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INFLUENCE OF DIFFERENT MINERAL ADDITIVES ON THE STRENGTH OF SELF-COMPACTING CONCRETE

Abstract: Self-compacting concrete is one of the revolutionary solutions of the concrete industry of the 20th century. Unlike vibrated concrete, self-compacting concrete contains significant amounts of fine particles, i.e. a mineral additive that greatly affects its performance. The most commonly used mineral additives are lime, fly ash, and silica fume. In this paper, we have considered the mechanisms of action of each of these additives on the structure and compressive strength of self-compacting concrete.

Key words: *self-compacting concrete, lime, fly ash, silica fume*

UTICAJ RAZLIČITIH MINERALNIH DODATAKA NA ČVRSTOĆU SAMOUGRAĐUJUĆEG BETONA PRI PRITISKU

Rezime: Samougrađujući beton spada u revolucionarna rešenja betonske industrije XX veka. Za razliku od vibriranog betona, samougrađujući sadrži i značajnu količinu sitnih čestica, tj.mineralni dodatak koji nemalo utiče na njegove performanse. Najčešće korišćeni mineralni dodaci su mleveni krečnjak, elektrofilterski pepeo i silikatna prašina. U ovom radu su razmatrani mehanizmi delovanja svakog od ovih dodataka na strukturu i čvrstoću pri pritisku samougrađujućeg betona.

Ključne reči: *samougrađujući beton, mleveni krečnjak, elektrofilterski pepeo, silikatna prašina*

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1. INTRODUCTION

Self-compacting concrete (SCC), by many authors, "the most revolutionary discovery of the concrete industry of the 20th century", does not require vibration during placing and compaction. Under the influence of its own weight it fully fills all parts of the skin, even in the presence of dense armature. Self-compacting concrete, besides cement, aggregates, water and superplasticizer, also contains a mineral additive, (most often lime, fly ash, granulated slag). Depending on the composition, there are three types of self-compacting concrete [2,3]:

Powder type, characterized by a large amount of fine particles (smaller than 0,15mm) most often orders of magnitude of 550-650kg/m. This enables plastic viscosity, and thus resistance to segregation. Yield strength is regulated by the addition of superplasticizer.

In viscosity type, the content of powdered particles is lower (350-450kg/m. Segregation resistance is controlled using viscosity modifiers, and the yield strength using superplasticizer.

In the combined type, the content of powdered particles varies from 450-550 kg/m, but the required rheological properties are achieved using viscosity modifiers and the proper amount of superplasticizer.

In this paper, based on our own experimental research, we have presented the effects of three different mineral additives (lime, fly ash, and silica fume), on the compressive strength of self-compacting concrete.

2. MINERAL ADDITIONS

2.1 Lime

Lime is used more as a cement additive rather than as a concrete additive. The European norm EN197 – 1 provides for two classes of Portland cement lime whose labels are CEM II/A-L 9or L-L instead of A-L) and CEM II/B-L (or L-L instead of B-L). The former contains between 6 and 20% lime and the latter 21 – 35%.

The requirements that the lime for cement should meet are the following: the content of $CaCO_3$ must be greater than 75%, the content of clay, determined by methylene blue test should not exceed 1.20g /100g, the total content of organic carbon must not exceed 0,20% for LL lime and 0,50% for L lime. It was thought that the lime was inert, but there has gradually been accepted the opinion that it contributes to the process of hydration by forming calcium mono carbo aluminates ($C_3A{\cdot}CaCO_3{\cdot}11H_2O$). The presence of lime causes the acceleration of hydration process and the hydration shrinkage of concrete in the first few hours, because the lime particles serve as nuclei for additional hydration.Vikat's time is also reduced. The increasing of the speed of hydration shrinkage and of hydration is much more pronounced in the cement type CEM II compared to CEM I/ [1].

2.2 Fly ash

The originators of the idea of applying fly ash, resulting from the combustion in concrete, were McMillan and Powers in 1934. In the late 40s the investigations carried out in Britain (Fulton and Marshall, led to the construction of dams Lednock, Clatworthy and Lubreoch, with fly ash as a cement additive. All these structures are, even 60 years later, in excellent condition [5].

