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Influence of Recycled Concrete Dust on the Properties of Self- Compacting Concrete (SCC)

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Concrete – composite material which economical effect mostly depends on the amount of binder material (usually cement), its type and fineness. Cement manufacturing generates great employment of energy resources. The demand for all kind of manufacturing natural resources are aimed to be reduced as much as possible. Alternative raw material resources are being introduced and tested together with increasing self-compacting concrete (SCC) popularity in Lithuania. Considering environmental requirements to reduce environment pollution according to ES 305/2011 regulation and importance of economic benefits it is aimed to investigate recycled concrete influence for self-compacting concrete durability properties. Assessing one of the main mechanical concrete property – compressive strength up to 1 year concrete hardening duration, it was observed, that replacing cement by concrete dust, practically no negative influence was observed. In some cases this replacement even improves concrete compressive strength (10 % concrete dust), except greater amount of additionally grinded concrete dust. In our case it was noticed, that replacing up to 10 % cement by concrete dust from 1.85 % to 2.09 % increases concrete closed porosity and predicted concrete resistance to freeze-thaw cycles increases up to 30 %. It allows to expect positive test results while real test would be carried out on the basis of Lithuanian standard LST 1428.17.

KEYWORDS: self-compacting concrete (SCC), crushed concrete, concrete dust, rheology, durability.

Introduction



It is necessary to ensure environmental pollution control together with sustainable industry development. Waste material produced in construction or demolition process is managed by valid legal regulating acts by European Union. It is aimed to use recycled materials for new products manufacture by creating long-term Lithuanian and European Union strategic waste management plans. Concrete dust emerges in concrete waste crushing procedure. It can help to reduce cement demand in concrete manufacturing and contribute to energy saving politics in long-term perspective (Sachdeva *et al.* 2013; Kürsat Esat Alyamaç *et al.* 2009).

In this paper properties of concrete products made by using SCC is being analysed while part of cement is replaced by recycled concrete dust. Assessing concrete compressive strength and resistance freeze-thaw cycles there are cases, when recycled coarse aggregates usage is ben-

eficial (Finoženok *et al.* 2009). It is possible to replace up to 30 % natural raw materials by crushed concrete aggregates. It was observed, that water demand for concrete mix increases, hardened concrete compressive strength decreases, water absorption increases when recycled concrete dust is used for concrete manufacturing in comparison to control specimens (McNeil *et al.* 2013; Bumanis *et al.* 2011). Mostly recycled concrete dust is utilized as construction waste and carried out to local dumps. It is possible to use this type of construction waste as fine and coarse aggregates in concrete production manufacturing process (Kazberuk *et al.* 2014). This principle helps to reduce natural raw materials demand up to 25 %, assessing slightly reduced concrete compressive strength and minimally increases shrinkage deformation. It is expected to manufacture concrete with the same or very similar properties by replacing part of cement with recycled concrete dust.

During the studies it was determined what recycled concrete dust can influence SCC manufacturing process. Cement is used as micro filler in flowing concrete mixes due to appropriate granulometric composition. In this case cement in concrete mixes is overdrawn and compressive strength is higher than required. Considering that sand in Lithuania is missing fine particles (0.125 mm), recycled concrete dust may be a solution for this shortage. In this case concrete mix granulometric composition become more smother. This could contribute to segregation and water separation problems (Topçu *et al.* 2009). Mostly manufactured SCC compressive strength classes are C30/37 and C35/45. Real compressive strength, which is mostly accessed greater than designed, and shrinkage deformations could be reduced by using recycled concrete dust.

Portland cement CEM I 42.5 R, produced by JSC „Akmenės cementas“, which specific surface – 360 m²/kg was used for this research. Five years old C30/37 crushed concrete dust was additionally sieved through 0.125 mm sieve. Part of emerged dust was additionally grinded in laboratory ball mill and sieved through the 0.125 mm sieve. Grinded and non-grinded dust, that particle size was smaller than 0.125 mm was used for research.

