АКАДЕМИЈА НАУКА И УМЈЕТНОСТИ РЕПУБЛИКЕ СРПСКЕ

НАУЧНИ СКУПОВИ
Knjiga XXXIX

ОДЈЕЉЕЊЕ ПРИРОДНО-МАТЕМАТИЧКИХ И ТЕХНИЧКИХ НАУКА
Knjiga 33

САВРЕМЕНИ МАТЕРИЈАЛИ

Бања Лука 2017

ACADEMY OF SCIENCES AND ARTS OF THE REPUBLIC OF SRPSKA

SCIENTIFIC CONFERENCES
Book XXXIX

DEPARTMENT OF NATURAL-MATHEMATICAL AND TECHNICAL SCIENCES
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Banja Luka 2017

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Бања Лука 2017.

SELF – COMPACTING CONCRETE WITH WASTE MATERIALS AS NEW ECOLOGICAL MATERIAL

I. Despotović

High building – Geodetic the school

Abstract: Construction industry uses vast amounts of natural resources, simultaneously producing significant amounts of construction waste, so that it has a great impact on the environment. Annual production of concrete in the world has reached 10 billion tons, classifying concrete in the most widely used building material. Having in mind the fact that 70 % of concrete is aggregate, it is clear what the quantity of natural and crushed aggregates requires.

Self-compacting concrete, being innovation in the field of concrete technology, contains a certain amount of powdered materials – fillers. There are various possibilities of selecting this component. If we used any of the industrial by-products, such as fly ash or silica fume, we would solve the problem of depositing these materials, and thus made concrete ecological material.

The research subject presented in this paper are properties and technology of self-compacting concrete made with various mineral additives: lime, fly ash, and silica fume, wherein the aggregates used, are both natural and recycled aggregates, obtained by demolition of retaining wall, whose amount is varied in the concrete.

Key words: Self – Compacting Concrete, recycled aggregate, fly ash, silica fume, lime.

1. INTRODUCTION

Construction industry uses vast amounts of natural resources, simultaneously producing significant amounts of construction waste, so that it has a great impact on the environment. Annual production of concrete in the world has reached· 10 billion tons, classifying concrete in the most widely used building material. Having in mind the fact that 70 % of concrete is aggregate, it is clear what the quantity of natural and crushed aggregates requires. Uncontrolled exploitation of aggregates from rivers seriously disrupts aquatic ecosystems and habitats, while the production of crushed natural aggregates increases harmful gas emissions, primarily of CO_2, which are responsible for the greenhouse effect. These gases are formed during blasting rocks and during the transportation of aggregates to the usually distant urban areas.

On the other hand, the amount of construction waste generated during the construction and demolition of buildings is growing rapidly, deepening the problem of disposing this waste, which is usually solved by making planned landfills (which occupy large areas of land and disposal is costly) or illegal dumps.

One of the solutions of the mentioned problems is recycling deposited building materials, primarily concrete. This idea is not new and developed countries, like Japan, the Netherlands, Belgium and Denmark achieve a high percentage of recycling of construction waste. Recycled concrete aggregates are mostly used in road engineering, for different fillings and making non-structural elements (curbs, fences, etc). Because of the uneven quality, the possibility of various impurities to rest during recycling, larger water absorption and lower bulk density, compared to natural aggregates, recycled aggregates require a series of tests and special technology of concrete making.

Self-compacting concrete, being innovation in the field of concrete technology, contains a certain amount of powdered materials – fillers. There are various possibilities of selecting this component. If we used any of the industrial by-products, such as fly ash or silica fume, we would solve the problem of depositing these materials, and thus made concrete ecological material.

