ISSN 1392–1320 MATERIALS SCIENCE (MEDŽIAGOTYRA). Vol. 11, No. 3. 2005

The Analysis of Secondary Raw Materials Usage in Self-Compacting Concrete Production

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Received 23 October 2004; accepted 06 March 2005

This work presents study of influence of thermo-electric fly ashes, dolomite siftings, quartz sand and granite fines on the properties of self-compacting concrete (SCC). During the research a part of cement was replaced by fly ashes (from 5 to 30 %), or quartz sand fines (from 2.5 to 10 %), or granite fines (from 2.5 to 10 %) and granulometrical composition of aggregates was modified by dolomite siftings fr. 0/2. It was established that fly ash and dolomite siftings did not increase water quantity necessary in order to make the same consistence of self-compacting concrete. It can be explained that small particles of fly ashes and dolomite siftings are contained among the particles of sand and coarse aggregates, and therefore the granulometrical composition is improved. There was observed no bleeding or segregation in self-compacting concrete with fly ashes, though the input of cement was less. If a part of cement is replaced with quartz sand fines (quartz-sand fines fineness are 1.28 time more than fineness of cement), the bleeding is observed, because their water absorption is lower.

The data of the experiments demonstrates that fly ashes and dolomite siftings positively modify the consistence of self-compacting concrete, increase the compression strength of concrete up to 15 %, when fly ashes was used, and up to 9 %, when dolomite siftings was used. Therefore admixtures of fly ashes and dolomite siftings reduce the shrinkage strains (with fly ashes up to 25.4 % and with dolomite siftings up to 18 %). There was established, that is rationally to replace 2.5…5 % of cement by quartz sand or granite fines.

Keywords: self-compacting concrete, fly ashes, inert microfiller, bleeding, segregation, shrinkage, durability.

1. INTRODUCTION

The natural aggregate reprocessing technologies used in Lithuania do not ensure that the small aggregate particles needed for concrete are not eliminated in washing process. The lack of small particles makes the aggregates of concrete quality lower and at the same time production waste is increased, that courses an ecological problem [1].

In order to solve this problem, a part of the necessary small particles could be substituted by various production wastes: fly ashes, dolomite siftings, quartz sand or granite fines.

Nowadays, when the self-compacting concrete (SCC) is produced more widely in the world, the main goal of all new experiments is to evaluate the rheological and physical characteristics and durability of self-compacting concrete, and also to guarantee its quality in different usage conditions [2]. It is very important to choose the right granulometrical composition of aggregates and pay a bigger attention to small aggregates fractions while designing the composition of self-compacting concrete. It helps to avoid segregation and bleeding, also to decrease cement quantity to get the same properties of concrete [3 – 5].

If these wastes are used in self-compacting concrete production in the right way, it is possible to extend the aggregate resources usage, to save sand and cement expenditures, to stabilize the changes of physical and mechanical properties of concrete and to get a fair technical and economical effect [6, 7].

Usage of fly ashes depends on their chemical and granulometrical composition and way of their collection.

Chemical activity of fly ashes is one of the most important properties that determines field of their use. Fly ashes compared with other active mineral admixtures is more chemically active than rotten – stone, geize and diatomite (less active then fly ash) and cheaper then SiO_2 silica fume [8, 9]. Some minerals that include fly ash in concrete (for example amorphous SiO_2, metakaolin CaO and MgO) can make chemical reactions with cement hydration products and compound stable hydro silicate combinations, that is why fly ashes are ascribed to active micro-fillers group, because active part of it (SiO_2) turns into hydro silicates compounds, the other part, that don't react with binding agent, remain as inert microfiller [10, 11]. Since in Lithuanian thermo-electric power stations coal is not used, the above- mentioned fly ashes is not available and it is necessary to pay for the transport and to bring fly ash from Poland, where they are collected as waste. Therefore, in order to make concrete cost lower we are trying to find alternatives for our own raw materials.