Grinded and non-grinded concrete dust specific surface was determined by Blaine method according to LST EN 196-6. Grinded concrete dust specific surface – 800 m²/kg (prevailing particles size 2.6 – 23 μm), non-grinded concrete dust specific surface – 500 m²/kg (prevailing particles size 23 – 50 μm). Crushed concrete particle size distribution was tested with a “Mastersizer 2000” apparatus. During the laser diffraction measurement, particles are passed through a focused laser beam. These particles scatter light at an angle that is inversely proportional to their size. The scattering of particles is predicted by the Mie scattering model. Measuring range is from 0.02 μm to 2000 μm. Particle size granulometric composition is given in Fig. 4 and Fig. 5. For fine aggregate “Kvesai” quarry sand fr. 0/4 was used, with bulk density 1670 kg/m³ and fineness module 1.61 and 0/1 fraction sand, which bulk density $\rho = 1450$ kg/m³, fineness modulus 2.91. For coarse aggregate gravel fr. 4/16 was used, with bulk density 1330 kg/m³. Hydration temperature changes in cement paste determined by pseudo adiabatic method.

For physical and mechanical concrete properties determination 100×100×100 mm concrete cubes and 100×100×400 mm prisms were cast. The compressive strength was determined according to LST EN 12390-3 and the relative shrinkage deformation determined by a length measuring apparatus incorporating a dial gauge capable of measuring the length accurately to 0.005 mm.

The general aim of the research was to find out the influence of grinded and non-grinded concrete dust for concrete durability properties. Cement amount in concrete mix was replaced 10 %, 20 %, and 30 % by concrete dust.

Different concrete mixes slump flow, slump flow up to 500 mm time, segregation properties and passing ability ratio was determined while different amount of grinded and non-grinded concrete dust was used as a replacement of cement in concrete mixes.

Materials and methods

Table 1

SCC concrete mixes for research

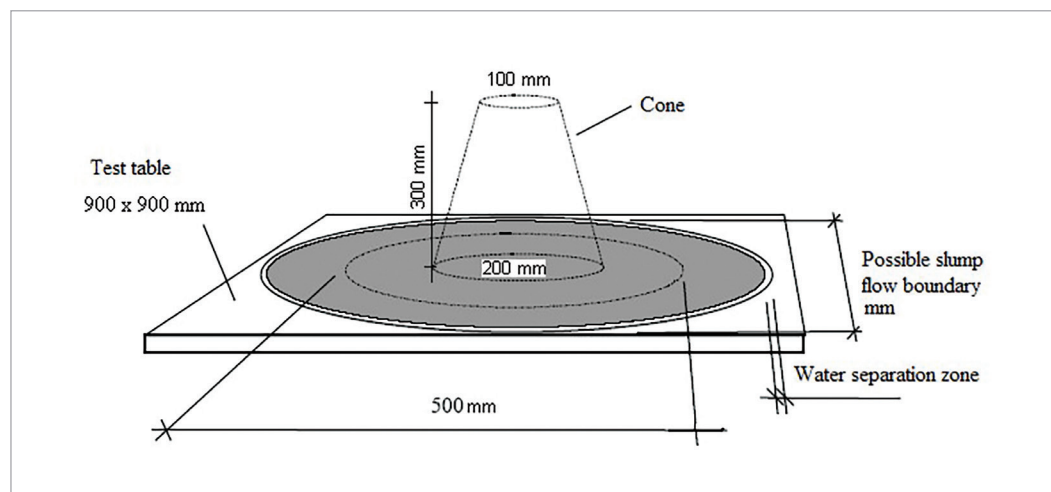
Composition No.	V/B	Water, l	Cement CEM I 42.5 R, kg/m ³	Fine aggregate, kg/m ³		Coarse aggregate, (Gravel) fr. 4/16, kg/m ³	Concrete dust Non grinded/grinded kg/m ³	Superplasticizer, kg/m ³	Stabilizer, kg/m ³
				Sand fr. 0/1	Sand fr. 0/4				
K	0.55	225	410	117	884	667	0.0/0.0	4.92	1.64
DN10	0.55	225	369	117	884	667	41/0.0	4.92	1.64
DN20	0.55	225	328	117	884	667	82/0.0	4.92	1.64
DN30	0.55	225	287	117	884	667	123/0.0	4.92	1.64
DM10	0.55	225	369	117	884	667	0.0/41	4.92	1.64
DM20	0.55	225	328	117	884	667	0.0/82	4.92	1.64
DM30	0.55	225	287	117	884	667	0.0/123	4.92	1.64

