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Compressive strength of cement mortar affected by sand microfiller obtained with collision milling in disintegrator

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Abstract

The cement and concrete industries are continuously searching for new effective microfillers which could be obtained with relatively low cost, are wide spread and which improves most important concrete properties – strength and durability. Traditionally fine sand is used as inert mineral filler to the concrete mixture to make material structure compact in micro level. To obtain powder mineral filler material often milling is used to reduce particle size distribution and morphology of obtained particles. Traditionally planetary ball milling is applied, however this method is ineffective if large quantity of material should be prepared. Grinding by collision is more effective method for refining of brittle material and one of the few machines for material grinding by collision is disintegrator. Current research deals with natural quartz, dolomite screening and natural quartz-dolomite mixed sand milling by collision in disintegrator at different energy rates and tested as micro filler in portland cement mortar as partial sand replacement. The time factor of sand storage after disintegration was investigated to detect potential changes of sand particle properties during milling. Results indicate that cement mortar prepared with disintegrated sand right after disintegration provides compressive strength increase up to 20% comparing to reference mixture and the time factor of disintegrated sand is significant to remain increased compressive strength results.

Keywords: Disintegration milling; microfiller, cement mortar, quartz and dolomite sand

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1. Introduction

One of the predominant technologies in mining, in the production of minerals and in materials treatment is grinding and the ball mills are mainly used. Grinding by collision is more effective method for refining of brittle material and one of the few machines for material grinding by collision is disintegrator [1]. The grindability of different hardness mineral materials using milling by collision in disintegration do not differ in particle size after multiple milling while the materials with higher hardness showed a decrease in the mean particle size after one step milling about 20 % [1]. To better describe the properties of different powders the characteristics of granularity and morphology should be described [2].

During the milling mechanical activation of solids may appear, especially using high energy milling, which results in enhanced reactivity of solids due to physicochemical changes induced by milling [3]. For example, Nikashina et al. have reported that mechanical activation of zeolites depends from milling energy therefore at low energy rates (0.5-0.7 kJ/g) the dominant process of milling is disintegration of particles and changes of their bulk porosity while at higher milling energies the amorphization prevails [4]. Terada and Yonemochi indicated that disintegration time of talc lead to decrease of mean particle size and increase of specific surface area and also polar part of surface energy was increased by 41 % and hydrophilic surface was indicated [5].

Cao et al. reported that high energy ball milling of boiler bottom slag destroys crystal phase of mullite and quartz and Al-O-Si and Si-O-Si bonds are fractured while amorphous Al_2O_3 and SiO_2 phase increase, which improves slag activity [6]. The amorphous materials containing SiO_2 often has pozzolanic activity which are beneficial for Portland cement based materials [7]. The milling time of coal combustion bottom ash in planetary ball mill increase the activity of obtained microfiller therefore cement could be replaced by the amount from 20 to 40 % [8]. If high energy milling using disintegrator could activate quartz sand enhancing hardening processes in cement composites which leads to higher compressive strength than this would be beneficial for concrete industry and would provide alternative method of obtaining effective reactive microfiller.

The current investigation researches the effect of quartz, dolomite and mixed sand milling by collision in disintegration at different energy rates as micro filler in portland cement mortar as partial sand replacement. The time factor of sand after disintegration was tested to detect potential activation of sand particles during milling.

2. Materials and methods

2.1. Methods

Laboratory disintegrator DSL-115 was used for collision milling of natural quartz sand, natural quartz and dolomite mixed sand and dolomite screenings obtained from crushing and washing dolomite rocks. Disintegrator consisted of two rotor system, with diameter of rotors 480 mm and 3 pins/blades roads, the rotation velocity of rotors was up to 3000 rpm, the impact velocity was up to 150 m/s. Two specific energy treatment regimes were applied: sand was disintegrated with E_s 8.4 and 25.2 kWh/T.

Disintegrated sand particle size was determined with Laser Particle Sizer Analysette 22 NanoTec (FRITSCH GmbH) and calculation was performed according to Fraunhofer calculation and Automatic Modell Detection. Measurement interval was from 0.01 to 200 μm. The morphology of all six disintegrated sands was observed with scanning electron microscope "Tescan" "Mira/LMU Schottky".