Quartz sand and granite fines, as well as dolomite siftings collected during the crushing of dolomite gravel, could be called microfillers. About 30 % of waste is comprised during the production of dolomite crushed. It is recommended to separate the parts bigger then 2 mm from them and use them in production of a heavyweight concrete. The other up to 2 mm dolomite fraction (which has 30 – 35 % of dispersive particles) could be used in production of self-compacting concrete, because such particles improve the technological properties of this concrete [12, 13]. It's a pity that nowadays these siftings are mostly collected in pulp fields and later are spread on the roads. Enough $CaCO_3$ and $MgCO_3$ are in these particles and therefore they could be used as technological raw materials in building materials and chemical industry or in

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Table 1. The characteristics of concrete aggregate and concrete mix with dolomite siftings fraction 0/2

Properties	The common aggregate mass is replaced by dolomite siftings, %			
	0	7	14	28
The dry aggregates bulk density, kg/m^3	1850	1900	1880	1850
Index of segregation, %	7.28	5.28	7.15	10.40
Slump flow, spread, mm	620	640	650	630
Slump flow, to 500 mm, s	4.88	4.92	3.81	4.83
Slump flow, to final, s	15.39	16.73	16.89	18.03

production of microfillers. When the temperature and pressure are normal, inert microfillers do not react chemically with cement and water. But they can improve granulometrical composition of cement, mortar or concrete and to increase their density, to influence capillary porosity, decrease lower water requirement and shrinkage strains [14, 15]. The aim of the paper is to establish how fly ashes, dolomite siftings, quartz and granite fines influence to properties of self-compacting concrete.

2. MATERIALS AND TEST METHODS

Materials used for tests: Portland cement CEM I 42.5R, produced by the JSC "Akmenės cementas", aggregates of Kvesu pit: 4/16 mm fraction gravel, 0/2 mm and 0/4 mm fractions sand, granite fines from the JSC "Granitas", quartz sand fines from the JSC "Anykščių kvarcas", dolomite siftings of 0/2 fraction from the JSC "Dolomitas", fly ashes collected in "Balux" firm's (Poland, Bialistok) thermo-electric power station and the additives: superplasticizer "Visco Crete-5-600" made in Switzerland company "Sika", 1.0 % from the mass of cement made on the basis of polycarboxylic resin and the stabilizer of the mix "Starvis 2006-L", made in Danish company "SKW-MBK".

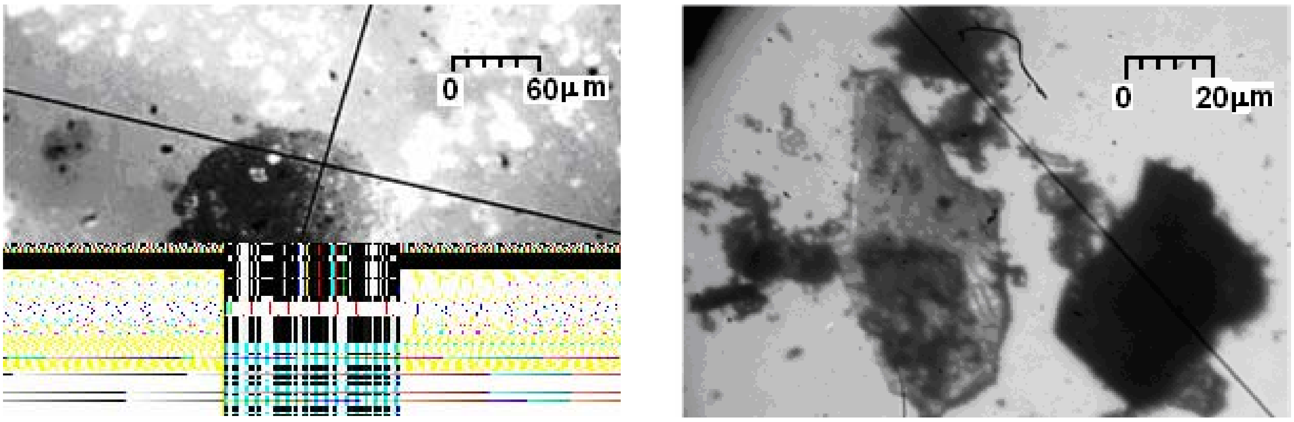
The specific surface of the fly ashes was measured applying Blain's method and was found to be 450 m^2/kg. The bulk density of the fly ashes is 650…700 kg/m^3. After the dolomite siftings has been sifted out, it was estimated that there are 40 – 45 % of small dispersive particles (0 – 0.125 mm) in the dolomite siftings, the bulk density of them being 1700 kg/m^3. The specific surface of the quartz sand fines (which is 470 m^2/kg) and the specific surface of the granite fines (which is 310 m^2/kg) were measured applying Blain's method. The bulk density of those materials is 1030 kg/m^3 and 1080 kg/m^3 respectively. Particle shape of dolomite siftings and granite fines were obtained using stereo microscope STEDDY-T.