Note: V/B – water and binder (cement + concrete dust) ratio. DN – non-grinded concrete dust; DM – grinded concrete dust. K – control mix.

Aiming to set SCC slump flow, the standard Abrams cone (Fig. 1) was used. Tests were carried out according to LST EN 12350-8. According to LST EN 206 SCC slump flow must be ≥ 550 mm to 650 mm, while minimum SF1 class is declared.

Fig. 1

SCC mixes slump flow and its speed determination



Concrete mix slump flow index is two tests results average in 10 mm accuracy. Herewith, standard concrete mix cone slump flow up to 500 mm time describes viscosity of this type of concrete. Separate concrete mixes slump indexes is determined by a corresponding material flow equation No. 1 parameters (Gumuliauskas *et al.* 2004):

- moulding and form filling uniformity – viscosity;
- formed product stability, its segregation – marginal shear stress.

$$\tau = \tau_0 + \mu\gamma, \text{ Pa} ; \quad (1)$$

where:

τ – flowing material shear stress, Pa; γ – flow speed gradient, s^{-1} ; μ – structural liquid viscosity, Pa·s.

For concrete mix segregation evaluation „Three cylinders test“, method by German scientist Mioder's graduation work was used (Fig. 2)

Aiming to ensure quality leak though the wall, concrete mix was poured with 45° angle to slanted three parts cylinder. After 30 minutes mixes in all three parts of cylinder were washed off thorough 8 mm sieve, because coarse aggregate largest particles are 16 mm in diameter. In upper and lower cylinder parts the mass of washed off particles could not differ more than 15 %. L-box testing equipment is used for concrete mix passing ability assessment by ratio $h_2/h_1 \geq 0.80$.

Water need for normal consistency cement paste, heat dissipation temperatures in cement paste during hardening process and concrete compressive strength after 3, 7, 14, 28 and one year was determined using different amount of both types concrete dust.

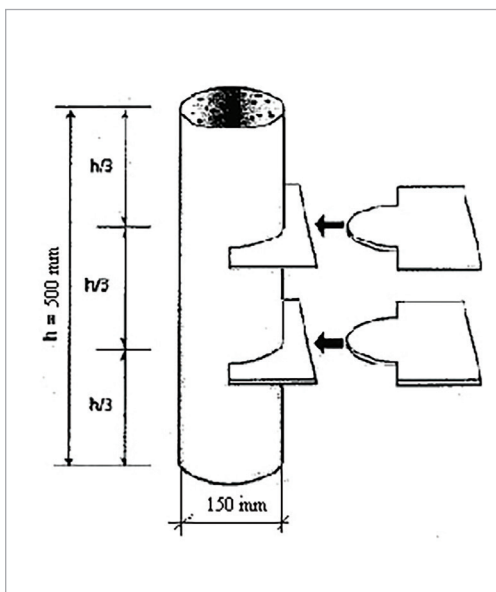


Fig. 2

Equipment for mix segregation index determination

According to water absorption kinetics concrete specimens porosity parameters were determined. Using GOST 12730.4–78 method (capillary) porosity, overall porosity and closed porosity (entrained air content) was set. Also pore size relative indexes were determined: λ – average pore size index and α – pore size uniformity index. This method is widely used to describe concrete pore structure, cavity and freeze-thaw cycles resistance prediction. Predicted freeze-thaw cycles number, which concrete will resist according to empiric dependence, while concrete resistance to freeze parameter K_f is known.