2. SELF – COMPACTING CONCRETE

Self – compacting concrete (SCC), according to many authors „the most revolutionary discovery of concrete industry of the 20th century", does not need vibrating when placing and compacting. Under the influence of its own weight, it completely fills all parts of the formwork, even in the presence of dense reinforcement. Its advantages are fast construction, a reduced number of required workers, better final surface, easier placement, and increased durability, greater freedom in designing elements, noise reduction, vibration absence, and therefore healthier work environment. It is estimated that when using self–compacting concrete instead of vibrated concrete, the need for workers is reduced by about 10 %; when using prefabricated elements, construction time is shorter by about 5 %, and demand for workers decreased by about 20 %; when applying sandwich elements (steel – concrete) time saving is 20%, and savings in the labour force 50%. The main disadvantages of the use of self – compacting concrete are higher material prices, stricter quality requirements and increasing pressure on the formwork compared to vibrated concrete [1].

The basic components of the mixes in vibrated and self – compacting concrete are the same, but ratios differ, so that SCC contains more fine aggregate and fine particles, as well as additives of the latest generation (modifiers of viscosity and high capacity water reduction) compared to vibrated concrete.

3. MINERAL ADDITIVES

The initiators of the idea of applying *fly ash*, resulted from coal burning, in concrete were McMillan and Powers (1934). At the end of 40s the experiments carried out in the UK (Fulton and Marshal) led to the construction of dams Lednock, Clatworthy and Lubreoch, with fly ash as a cement additive. All these structures are after 60 years in excellent condition [2]. During the combustion of coal in a furnace at temperatures between 1250°C and 1600°C, non-combustible particles combine to form 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, pozzollanic reaction starts between silicon dioxide (SiO_2) and calcium hydroxide ($CaOH_2$) or lime, which is a by-product of hydration of Portland cement. The resulting products of hydration fill pores reducing the porosity of the matrix. These products differ from the products formed in concrete containing only Portland cement.

Silica fume is formed during melting quartz at high temperature in an electric arc furnace, wherein silicon or ferrosilicon occurs. Because of the huge amount of electricity needed, these furnaces are located in the countries with significant electrical potential, such as Scandinavian countries, USA, Canada, South Africa and Australia. High purity quartz is heated to 2000°C using coal, coke or wood chips as fuel and then electric arc is introduced in order to remove metals. By melting quartz, silicon oxide is released in gaseous state, and it is mixed with oxygen in the upper parts of the furnace, where it oxidizes turning into tiny particles of amorphous silicon dioxide. Particles are carried out from the furnace through the collector and cyclone, where the unburned parts of coal are removed, and then "blown" into the special filter bags.

Due to its nature, even a small addition of silica fume significantly changes physical and chemical properties of concrete. The customary dosage of 8- 10% by weight of cement means between 50 000 and 100 000 microspheres of dust per cement grain, which directly increases the cohesion of concrete. If silica fume is used in the powder form, there will be a need for a greater amount of water to allow mixing and placement of concrete so it is necessary to apply plasticizers and superplasticizers. Because of higher specific area and higher content of silicon dioxide, silica fume is much more reactive than fly ash or granulated slag. This increased reactivity initially increases hydration rate of C_3S cement mineral, but after two days the process becomes normal.

Lime is more widely used as a cement additive than a concrete additive. European norm EN197 - 1 provides two classes of Portland cement with lime whose labels are CEM II/L (or L-L instead of A-L) and CEM II/BL (or L-L instead of B-L). The former contains between 6 and 20% of lime and the latter 21 – 35%. Requirements that lime for cement should meet are the following: $CaCO_3$ content should be greater than 75%, clay content, determined by methylene blue test, must 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. The presence of lime causes the acceleration of the hydration process and hydration shrinkage of concrete in the first few hours, because the particles of lime are used as additional cores for hydration.

4. RECYCLED AGGREGATE

The use of recycled aggregates in structures is still relatively new. Buck (1977) defines its beginning in the period immediately after the Second World War, when there was a tremendous need for building new facilities and infrastructure and at the same time, clearing the existing ruins. After that, the use of recycled aggregates stopped but during 70s the US started to re-use recycled aggregates in non-construction purposes, mainly as fill material and different fillings in road engineering [3]. Due to the above mentioned reasons, testing of recycled aggregates (not just concrete) and their application are more relevant today than ever, because the need for aggregates globally reached 26.8 billion tons per year [4]. For example, the US annually recycles about 149 million tons of concrete waste. According to the data from the annual report of the European Association for aggregates (2010), recycled aggregates make 5% of the total production of aggregates in the European Union, where Germany is the largest producer, followed by Great Britain (49 million tons), the Netherlands (20 million tons) and France (17 million tons). In Australia, around 50% of the concrete waste is recycled, while in Japan, the impressive 98% of concrete waste is turned into recycled aggregate [5]. It is estimated that in the Republic of Serbia, about 1 million tons of construction waste and demolition waste is annually produced. This waste ends up in landfills of municipal waste, and is also used as inert material for coverage of waste at landfills. Recycling construction waste actually does not exist [6].

