2, while mixed sand contains SiO_2, CaO and Al_2O_3. Dolomite screening mainly contains CaO and MgO. Washed natural QS and MS contained fines <0.125mm below 0.3wt.%. 25wt.% of natural DS was fines <0.125mm with distribution of d_{90}, d_{50} and d_{10} values of fines 112.3µm, 53.2µm and 10.5µm respectively.

The particle size distribution was carried out on the vibratory sieve shaker Analysette 3 PRO for fractures between 0.05-2 mm and the laser diffraction particle sizer Analysette 22 Compact for fractures <50 µm. The morphology for obtained powder material was described with scanning electron microscope Tescan Mira/LMU. Specific surface area (S_{BET}) was determined by ESA analysis with using of PSKh instrument (Hodakov's Company, Russia).

Results and Discussion

The results of the milling experiments expressed by the grindability curves are given in Fig 2 a) and b). Preliminary milling of QS, MS and DS with specific energy E_s 8.4 kWh/t increases the fineness of natural sand from macro to micro scale. The particle size reduction comparing QS and MS was efficient for MS which contained quartz and limestone particles. The increase of milling energy to E_s 25.2 kWh/t effectively reduced mainly the size of largest particles. Higher milling energy E_s was necessary to reduce the QS particles with d_{10} below 10µm. The difference in the speed of decreases in the size of QS, DS and MS particles is explained by the differences in their mechanical properties (Table 2). The density of selected sand was nearly equal but hard and durable QS sand takes longer to grind. Results indicate that the particle size reduction after collision milling in disintegrator reduces the d_{10}, d_{50} and d_{90} values for all tested sand types (Table 3). The size reduction of softer and less durable DS and MS is much more immediate. Similarly, the S_{BET} of DS and MS increases faster than that of QS (Table 4). The dependence of the obtained material particles' new surface area on the $\underline{E}_s$ of treatment has been shown in the Table 4.

Table 2. Physical and mechanical properties of main minerals in tested sands

Property	Dolomite (DS)	Limestone (in MS)	Quartz sand (QS)
Specific Gravity, g/cm^3	2.6 to 2.7	2.5 to 2.7	2.8 to 2.9
Mohs Hardness	3.5 to 4	3 to 4	7
Compressive strength, MPa	40-170	60-170	200-250

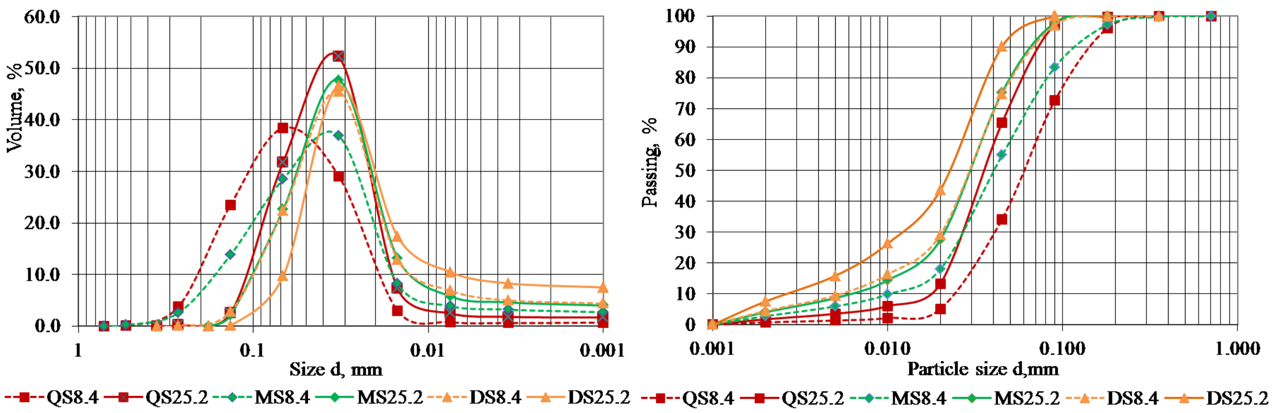

Fig. 2. Particle size distribution of disintegrated sand: a) Particle-size distribution of disintegrated sand; b) A cumulative particle size distribution of disintegrated sand