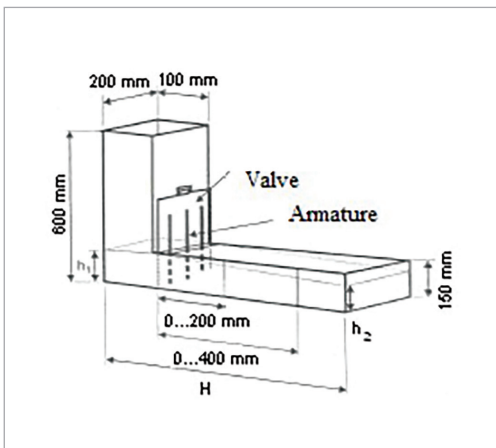


Fig. 3

„L-box“ testing equipment by LST EN 12350-10

To enlarge concrete dust specific surface (fineness) concrete dust was additionally grinded in ball mill. It was observed that optimal grinding duration is 30 minutes. Increasing grinding duration up to 45 minutes, particles specific surface enlarges very slightly. That is why grinding duration increasing becomes irrational due to demand for significantly larger amount of energetic resources. After cement is mixed with water and cements particles are moistened, mineral crystals start to solve and heat is emitted. It can be noticed concrete dust emits very small amount of heat, so, all in all, amount of emitted heat depends on cement amount in the system. Pursuing to determine influence of concrete dust to mixtures of cement and concrete dust setting, exothermal heat was monitored during hydration (Fig. 6, 7).

Results and discussions

Fig. 4

Granulometric composition of non-grinded concrete dust

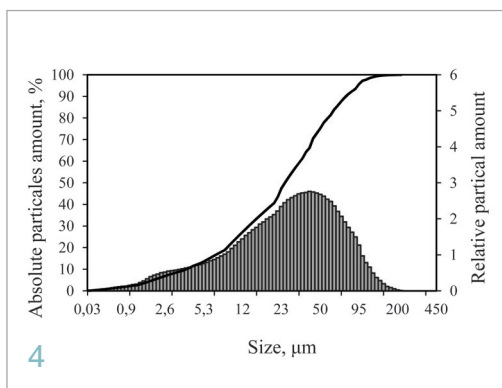


Fig. 5

Ranulometric composition of concrete dust after 30 min. of grinding

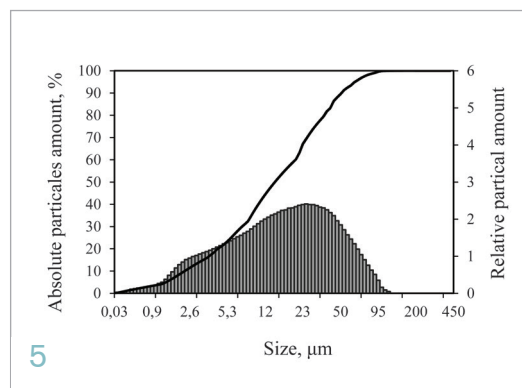


Fig. 6

Hydration temperature changes in cement paste using non-grinded concrete dust

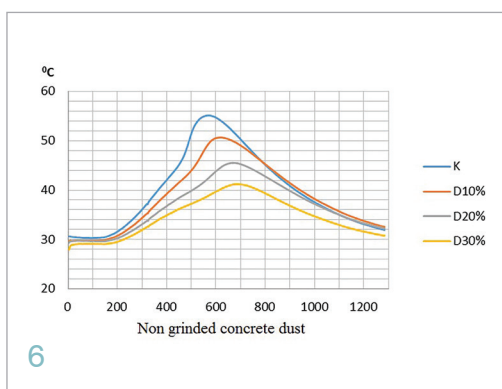
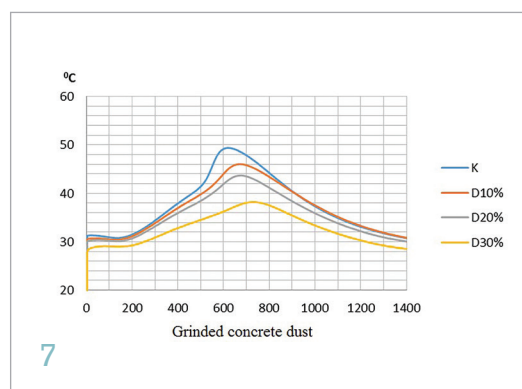