During the combustion of coal in a furnace at a temperature between 1250°C and 1600°C, non-combustible particles are fused, forming spherical glassy droplets of silicate (SiO_2), aluminate (Al_2O_3), iron oxide (Fe_2O_3) and other, less important constituents. When fly ash is added to concrete pozzolanic reaction between silica (SiO_2), and calcium hydroxide ($Ca(OH)_2$) or lime, which is a by-product of hydration of Portland cement, begins The resulting hydration products fill the pores, reducing the porosity of the matrix. These products are different from the products formed in the concrete containing only Portland cement. Particles smaller than 50μm are mainly spherical, while larger particles may be irregularly shaped. Spherical particles significantly contribute to the fluidity of the concrete in plastic state, optimizing the packaging of particles. They behave like "spherical connections" in concrete, reducing the required amount of water to achieve the required workability.

2.3 Silica fume

Terms condensed silica fume, microsilica, silica fume, and volatilized silica are equally used for the by-product obtained from the exhaust gases during the melting of silicates, iron silicates and other metal alloys in furnaces. Terms microsilica and silica fume are commonly used in the cement and concrete industry, while the European standard EN 13253-1 uses only the term silica fume.

Silica fume was first "discovered" in Norway, in 1947, when setting up filters for the exhaust gasses from the furnace, in order to prevent pollution of the environment, became mandatory. Large portion of these gasses was made from very fine powder with a high percentage of silica. As pozzolanic properties of silica were already known, the detailed studies on the Norwegian Institute of Technology began.

Adding silica fume causes significant changes in the structure of the matrix, not only because of its physical presence but also because of pozzolanic reaction, which create dense, redefined pore system and greater strength. It is better to use it as a cement additive rather than as a replacement. To achieve optimum performance of concrete, the proper curing is needed.

3. OUR OWN EXPERIMENTAL RESEARCH

In the experimental part of the work we used cement PC 42.5R by HOLCIM Ltd (Popovac,Serbia) , lime "Jelen Do" from Jelen Do, fly ash from the power plant Obrenovac B, product sikafume by Swiss manufacturer of construction chemistry SIKA, and superplasticizer ViscoCrete 5380 by the same manufacturer. The criterion in the mix designing was achieving the same consistency of concrete, i.e. of slump - flow class SF2, which comprises the usual application of concrete and involves spreading of 66 to 75cm.

When preparing concrete mixtures, the aggregate was first mixed with half of the required water for about 30 seconds, and then other components were added. For the purposes of the experiment, three three-fraction self-compacting concrete mixtures were made, and their composition is shown in Table 1, with the markings SCCL for the mixture with limestone, SCCF for the mixture with fly ash, and SCCS for the mixture with silica fume.

Material (kg/m^3)	SCCL	SCCF	SCCS
cement	400	400	400
lime	120	0	0
fly ash	0	120	0
silica fume	0	0	52
0/4mm	770.86	770.86	770.86
4/8mm	306.28	306.28	306.28
8/16mm	532	532	532
water	170.8	192.66	185.71
VSC5380	4.94	4.94	4.94
ωc (wat-cem. ratio)	0.43	0.48	0.46
ωp (wat.-powd. rat)	0.33	0.37	0.41

Table 1. Composition of concrete mixtures

4. RESEARCH RESULTS

The obtained results of fresh concrete tests are shown in Table 2, the results of tests of density in hardened state after 2.7 and 28 days in Table 3, and the results of the compressive strength after 2,7 and 28 days in Table 4. Figures 1, 2, and 3 show the structure of concrete.

Concrete mixture	Density kg/m^3	Slump-flow d_{sr}, cm	T_{500} s	L-box H_1/H_2	Sieve segregation%
SCCL	2418	73	4	1	12.4
SCCF	2288	70	4	0.94	11
SCCS	2416	66	6	0.91	6.8

Table 2. Results of fresh concrete tests

	SCCL	SCCF	SCCS
2 days	2396	2262.4	2366.4
7 days	2469.2	2289.7	2361.8
28 days	2426.7	2306.2	2376.3

Table 3. The density in hardened state

	SCCL	SCCF	SCCS
2 days	46	36.34	40.4
7 days	58.24	52.18	58.05
28 days	66.68	64	72.31