The disintegrated sand was applied as microfiller in cement mortar at different ages after disintegration milling to detect the effect of time on sand reactivity in cement mortar. In first attempt when disintegrated sand was applied to cement mortar mixture was right after disintegration (0 days). Then after 2 days the mixing procedure was repeated with 2 day old disintegrated sand (2 days) and the same procedure was repeated after 28 days of disintegration (28 days). The consistence of fresh mortar (by flow table) according to LVS EN 1015-3 was determined. Prepared mortar mixture was cast in 40x40x160 mm prismatic moulds. Compressive strength of hardened mortar was tested according to LVS EN 1015-11 at the age of 7 days and 28 days

2.2. Materials

Two types of sand were used to prepare cement mortar. Both sands come from Saulkalne-S (Latvia) – pure natural quartz sand with fraction 0/1 mm and natural mixed quartz-dolomite sand with fraction 0.3/2.5 mm respectively. Cement mortar was prepared according to mixture compositions given in Table 1. Reference mixture contained cement to sand ratio 1:2 respectively. Quartz sand 0/1 mm and quartz-dolomite sand 0.3/2.5 mm ratio in mixture composition was 1:1. The water to cement ratio was constant for all mixtures and it was 0.4. Superplasticizer was added 0.425 % from the weight of cement. Quartz and quartz-dolomite sand was disintegrated with E_s 8.4 and 25.2 kWh/T and partially (10 wt.% from total amount of sand) replaced natural sand each. Mixture composition Q8 contained disintegrated quartz sand 0/1 mm with E_s 8.4 kWh/T and it replaced 20 wt.% of quartz sand, similar mixture composition Q25 contained disintegrated quartz sand 0/1 mm with E_s 25.2 kWh/T and replaced 20 wt.% of quartz sand 0/1 mm. Similar mixture composition M8 and M25 contained 10 wt.% of disintegrated 0.3/2.5 mm quartz-dolomite (M-mixed) sand with E_s 8.4 and 25.2 kWh/T and replaced quartz-dolomite sand by 20 wt.%. Additional natural dolomite screenings from dolomite quarry Birzi (Latvia) with fraction 0/4 mm was disintegrated with E_s 8.4 and 25.2 kWh/T and partially replaced 10 wt.% of quartz sand and quartz-dolomite sand (mixture compositions D8 and D25).

The mixing procedure of cement mortar contained of mixing all dry components together for 1 minutes using electrical one shaft hand mixer. Then calculated water with superplasticizer was added to the mixture and mixing continued until homogenous mixture was prepared. In total 2.5 l of mortar was prepared for each mixture composition.

Table 1. Mixture composition of prepared mortar with disintegrated sand.

Component	Mixture composition (mass ratio)						
	REF	Q8	Q25	M8	M25	D8	D25
Cement Cemex CEM I 42.5N	1	1	1	1	1	1	1
Quartz sand 0/1 mm	1	0.8	0.8	1	1	0.9	0.9
Quartz and dolomite natural sand 0.3/2.5 mm	1	1	1	0.8	0.8	0.9	0.9
Disintegrated quartz sand (E_s=8.4 kWh/T)	-	0.2	-	-	-	-	-
Disintegrated quartz sand (E_s=25.2 kWh/T)	-	-	0.2	-	-	-	-
Disintegrated quartz and dolomite mixed sand (E_s=8.4 kWh/T)	-	-	-	0.2	-	-	-
Disintegrated quartz and dolomite mixed sand (E_s=25.2 kWh/T)	-	-	-	-	0.2	-	-
Disintegrated dolomite screenings (E_s=8.4 kWh/T)	-	-	-	-	-	0.2	-
Disintegrated dolomite screenings (E_s=25.2 kWh/T)	-	-	-	-	-	-	0.2
Water	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Superplasticizer	0.425%*	0.425%*	0.425%*	0.425%*	0.425%*	0.425%*	0.425%*
Workability, Ø, mm	240	210	200	190	200	230	210