The experimental studies were carried out in the following succession: the part of the cement was replaced with fly ashes (from 5 to 30 %), or quartz sand fines (from 2.5 to 10 %), or granite fines (from 2.5 to 10 %). Because the dolomite siftings are coarser than fly ashes, sand or granite fines, to replace cement by them it is not rationally. But dolomite siftings particles much more smaller than standard sand particles and they can improve granulometric composition of all concrete mix aggregates. Therefore when experimental investigations were carried out, the part of concrete aggregates was replaced by dolomite siftings (from 7 to 28 %). Proportion of control concrete mixture (materials content per 1 m^3 of concrete): Portland cement CEM I 42.5 R – 370 kg/m^3; sand fr. 0/2 – 502 kg/m^3; sand fr. 0/4 – 501 kg/m^3; gravel fr. 4/16 – 785 kg/m^3; water – 203 kg/m^3; superplasticizer "Visco Crete-5-600" – 3.7 kg/m^3. The self-compacting concrete mixes were mixed in the laboratory mixer of constrained mix for about 4 – 5 minutes. In order to increase the homogeneity of the mixes and to improve the rheological properties, two stages of mixing were applied: 1 stage – the cement, aggregates and 2/3 of water were mixed for about 2 minutes; 2 stage – superplasticizer "Visco Crete-5-600" (1.0 % from the mass of cement) was poured into the amount of water that was left and the concrete mix has been kept for about 1 minute. The slump flow of self-compacting concrete mixes was kept constant at about 620…650 mm. The stability of the mix sedimentation was measured applying the "Three cylinder test" method. In order to secure a good flow down the wall, immediately after the mixing the concrete mix was poured into a three part cylinder that was oblique at an angle of 45°. The concrete mix from the upper and lower parts of the cylinder was washed through the 8 mm sieve in 30 minutes, because the diameter of the largest particles of the used aggregates was 16 mm. The part of the mass of the aggregate that was left on the sieve cannot differ more that 15 %. Further on, standard cubes were prepared – 10 × 10 × × 10 cm and the prisms of which were 7 × 7 × 21 cm. For 28 days the cubes were hardened in the regime chamber at the temperature of 20 ±2 °C and at the relative humidity of 95 %. The compressive strength, density, water absorption, the freezing resistance, the modulus of elasticity and shrinkage strains were measured by these experiments.

3. TESTING RESULTS

3.1. The influence of dolomite siftings to SCC mix and product properties

There were chosen four compositions with the amount of the dolomite siftings varying from 0 % to 28 % from all aggregates mass to prepare self-compacting concrete mixes. In order to find out how the common granulometrical composition of the aggregate changes, the experiment of their bulk density was performed. The results of the experiment are indicated in the Table 1. As can be seen from the Table 1, the bulk density of the dolomite siftings increases while the mass of the aggregate is changed 7 – 14 %. It can be explained because the small fraction particles of the dolomite siftings (0 – 0.125 mm) stows between the particles of sand and aggregates, it improves the granulometrical composition of the concrete aggregate, increases the density of the concrete mix. The



a b

Fig. 1. Particle shapes of a) dolomite siftings (×120) and b) granite fines (×360) powder as supplied