Table 4. The compressive strength after 2,7 and 28 days

5. ANALYSIS OF RESULTS

Slump-flow test was used to check the first of the four key features of SCC: mobility, i.e. flowability. Spreading amounted from 66 to 73cm, which all of the designed mixtures put in the class SF2, which corresponds to the most common use of concrete in construction.T500 is the time that concrete reaches 500mm, and is measured during the performing of the slump-flow test. It represents a test of the viscosity of the mixture; the recommended interval for the class SF2 is 3.5-6.0 s, in which all the mixtures "fit". Results are in the range of 4 – 6s, wherein the concrete mixes with silica fume were the slowest. Time longer than 2s puts them in the class of viscosity VS2. Neither segregation nor separation of the water was observed. L-box test was used to check the third key feature: ability of self-compacting concrete to pass between the reinforcing bars without blocking. All mixtures meet the criteria for the relative height of the concrete at the ends of L-box to be at least 0.8, and as the research was done with three reinforcing bars, which is a requirement for thicker reinforced structures, their class is PA2 [4]. Test results are in the range of 0.91 – 1.0, where the mix with lime achieved the best result .The biggest difference at the ends of L-box was measured in mixtures with silica fume, which is the logical consequence of the minimum spreading. Blocking of aggregate grains between the reinforcing bars was not recorded Segregation resistance, as the fourth feature of fresh SCC, was tested by sieve segregation rest. Results show that all mixtures are resistant to segregation and belong to the class SR2 (<15%). Density of concrete in fresh state in the mixtures with lime and silica fume was almost the same, 3.4% higher than the density of the mix with fly ash.

After 2 days, the concrete mix with lime had the highest density in the hardened state and the mix with fly ash the lowest (the difference 133.6 kg/m3 tj. 5.6%). This trend held even after 7 days, except that the difference was 179.5 kg/m3 (7.3%). After 28 days, the concrete with lime had the highest density, 2426.7 kg/m3, 123.4 kg/m3 (5.1%) greater than the concrete with fly ash.

The concrete with lime had the highest compressive strength after 2 days, 5.6MPa (11.7%), and 9.66MPa (21%) greater than the concrete with silica fume and fly ash. After 7 days compressive strengths of concrete with lime and silica fume are nearly equal and 6MPa (10.4%) greater than the strength of concrete with fly ash. After 28 days, the concrete with silica fume had the greatest compressive strength, 5.6 MPa (7.8%) greater than the concrete with lime, i.e 8.31MPa (11.5%) greater than the concrete with fly ash. Figure 1 shows the structure of concrete with lime – SCCL; there can be seen a contact of lime, which occurs in crystals with flat and smooth surface, no larger than 5 μm, and cement paste (in Figure 1, most likely CaO grain from the paste). The structure is pretty homogenous, there are visible pores of irregular shapes that are often elongated and resemble cracks, size to 10 μm. Porosity of concrete with fly ash – SCCF is highly expressed (Figure 2), with the pore diameters ranging from 30 to 90 μm but more often there are small pores with the diameters 30 - 40 μm. In Figure 3, there can be noticed very homogenous and compact structure of concrete with silica fume, the pores are small, order of magnitude of 7-8 μm.