*from the amount of cement

3. Results and discussion

3.1. Properties of disintegrated sand

The particle size reduction due to collision milling using disintegrator is given if Table 2 and Fig.1. The d_{10} value of disintegrated sand shows that particle size of sand reduces with the increase of milling energy. The high energy disintegration of quartz sand (Q8 and Q25) reduces d_{10} value from 14.47 to 8.50 µm while for quartz-dolomite sand (M8 and M25) d_{10} reduces from 9.70 to 7.91 µm and dolomite sand (D8 and D25) from 6.62 to 4.58 µm respectively. The median value of particle (d_{50}) show slight particle size reduction for quartz sand – from 42.23 to 41.17 µm respectively while for M8 and M25 the d_{50} value reduces from 41.3 to 27.61 µm and for D8 and D25 from 28.48 to 19.94 µm respectively. Also d_{90} value show particle size reduction – 96.57 µm for Q8 to 81.16 µm for Q25, 93.67 µm for M8 to 54.08 for M25 and 66.84 µm for D8 to 38.59 µm for D25.

Table 2. d_{10}, d_{50} and d_{90} values of disintegrated sand

Sample	d10 (µm)	d50 (µm)	d90 (µm)
Q8	14.47 ± 0.23	42.23 ± 1.20	96.57 ± 1.37
Q25	8.50 ± 0.56	41.17 ± 0.38	81.16 ± 1.37
M8	9.70 ± 0.91	41.30 ± 1.86	93.67 ± 2.20
M25	7.91 ± 0.17	27.61 ± 0.52	54.08 ± 2.81
D8	6.62 ± 0.29	28.48 ± 1.60	66.84 ± 4.94
D25	4.58 ± 0.03	19.94 ± 0.46	38.59 ± 1.20

Laser grading analysis shows that dolomite screenings (D25) has the finest particle size if applied collision milling energy was E_s 25.2 kWh/T followed by quartz-dolomite sand (M25). Laser grading analysis show that collision milling of quartz sand (D8 and D25) has the lowest milling efficiency and particle size reduction. The range of particle size for Q8 was from 2.3 to 144 µm, for Q25 - from 2.2 to 118.5 µm. The fine particle range did not reduce in particle size while the largest particles were milled to finer particles. The quartz-dolomite sand particle range was from 2.7 to 142 µm for M8 and reduced from 2.5 to 78 µm for M25. Similar to pure quartz sand disintegration the finest particles was equal for both disintegrated sands while the largest particles reduced in size by increasing the specific energy applied for milling. Dolomite screenings disintegrated with E_s 8.4 kWh/T was with particles in range from 2.1 to 103 µm (D8) and reduced to range from 1.8 to 51 µm with applied milling energy E_s 25.2 kWh/T (D25).

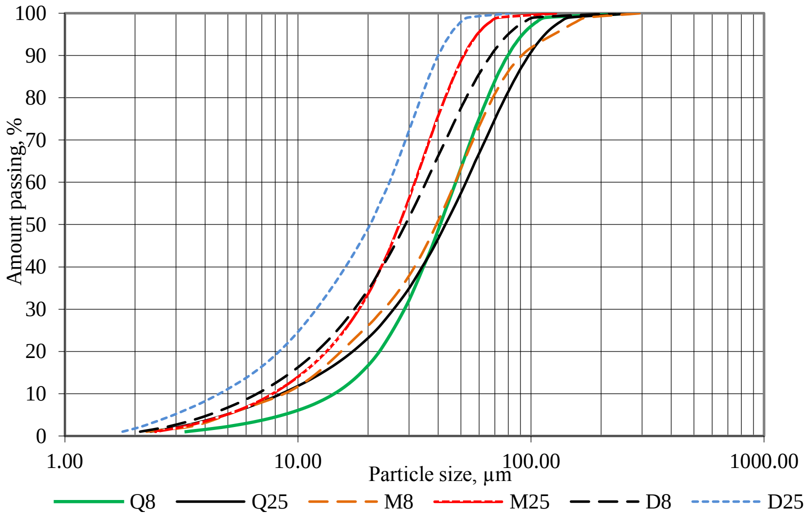

Fig. 1. Particle size distribution of disintegrated sand.

The morphology of disintegrated sand is given in Fig.2. SEM analysis indicate that largest particles have quartz sand Q8 and Q25 (Fig. 2 a and b); however increased milling energy reduces overall sand particle size. The quartz sand particles have plate like structure with smooth surface. The collision of particles in disintegrator splits the particle creating layered pieces. Increased of E_s reduces the layered particle size. Quartz and dolomite sand M8 and M25 (Fig. 2 c and d) have smaller particles compared to pure quartz sand which were observed with SEM. Two types of particles can be divided: particles with smooth surface, which probably are quartz particles and particles with rough surface, probably dolomite. Dolomite screenings contains particles which have rough surface, they are more angular and with the smallest particle size. The increased milling energy reduces particle size while shape factor and surface smoothness was not affected significantly.