increase of the slump flow of concrete mix was noticed in the concrete mixes with the admixtures of dolomite siftings (from 7 to 14 %), though the requirement of water has not increased. The increase of the initial slump flow speed of mix spread till the limit of 500 mm was fixed as well (Table 1). The explanation of it is that the shape of the dispersive particles of the dolomite siftings is ellipsoid or sphere, thus the particles, having the smallest specific surface, situate in the mix in a more complex manner, consolidate easier, and less water is needed to moisten them (Fig. 1). While studying the stability of the sedimentation it is worth to note that the segregation of the mix is reduced changing 7 – 14 % of all aggregate mass by dolomite siftings.

Dolomite siftings also have a positive influence on the properties of hardened concrete. Since there not enough small particles in Lithuanian sands, dolomite siftings fill this gap perfectly.

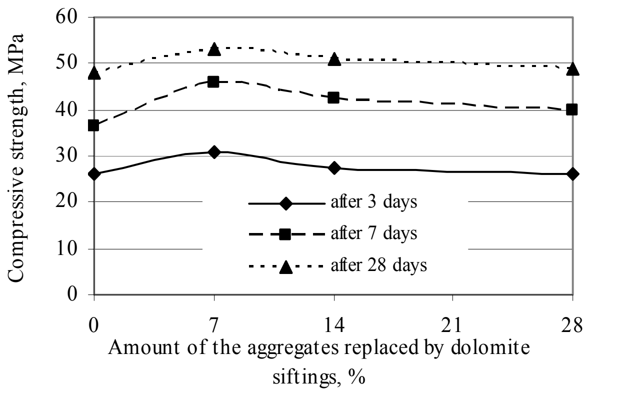


Fig. 2. Dependence of concrete compressive strength on the amount of replaced aggregates by dolomite siftings

At the same time while improving the concrete aggregate granulometrical composition, dolomite siftings increase concrete compressive strength and modulus of elasticity, also decrease shrinkage strains (Fig. 2, 3). Relative deformation of shrinkage were started to test one day after casting of specimens when specimens where demolded. Moisture content in specimens was tested by specimens weighting.

The strength and modulus of elasticity of concrete increased after replacing 7 – 14 % of all the aggregates

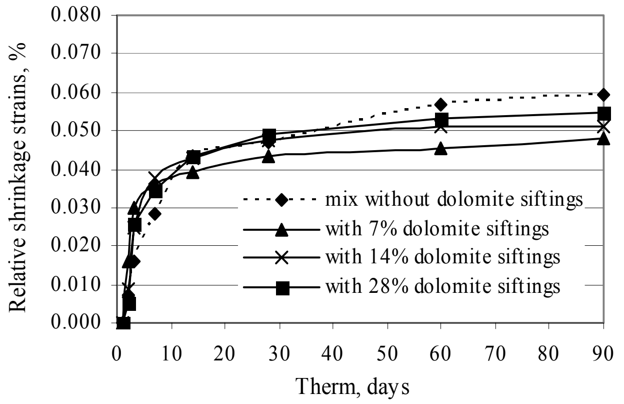


Fig. 3. Dependence of concrete shrinkage strains on the amount of replaced aggregates by dolomite siftings

mass by dolomite siftings. Strength also increases because of enough amount of $CaCO_3$, therefore those siftings could partially react with aluminates compounds, making a new calcium carboaluminate complexes, which inosculating together make the cement stone stronger [11]. Replacing a bigger amount of aggregates by dolomite siftings, the strength and modulus of elasticity is decreasing. And it is also observed, that while increasing the amount of siftings, the capillary pore average index λ is also increasing; as the result, the water absorption is increased and freezing resistance is decreased (Table 2).

Volume shrinkage strains, when a part of aggregates replaced with dolomite siftings (from 7 to 28 %), decrease gradually in the hardened concrete (Fig. 3). It could be explained that dolomite siftings divide the capillary pores of the liquid part of the concrete mortar. When concrete with smaller capillary pores is hardening, the moisture moves out slower.