Table 3. The d_{10}, d_{50} and d_{90} of the particle size distribution of disintegrated natural quartz sand (QS), mixed sand (MS) and dolomite screenings milled with Es 8.4 kWh/t and 25.2 kWh/t

Sample	d_{10} (µm)	d_{50} (µm)	d_{90} (µm)
QS8.4	24.5	59.7	141.0
QS25.2	17.7	35.6	71.5
MS8.4	10.0	40.5	116.5
MS25.2	6.0	30.0	64.7
DS8.4	5.3	29.8	66.4
DS25.2	2.7	23.0	48.0

Table 4. Specific surface area S_{BET} of natural and milled sand

Sample	Specific surface area, cm^2/g		
	Initial	8.4 kWh/t	25.2 kWh/t
QS	<50	665	2716
MS	<30	2553	3571
DS	<30	3491	4166

As shown in Fig. 3, the medium size of particles (d/d_0), and the ratio of specific surface areas of the ground powders and initial sands (A/A_0) comply with the specific energies of grinding at various grinding parameters.

The morphology of disintegrated sands is given in Fig.4 and 5. The collision of QS particles in disintegrator at E_s 8.4kWh/t splits the largest particle creating plate like pieces and creates wide range of particles and QS particles has smooth surface while DS particles have angular shape and rough surface. The increase of E_s reduces the size of largest plate-like particles and grading of particles are more even.

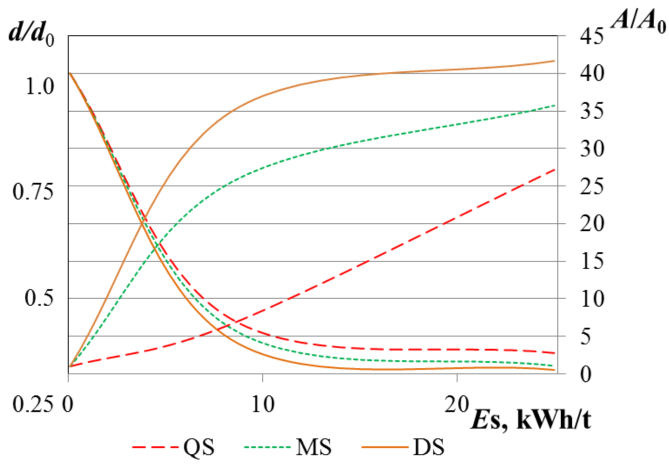

Fig. 3. Dependence of the ratio of median size d to the initial median size d_0 and the ratio of specific area A to its initial value A_0 on the specific energy of grinding.

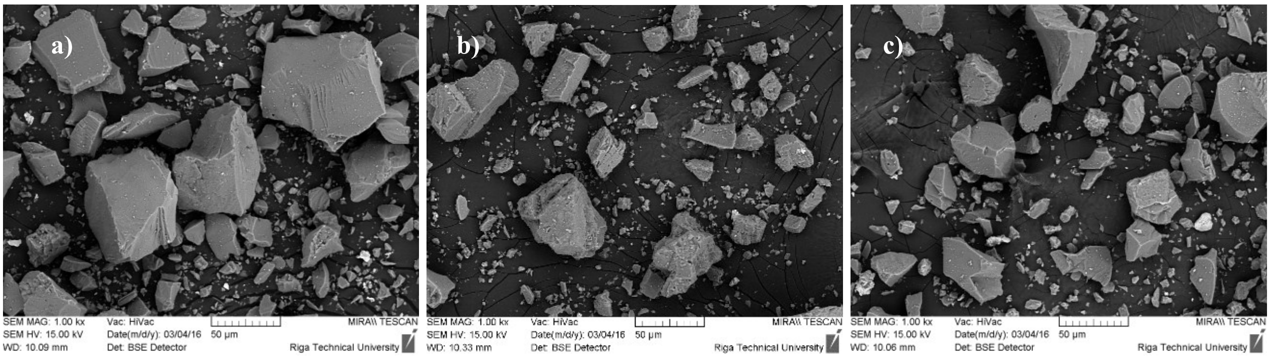

Fig. 4. Disintegrated sand particle morphology. Sand disintegrated with milling energy E_s 8.4 kWh/t: a) quartz sand 0/1mm, b) dolomite screenings 0/4mm and c) quartz-limestone sand 0.3/2.5mm