Fig. 7

Hydration temperature changes in cement paste using grinded concrete dust



Lower exothermal warmth emission tendency can be clearly noticeable when part of cement is replaced by concrete dust. In comparison to cement replacement by grinded concrete dust, exothermal warmth emission is slightly higher when cement is replaced by non-grinded concrete dust. Assuming obtained results, conclusion can be made, that concrete, for which production concrete dust was used is more suitable for massive constructions, where lower hydration temperature change will be sensed between inner and outer construction layers. For this reason it is possible to expect less construction cracks in both, outer and inner construction parts.

Table 2

Rheological properties indexes f concrete mix

Properties	Part of cement replaced by grinded and non-grinded concrete dust, %						
	0	10 DN	20 DN	30 DN	10 DM	20 DM	30 DM
Slump flow SF, mm and class	610/SF1	600/SF1	650/SF1	550/SF1	640/SF1	630/SF1	620/SF1
Segregation index, %	10.4	6.7	5.1	1.2	5.1	2.9	1.0
Slump flow up to 500 mm duration, s and viscosity class	3.5/VS2	3.0/VS2	2.5/VS2	4.5/VS2	2.0/VS2	2.5/VS2	3.5VS2
Passing ability ratio, PL (L box)	0.95/PL1	0.95/PL1	0.97/PL1	0.83/PL1	0.90/PL1	0.88/PL1	0.84/PL1

Note: DN – non-grinded concrete dust; DM – grinded concrete dust.

In every concrete mix case slump flow value was determined. It is observed, that in comparison to control composition, the greatest deviation reveals in case, when 30 % of cement mass was replaced by non-grinded concrete dust and slump flow decreases by 60 mm. In case, when 20 % of cement mass was replaced by non-grinded concrete dust, slump flow increased by 40 mm, when 10 % -

slump flow increased by 10 mm. When cement was replaced by grinded concrete dust 10 %, 20 % and 30 % of cement mass, slump flow increased by 30, 20 and 10 mm, respectively.

Slump flow up to 500 mm changed least when 10 % concrete dust was used. From 3.5 to 3.0 s in case when cement was replaced by non-grinded concrete dust and up to 2.0 s, when replaced by grinded concrete dust. In case when 30 % cement mass was replaced by non-grinded concrete dust slump flow up to 500 mm was 4.5 s, what is 1.0 s longer in comparison to control composition. In all other cases duration left the same or less than control (Zhimin *et al.* 2009)

In comparison to control composition segregation index decreased in every case, when part of cement was replaced by concrete dust. Segregation changed least, when 10 % non-grinded concrete dust was used and decreased the most when 30 % grinded and non-grinded concrete dust was used. Respectively 8.7 and 10.4 times.

Passing ability ratio result in comparison to control test was better when non-grinded concrete dust was used. Though replacing 30 % cement mass by grinded or non-grinded concrete dust results were almost the same, nevertheless slump flow index changed less in replacing cement by non-grinded concrete dust case. Comparing all compositions to control composition this index values were lower than control, except when 10 % cement mass was replaced by non-grinded concrete dust.

Assessing one of the main mechanical concrete property – compressive strength up to 1 year concrete hardening duration, it was observed, that replacing cement by concrete dust, practically no negative influence was observed (Sumanth *et al.* 2013) In some cases this replacement even improves concrete compressive strength (10 % concrete dust), except greater amount of additionally grinded concrete dust.

It was noticed that 20 % and 30 % replacement of cement by grinded concrete dust compressive strength of concrete specimens decreased (Corinaldesi *et al.* 2010). Cement replacement by analogical amounts of non-grinded concrete dust compressive strength left the same. Replacement of 10 % concrete dust, independently from fact that dust was grinded or not, compressive strength increased up to 14 % after 28 days hardening and up to 17 % after one year hardening.