When the level of moisture change is steady, concrete with 7 – 14 % dolomite siftings looses 37 % less moisture, than in the case when dolomite siftings are not used. It is also observed that in a hardened concrete which aggregate composition was modified by dolomite siftings (7 – 14 %) the tension strains increases, i.e. concrete maintains its elastic properties under larger strains, which allows concrete return back to the initial state when load is removed (Fig. 4).

Table 2. Properties of concrete with dolomite siftings fr. 0/2

Properties	The common aggregate mass is replaced by dolomite siftings, %			
	0	7	14	28
Water absorption, %	6.55	5.65	6.17	6.41
Open capillary pores average rate, λ	2.29	1.96	2.11	2.21
The freezing resistance criterion, Ks	1.20	1.44	1.35	1.25
Modulus of elasticity E, MPa	31121	34402	32398	32027

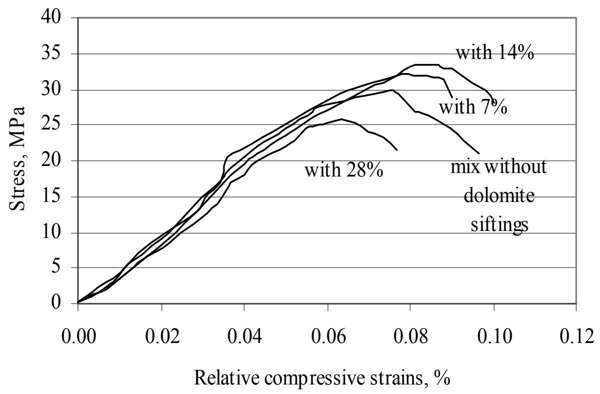


Fig. 4. Effect of concrete strain deformations on amount of replaced aggregates by dolomite siftings

3.2. The influence of microfillers (fly ashes, quartz sand and granite fines) on SCC mix and product properties

In order to estimate the influence of microfillers on the properties of the SCC mix, different concrete mixes were mixed where cement was replaced by fly ashes (from 5 to 30 %), or to quartz sand fines (from 2.5 to 10 %), or to granite fines (from 2.5 to 10 %). Examination of the general aggregate granulometrical composition, index of segregation and slump flow was performed (Table 3). It was observed, that fly ashes did not increase water demand for the same consistence concrete mix. This can be explained that fly ashes particles contain between the particles of sand and aggregates and therefore the granulometrical composition is improved and density of concrete is increased. No bleeding or segregation in self-compacting concrete with fly ashes was observed notwithstanding that the input of cement was lesser. If a part of cement is changed to quartz sand fines (quartz sand fines fineness is 1.28 time more than fineness of cement), the bleeding is observed as their water requirement is lower. Therefore in mixing process a “Starvis 2006-L“ was used in order to avoid the above-mentioned problem.

One can observe from the results of the experiments that if cement is replaced to 2.5 – 5 % quartz sand fines, or 2.5 % granite fines, the bulk density slightly increases. This can be explained that these fines contain between the particles of sand and aggregates and therefore improving the granulometrical composition, increasing the concrete mix density and decreasing the demand for the cement. Changing cement with increasing quantity of quartz sand fines it was observed that the mix slump flow remained almost unchanged, while using granite fines the slump flow remained unchanged only with 2.5 %; if this quantity is increased, the slump flow rapidly decreases (Table 3). The explanation is that the particles of the granite fines are sharp-edged therefore for their surface moistening more water are needed while the concrete mix is less preparing. To avoid this, the superplasticizer quantity can be slightly increased (it is recommended not to use more than 2 % of the cement mass). In the mixes where the quartz sand fines were used in place of cement, the initial speed of the sump flow increased to 500 mm, as well as to the final limit. It is important to note in the mix sedimentation stability research that replacing cement with 2.5 – 7.5 % quartz sand and granite fines, the mix segregation is decreased.

From the hardened concrete research one can observe, that if cement was replaced by fly ashes (up to 5 %), concrete compressive strength and modulus of elasticity increases more than if the same quantity of cement was replaced by quartz sand or granite fines. It is so the fly ashes does not only improve the granulometrical composition of concrete mix, but because they consist of more than 40 % amorphous SiO_2 and chemically react with the products of the cement hydrolysis process, increasing the above-mentioned properties even further (Fig. 5).