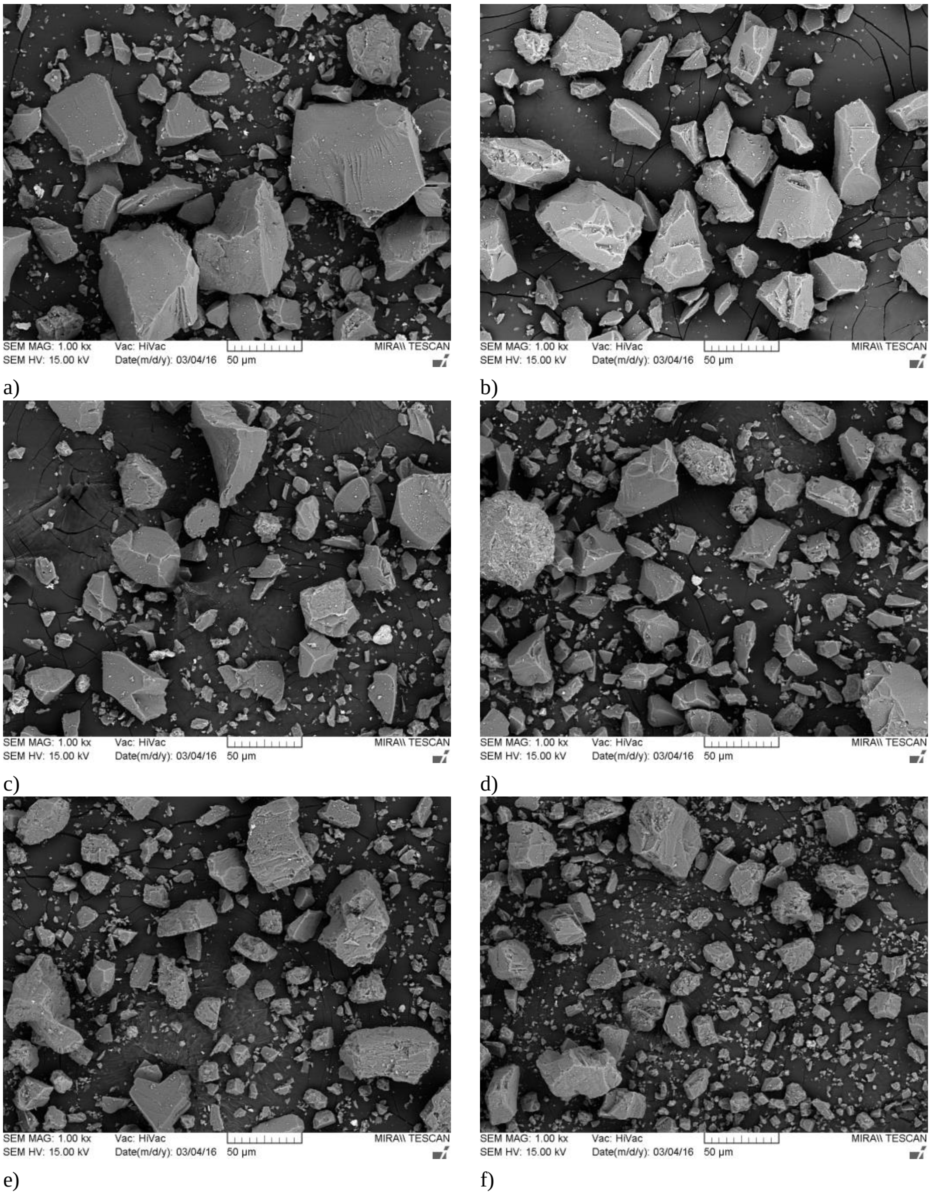

Fig. 2. Disintegrated sand particle morphology. Sand disintegrated with milling energy E_s 8.4: a) quartz sand 0/1 mm, c) quartz-dolomite sand 0.3/2.5 mm; e) dolomite screenings 0/4 mm. Sand disintegrated with milling energy E_s 25.2 kWh/T: b) quartz sand 0/1 mm; d) quartz-dolomite sand 0.3/2.5 mm; f) dolomite screenings 0/4 mm.