Applying prediction for resistance to freeze-thaw cycles method according to concrete resistance to freeze-thaw cycles parameter K_F , resistant to freeze-thaw cycles concrete will be in case when reserve pores volume will be greater than water in concrete pores volume increment while water

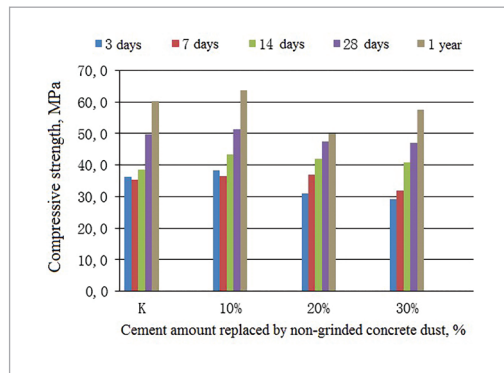


Fig. 8

Concrete compressive strength with non-grinded concrete dust

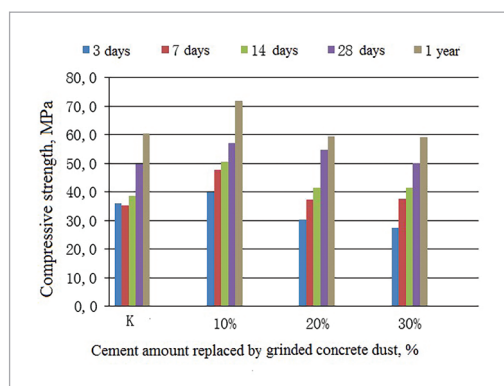


Fig. 9

Concrete compressive strength with grinded concrete dust

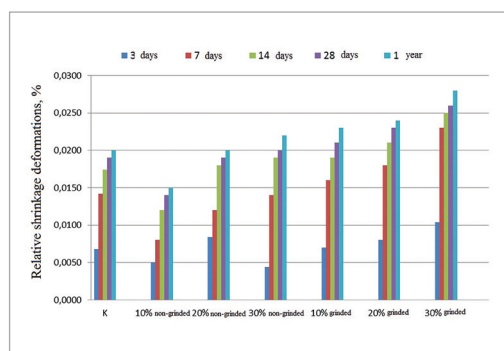


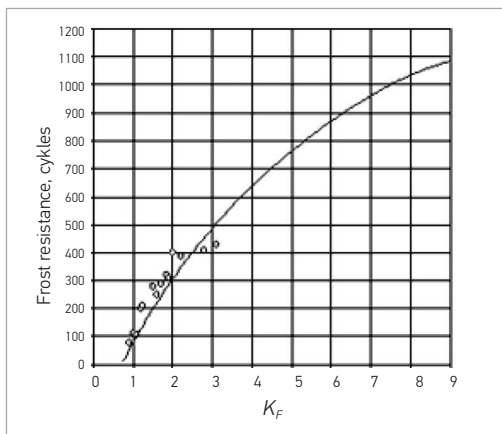
Fig. 10

Relative shrinkage deformation comparison of different concrete mixes

turns to ice. It is found experimentally that concrete resistance to freeze-thaw cycles number depends on entrained air content. General dependence of this expression is given in Fig. 11.

Fig. 11

Concrete resistance to freeze-thaw cycles dependence on resistance to freeze-thaw cycles parameter K_F (Sheikin et al. 1989)



As it is seen from resistance to freeze-thaw cycles parameter K_F expression, concrete resistance to freeze-thaw cycles depends on V/C ratio, which determines open porosity. Moreover it depends on air content in concrete mix, which meets closed porosity. Increasing entrained air content in concrete mix affects the number concrete resistance to freeze-thaw cycles positively.

That is ensured by many different authors and their carried out experiments. Obtained results are given in table 3.