Substituting cement with bigger quantities of the used microfillers, the compressive strength and the modulus of elasticity decrease (Fig. 6).

Table 3. Properties of concrete aggregates and concrete mix with microfillers

Properties	Amount of cement replaced by quartz sand and granite fines, %				
	0	2.5	5	7.5	10
The dry aggregates bulk density, kg/m^3	1850	1870/1860*	1850/1820*	1830/ ---	1820/1800*
Index of segregation, %	7.28	4.03/4.85*	5.00/6.85*	5.57/ ---	7.50/9.67*
Slump flow, spread, mm	620	620/620*	630/580*	620/ ---	620/540*
Slump flow, to 500 mm, s	4.88	4.54/4.60*	4.04/5.50*	3.95/ ---	4.50/5.50*
Slump flow, to final, s	15.39	13.65/15.00*	14.20/18.00*	13.80/ ---	14.90/18.34*

Note**:** * – cement replaced by granite fines.

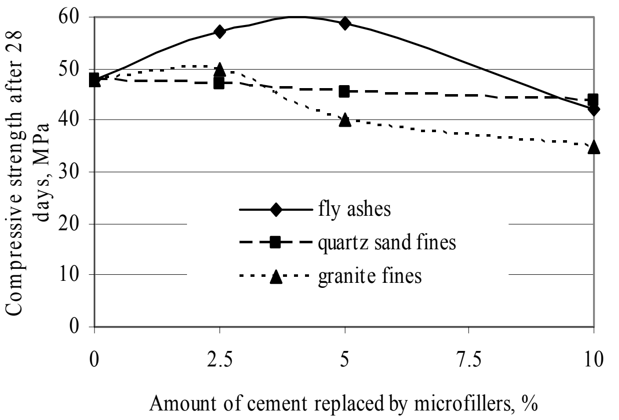


Fig. 5. Dependence of concrete compressive strength on amount of cement replaced by microfillers

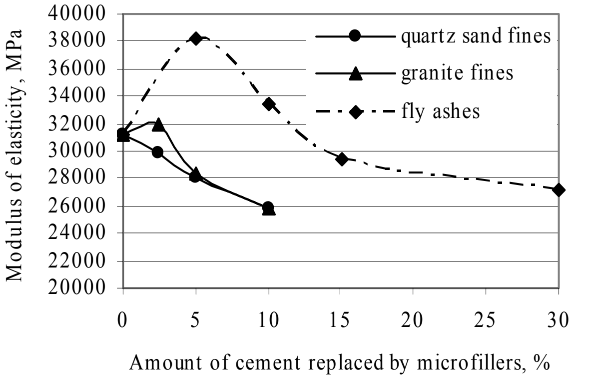


Fig. 6. Dependence of concrete elasticity modulus on amount of cement replaced by microfillers

After replacing the part of the cement with the microfillers, after the 90 days the volume shrinkage strain in the hardened concrete decreases mostly using 5 % of fly ashes (Fig. 7). It can be explained that the fly ashes do not only makes smaller the capillary pores of the mortar part of the concrete thus blocking the way for the humidity to escape, but the granules of fly ashes also stick over with gel and when the systems is drying, the granules are intercepted the compressive forces and at the same time they react against the shrinkage. As the mass humidity change becomes steady, the concrete (the cement in which has been changed into the fly ashes from 5 to 30 %) lost up to 20 % less humidity comparing with loss of humidity when the fly ashes were not used. Using the granite fines it was noticed that the humidity change decreased up to 5 % while changing 2.5 – 5 % of cement into the granite fines. It was also observed that if the cement of the hardened concrete is replaced with 5 % of fly ashes, or 2.5 % of granite fines, the elastic deformations increase; i.e. the concrete sustains its characteristics of elasticity even if the greater post – tensioning is given, in the presence of which the concrete comes back to the initial state as the load is removed [16]. Besides, when the cement is replaced with fly ashes (from 5 to 30 %), or with granite fines (from 5 to 10 %) greater plastic deformations of the concrete are obtained (up to 38 % and up to 44 %) (Fig. 8). Thus, while tensions are increasing, concrete with the admixture of fly ashes and granite fines does not cracking longer time.