3.2. Fresh and hardened mortar properties

The fresh mortar workability dependence from disintegrated sand processing is given in Table 1. It was observed that partial sand replacement (10 wt.%) with disintegrated sand reduced workability from 240 mm to 190-230 mm. This could be due to the fine particles which were obtained after disintegration in the mixture composition therefore additional water is necessary to remain workability.

Obtained cement mortar compressive strength at the age of 7 days was 60 MPa and reached 65 MPa at the age of 28 days. For better comparison between different cement mortar mixtures relative compressive strength in % was calculated comparing to reference mixture (REF) strength. Relative compressive strength of cement mortar with different types of disintegrated sands at the age of 7 days is given Fig. 3. Relative compressive strength for REF mixture with compressive strength of 60 MPa was 100 %. It was detected that the age of disintegrated sand application in cement mortar was essential for high strength gain. The immediate application of disintegrated sand in cement mortar mixture could increase compressive strength up to 111 % for Q8 and up to 114 % for Q25. Quartz and dolomite sand was less effective and still increased compressive strength to 104 % and 109 % in mixture M8 and M25 respectively. Dolomite screening performed relative strength increase from 105 % for D8 to 107 % for D25. The specific energy increase for treating sand in collision milling in disintegration showed higher compressive strength in cement mortar compared with REF.

If disintegrated sand was applied after 2 days of processing sand the effectiveness of sand as microfiller reduced significantly. Compressive strength index increased to 104 % for mixtures with disintegrated quartz sand (Q8 and Q25), from 102 to 106 % for quartz and dolomite mixed sand (M8 and M25) and from 102 to 104 % for dolomite screening (D8 and D25). Prolonged storage of disintegrated sand up to 28 days even decreased compressive strength of cement mortar. For mixture composition Q8 it was 96 %, for Q25 – 103 %. Higher energy milling for quartz sand provided positive strength increase. Dolomite and quartz mixed sand reduced compressive strength to 97 and 99 %, but disintegrated dolomite screenings reduced strength to 96 and 97 %. Strength reduction after storage period could be explained by reduction of activity of disintegrated sand and active microfiller turns into the dust which traditionally deteriorates cement composite properties.

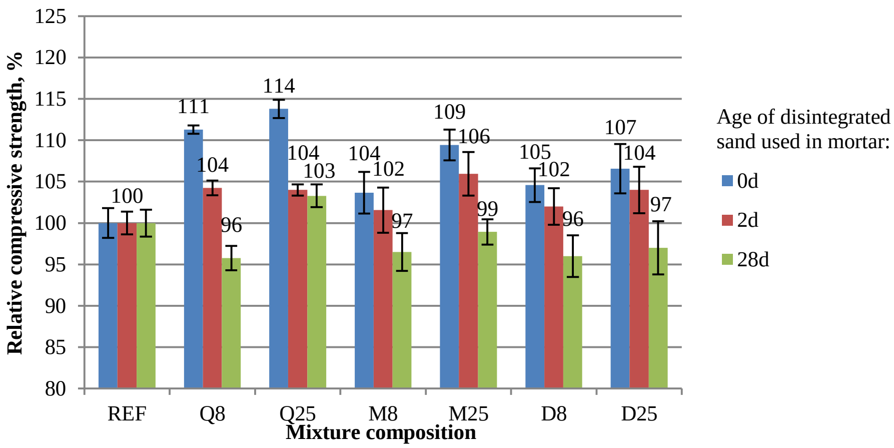

Fig. 3. Compressive strength index (%) of cement mortar at the age of 7 days made with 0, 2 and 28 day old sand after disintegration.