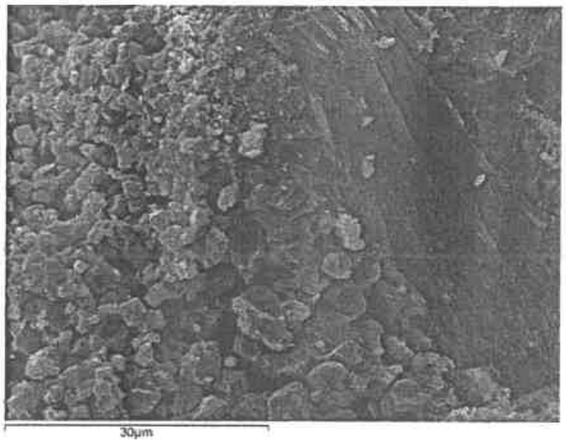

Figure 1. Sample SCCL: Contact of lime and cement paste

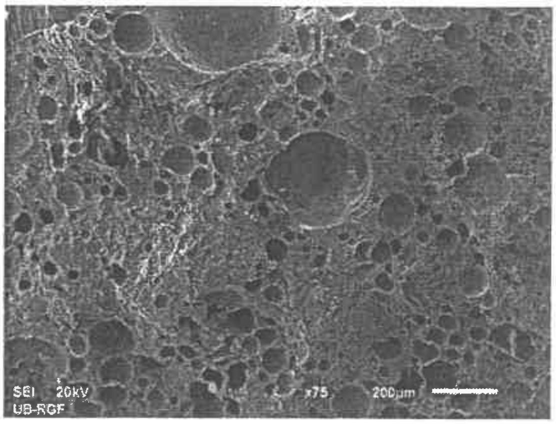

Figure 2. Sample SCCF: Sponge rubber concrete structure

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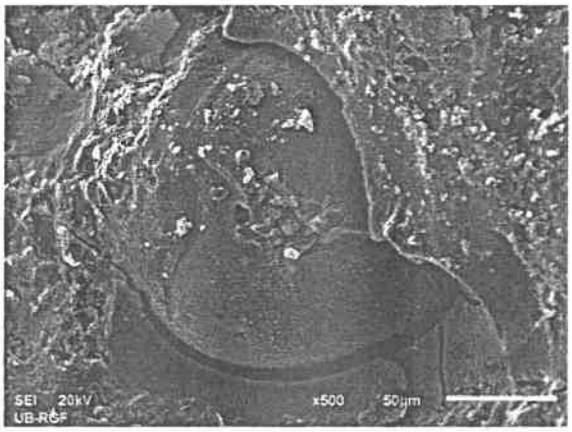

Figure 3. Sample SCCS: Silicate bead in cement paste

6. CONCLUSIONS

Properties of fresh self-compacting concrete depend on the type of mineral additive. The best properties of self-compacting are achieved using lime. This type of concrete had the best fluidity and viscosity, after passing through the reinforcement was completely horizontal, but the largest spreading in it caused the lowest segregation resistance. The mixture with fly ash had the best relationship with the diameter. Because they are very small (100 times smaller than a grain of cement), with a very large surface area of grain (15000 – 20000 m^2/kg), čestice silikatne prašine značajno povećavaju koheziju betona i nepovoljno utiču na samougradljivost svežeg betona. silica fume particles significantly increase the cohesion of concrete and adversely affect the self-compacting of fresh concrete. The mix with silica fume was hardly mobile, had the smallest diameter of spread, but also the greatest resistance to segregation.

Density of concrete in fresh state had similar values in the mixture with lime and silica fume, while in the mixture with fly ash it was lower.

To achieve consistency designed, it was necessary to intervene in the quality of water, that is to apply a different water-cement factor at the same other constituents of concrete. The greatest amount of water to achieve the desired consistency, was needed in the mixtures with fly ash, while in the concrete with silica fume it was also necessary to increase the amount of water needed.

Density of concrete in hardened state was not too different in concretes with lime and silica fume, while the concrete with fly ash had significantly lower values. This is, again, an expected result, having in mind the microstructure of concrete, which is sponge rubber in the concrete with fly ash, but compact in the concrete with lime or silica fume.

The greatest compressive strength after 2 days was noticed in the concrete with lime, after 7 days compressive strengths in the concrete with lime and in the concrete with silica fume nearly equated, whereas after 28 days, concretes with silica fume had the greatest compressive strength. Concretes with fly ash had the lowest compressive strength.

Impact of lime on concrete compressive strength: SEM analyses show the presence of lime particles in the concrete even after 28 days, and on the other hand, the two day increment of the strength confirms that these particles constitute the nucleus for hydration C_3S and C_2S thus speeding the reaction of hydration. This supports the thesis that lime is chemically inert.

Impact of fly ash on concrete compressive strength: When fly ash is added to concrete, pozzolanic reaction between silica (SiO2) and calcium hydroxide (Ca(OH)2 or lime, which is a by-product of hydration of Portland cement, starts. Weak pozzolanic reaction takes place during the first 24 hours at 20°C. Zbog toga se za datu količinu cementa, sa povećanjem sadržaja letećeg pepela postižu niže rane čvrstoće. Prisustvo letećeg pepela usporava reakciju alita u okviru Portland cementa u ranom stadijumu. Međutim, produkcija alita se kasnije ubrzava zahvaljujući stvaranju jezgara hidratacije na površini čestica letećeg pepela. SEM analize jasno pokazuju izuzetno sunđerastu, tj. poroznu strukturu betona sa letećim pepelom.

Impact of silica fume on concrete compressive strength: Silica fume is a pozzolan and it needs the presence of calcium hydroxide to be activated. Calcium hydroxide occurs in the process of cement hydration, so that silica fume can be activated only when cement starts to react. As silica fume reacts and produces calcium silicate hydrates, cavities and voids in concrete are filled, and at the same time the crystals formed, connect the space between the cement particles and aggregate grains. If silica fume is added to the mix, it is clear that the concrete matrix will be very homogenous and dense, resulting in improved strength.

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