Table 3

Porosity parameters of samples and predicted resistance to freeze-thaw cycles

Concrete dust, %	Overall porosity, %	Open porosity, %	Closed porosity, %	Pores distribution according to size index, α	Average pores size index, λ	Resistance to freeze-thaw cycles parameter, K_F	Predicted resistance to freeze-thaw cycles, cycles
0	15.95	14.10	1.85	0.63	1.33	1.46	200
10	15.42/15.55*	13.33/14.34*	2.09/1.21*	0.72/0.68*	1.15/2.25*	1.74/0.93*	255/90*
20	17.87/16.12*	16.07/15.32*	1.80/0.80*	0.59/0.61*	1.83/2.40*	1.25/0.58*	120/~30*
30	16.47/16.30*	15.18/15.55*	1.29/0.76*	0.69/0.62*	2.56/3.02*	0.94/0.54	90/~30*

Note: * - used grinded concrete dust (DM)

Summarizing obtained results it can be concluded that average pores size index λ varies from 1.15 (using 10 % DN) to 3,02 (using 30 % DN). With reference to given calculation method it is considered that if this index is less than 1.50, then pores, that are in concrete will be small enough and will have positive influence to concrete resistance to freeze-thaw cycles. Pores distribution according to size index varies from 0.59 (using 20 % DN) to 0.72 (Using to 10 % DN). Pores are more uniform if this index is closer to 1.00. Usually in small pores, that size is up to 300 μm , when α index is closer to 1.00 value, concrete is more resistant for to freeze-thaw cycles as the result.

Assuming that closed concrete porosity is identical to entrained air content in concrete mix it is needed to notice, that in general case on the basis of LST EN 206:2014 and LST 1974:2012 standards, entrained air content in concrete mix, which positively influences concrete resistance to freeze-thaw cycles, must be at least 4 %. According to LST EN 206:2014 table 21, individual values cannot exceed highest deflection limit + 5 %. It cannot be greater than 9 % or be none the less than lower minor deflection limit - 0.5 %, which is 3.5 % entrained air content. In our case it was noticed, that replacing up to 10 % cement by concrete dust from 1.85 % to 2.09 % increases concrete closed porosity and predicted concrete resistance to freeze-thaw cycles increases up to 30 %. It allows to expect positive test results while real test would be carried out on the basis of

Lithuanian standard LST 1428.17. Also it should be mentioned that additional concrete dust grinding negatively influences concrete durability.

Assuming relative shrinkage deformations the tendency is observed that this index in long term perspective increases while part of cement replacement by concrete dust increases. Exceptional case was noticed when 10 % of cement mass was replaced by non-grinded concrete dust. In this case relatively shrinkage deformations were less in comparison to control specimens. This can be explained by better mix granulometric composition, because non-grinded concrete dust particle average size is slightly smaller than usual cement particles and particles specific surface is up to 2 times greater than cement. Increasing concrete dust amount up to 20 % or 30 % of cement mass, due to greater specific surface and overall cement system dilution also increase water demand. Greater open porosity occurs which causes greater shrinkage deformations and worsens concrete durability properties.

- _ It is very important to attain proper technological-rheological properties (slump flow, passing ability ratio, viscosity) in SCC production process. Cement replacement by concrete dust up to 30 % can help to implement these properties.
- _ Increasing concrete dust amount in concrete mix gives an effect of lower cement hydration exothermal warmth emission. It has positive impact for massive concrete constructions
- _ Assessing one of the main mechanical concrete properties – compressive strength up to one year concrete hardening it was noticed, that cement replacement by concrete dust practically has no negative impact to this index and it even improves compressive strength (10 % cement replacement by concrete dust).
- _ Replacing cement by concrete dust up to 10 % of mass, from 1.85 % up to 2.09 % increases concrete closed porosity. Predicted concrete resistance to freeze-thaw cycles increases about 30 %.
- _ Assessing obtained results, conclusion can be made, that concrete non grinded (sieved by 0.125 mm) dust may be an alternative for more ecological, cheaper and more durable SCC concrete production.

Conclusions

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