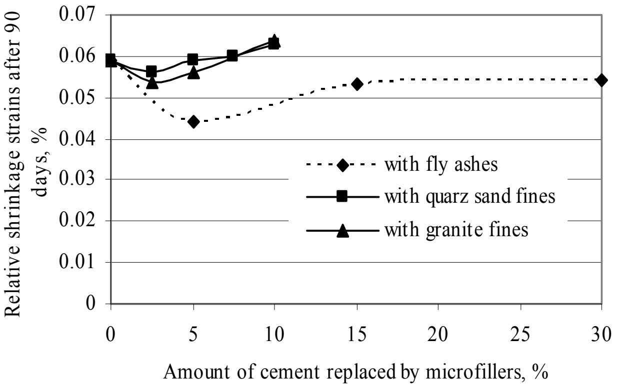


Fig. 7. Dependence of concrete shrinkage strains on the amount of cement replaced by microfillers

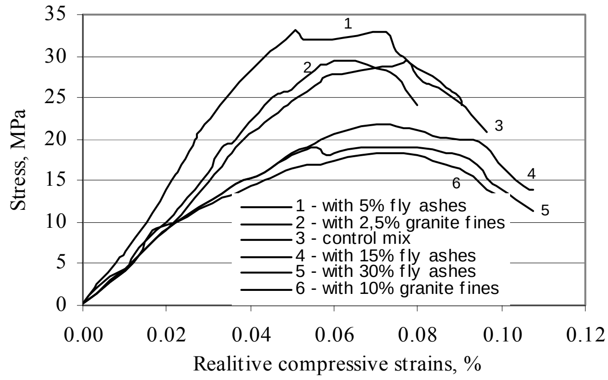


Fig. 8. Effect of concrete strain deformations on amount of cement replaced by microfillers

The carried out studies showed that it is the most rational to replace the cement with up to 5 % of quartz sand fines, or with up to 2.5 % granite fines. If the greater amount is replaced the average size rate λ of the capillary pores increases, consequently the water absorption increases and the freezing resistance decreases (Table 4).

Table 4. Properties of concrete if cement is substituted with microfillers

Properties	Amount of cement replaced by quartz sand and granite fines, %				
	0	2.5	5	7.5	10
Water absorption, %	6.55	6.50/6.00*	6.46/6.78*	6.69/ ---	6.89/7.06*
Open capillary pores middle rate, λ	2.29	2.32/2.08*	2.75/2.68*	2.90/ ---	2.89/2.96*
The freezing resistance criterion, Ks	1.20	1.25/1.33*	1.08/1.10*	0.95/ ---	0.90/0.95*

Note**:** * – cement replaced by granite fines.

4. CONCLUSIONS

1. It is rationally to change 7…14 % of all aggregates mass by dolomite siftings in self-compacting concrete mixes. As a result of this are, that in concrete mix there isn't segregation, increasing slump flow and getting better mechanical properties of concrete.
2. The use of fly ashes in self-compacting concrete mixes reducing possibilities of bleeding and segregation. Then 5…10 % of cement is replaced by fly ashes getting better mechanical and physical properties of concrete and expenditures of cement diminishing.
3. It is effective to change up to 5 % of cement by quartz sand fines only then stabilizer "Starvis 2006-L" is used, because the quartz sand fines have high surface area and low water absorption.
4. The granite fines is effective to use only 2.5…5 % from cement mass in self-compacting concrete. Then changing more cement part by granite fines, it is necessary to pick up quantity of superplasticizer, that to keep the mixes slump-flow in same level without negative factors.
5. Correct using of Lithuanian pitches and aggregates producing factories wastes gives possibilities to produce high performance self-compacting concrete with lower expenditures.

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