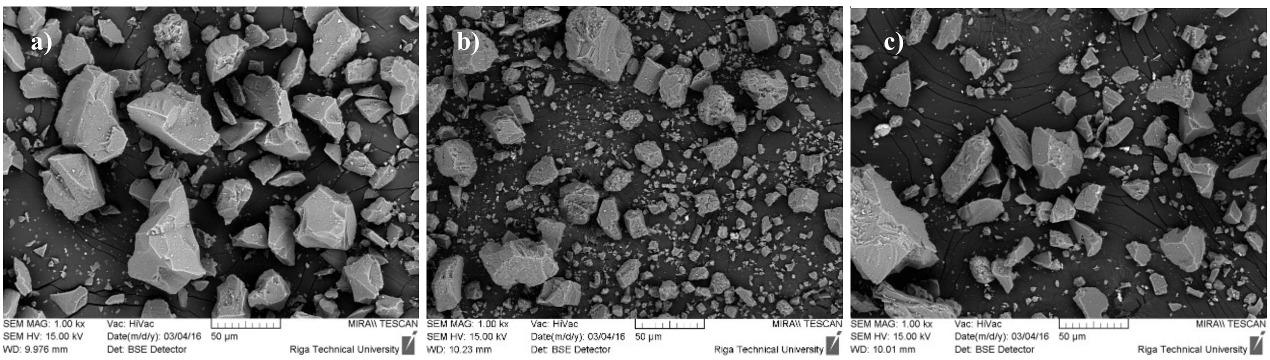

Fig. 5. Disintegrated sand particle morphology. Sand disintegrated with milling energy E_s 25.2 kWh/t: a) quartz sand 0/1mm, b) dolomite screenings 0/4mm, c) quartz-limestone sand 0.3/2.5mm

Conclusion

As a result of preliminary milling of natural quartz sand (QS), quartz-limestone sand (MS) and dolomite screenings (DS) with specific energy E_s 8.4 kWh/t increases the fineness of natural sand from macro scale to micro. The increase of milling E_s from 8.4 to 25.2 kWh/t reduces the sand particle size with efficiency regarded to the sand type which was milled. The DS and MS sand were milled with higher efficiency comparing with QS due to their natural mechanical and physical properties. The increase of milling E_s reduces the size of largest plate-like sand particles and grading of particles are more even. The desintegration milling of QS, MS and DS with E_s 25.2.kWh/t reduced the d_{50} value to 35.6, 30.0 and 23.0 µm and increased specific surface area to 2716, 3571 and 4166 cm^2/g respectively. Presented technology proves to be an easy and effective method to obtain micro-filler mineral material with wide range of application. The Obtained material could be used as microfiller in cement composites, biopolymers, ceramics etc. In following researches the effect of mechanical activation of disintegrated sand will be tested in cement composites.

Acknowledgments

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References

[1] D. Goljandin, P. Kulu, H. Käerdi, A. Bruwier, Disintegrator as Device for Milling of Mineral Ores, Mater. Sci. 11 (2005) 398-402.
[2] D.L. Zhang, Processing of Advanced Materials Using High-Energy Mechanical Milling, Prog. Mater. Sci. 49 (2004) 537-560.
[3] S.P. Mehrotra, T.C. Alex, G. Greifzu, R. Kumar, Mechanical Activation of Gibbsite and Boehmite: New Findings and their Implications, Trans. Indian Inst. Met. 69 (2015) 51-59.
[4] V.A. Nikashina, A.N. Streletskii, I.V. Kolbanev, I.N. Meshkova, V.G. Grinev, I.B. Serova, T. S. Yusupov, L.G. Shumskaya, Effect of Mechanical Activation on the Properties of Natural Zeolites, Inorg. Mater. 47 (2011) 1341-1346.
[5] U. Gbureck, Mechanical Activation and Cement Formation of β-tricalcium Phosphate, Biomat. 24 (2003) 4123-4131.
[6] N. Vdović, I. Jurina, S.D. Škapin, I. Sondi, The Surface Properties of Clay Minerals Modified by Intensive Dry Milling — Revisited, Appl. Clay Sci. 48 (2010) 575-580.
[7] G. Shakhmenko, A. Korjakins, G. Bumanis, Concrete with Microfiller Obtained from Recycled Lamp Glass, in 10th Int. Conf. Modern Building Materials, Structures and Techniques (2010) 280-284.