Similar tendencies remain for cement mortar at the age of 28 days (Fig.4). Compressive strength continued to increase for mixture composition Q8 and Q25 which was mixed right after disintegration of sand (0 days). Relative compressive strength increased to 117 % for Q8 and 120 % for Q25. For quartz and dolomite mixed sand compressive strength increased to 105 and 110 % (M8 and M25) and for mortar with dolomite screenings to 104 and 111 % (D8 and D25). Mortar samples prepared after 2 days of sand disintegration provided lower relative strength results comparing to mortar prepared after 0 days however results were higher comparing to REF: 111 % and 105 % for Q8 and Q25, 108 % for both M8 and M25 and 106 to 107 % for D8 and D25. Mortar prepared after 28 days of disintegration of sands showed decrease of relative compressive strength in most cases, similar to mortar properties at the age of 7 days. Compressive strength reduced from 96 to 99 % for all cases except for samples Q25 which remained similar to REF (101 %).

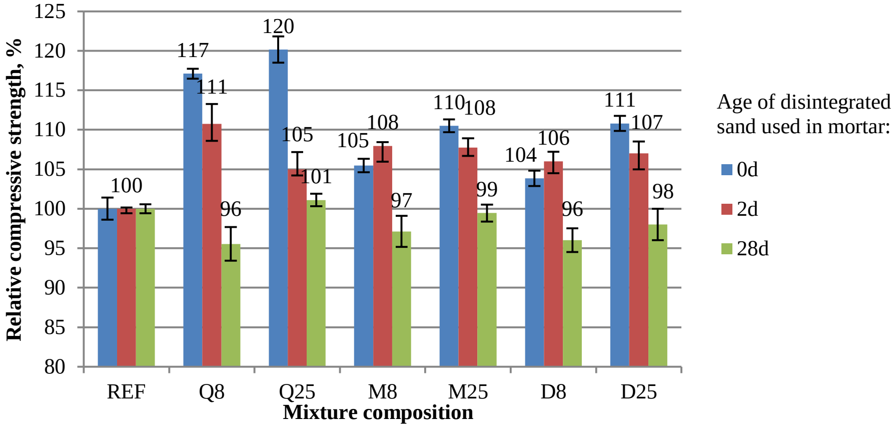

Fig. 4. Compressive strength index (%) of cement mortar at the age of 28 days made with 0, 2 and 28 day old sand after disintegration

4. Conclusions

Collision milling using disintegrator effectively reduces particle size of fine sand (0/4 mm) to micro levels (1.8 to 144 µm). The increase of specific energy from 8.4 to 25.2 kWh/T during milling reduces only largest particle size but did not reduce smallest particle range and was limited to minimum 1.8 µm. It was observed that the milling energy increase effectively reduced particle size of dolomite mineral sand while quartz sand particle size reduction was less effective. It was detected that the application time factor of disintegrated sand in cement mortar has the critical impact on mortars compressive strength: the highest strength of cement mortar was detected if disintegrated sand was applied in mixture composition right after disintegration. The activity of disintegrated sand decreases with time dramatically. Two days old disintegrated sands applied in cement mortar reduced the increase of compressive strength but was still higher (5 to 11 %) comparing to reference mixture while at the age of 28 days disintegrated sand deteriorates compressive strength (-1 to -4 %) and it was lower comparing to reference mixture. It was concluded that instant application of disintegrated sand could increase compressive strength of cement mortar up to 20% if disintegrated quartz sand with milling energy 25.2 kWh/T is used as partial sand replacement up to 10 wt.% in cement mortar mixture composition.

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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] P. Peetsalu, D. Goljandin, P. Kulu, V. Mikli, Micropowders Producted By Disintegrator Milling, Powder Metall. 3 (2003) 99–110.
[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] K. Terada, Physicochemical properties and surface free energy of ground talc, Solid State Ionics 172 (2004) 459–462.
[6] J. Cao, Y. Fang, R. Fan, Y. Wan, H. Qian, Y. Zhou, W. Zhu, Influence of mechanochemical effect on physical properties of boiler bottom slag, Cailiao Kexue yu Gongyi/Material Sci. Technol. 23 (2015) 111–114.
[7] I. Pundienė, M. Kligys, J. Šeputytė-Jucikė, Portland Cement Based Lightweight Multifunctional Matrix with Different Kind of Additives Containing SiO_2, Key Eng. Mater. 604 (2014) 305–308.
[8] D. Bajare, G. Bumanis, L. Upeniece, Coal Combustion Bottom Ash as Microfiller with Pozzolanic Properties for Traditional Concrete, Procedia Eng. 57 (2013) 149–158.