Technological process for the production of recycled aggregates involves crushing pieces of old concrete to a certain grain size and their sieving, which is preceded by the separation of metal parts, using magnetic separator, and manual or mechanical removal of foreign substances. Grains of recycled aggregate, obtained by this recycling process, consist of grains (or grain parts) of natural aggregates and cement mortar of original concrete which partially or completely wraps them. The presence of old cement mortar, which is of less density and higher porosity than grains of natural aggregates, significantly affects a number of physical and mechanical properties, of both recycled aggregate and concrete with recycled aggregate, i.e. causes „worse" properties of recycled aggregate compared to natural aggregate.

5. MY OWN EXPERIMENTAL RESEARCH

5.1 Composition of concrete mixes

For the purposes of the experimental work, nine three-fraction concrete mixes have been made. Cement PC 42.5R (Holcim Popovac) has been used as well as mineral additives: lime (manufacturer „Jelen Do"), fly ash (from the power plant „Nikola Tesla B" in Obrenovac), and silica fume (product of Sikafume , a manufacturer of building chemicals SIKA); natural aggregate (Luka „Leget", Sremska Mitrovica), recycled aggregate obtained by crushing demolished retaining wall in the quarry Ostrovica, near Nis. Control concrete was made with each of the additives and a natural aggregate; in mixes K50, P50 and S50, fraction 8/16mm was replaced by the recycled aggregate, and in mixes K100, P100 and S100, both coarse fractions (4/8 and 8/16) were replaced by recycled fractions. In all the mixes, superplasticizer ViscoCrete 5380 (manufacturer SIKA) has been used, which was dosed according to the manufacturer. The criterion in the designing mixes was to achieve the same consistency of concrete, i.e. slump-flow class SF2, which includes the usual uses of concrete and involves spreading from 66 to 75cm. While making concrete mixes, the aggregate was first mixed with half of the required water for a period of about 30 seconds, and then other components were added. When used recycled aggregate, the amount of water which was absorbed by the aggregate in 30 minutes (II fraction 2.22%, III fraction 1.5%) was added, although this principle could not be consistently applied.

The fresh concrete tests were done for density, fluidity – slump flow test according to EN 12350-8, viscosity – T500 test according to EN 12350-8, the ability of the passage between the reinforcement – L box test according to EN 12350-10, segregation resistance – Sieve segregation test according to EN 12350-11.

The hardened concrete tests were done for density, compressive strength, tensile strength by bending, shrinkage, water impermeability, water absorption, and SEM analysis (Scanning Electron Microscopy).

Composition of concrete mixes is shown in Table 1.

Table 1: Concrete mixes

	cement (kg/m3)	lime (kg/m3)	fly ash (kg/m3)	silica fume (kg/m3)	0/4mm (kg/m3)	4/8mm (kg/m3)	8/16mm (kg/m3)	water (kg/m3)	VSC5380 (kg/m3)
EK	400	120	0	0	770.86	306.28	532	170.8	4.94
EP	400	0	120	0	770.86	306.28	532	192.66	4.94
ES	400	0	0	52	770.86	306.28	532	185.71	4.94
K50	400	120	0	0	809.14	306.28	505.43	182.86	5.08
P50	400	0	120	0	809.14	306.28	505.43	214.28	5.08
S50	400	0	0	52	809.14	306.28	505.43	197.14	5.08
K100	400	120	0	0	809.14	306.28	505.43	189.5	5.08
P100	400	0	120	0	809.14	306.28	505.43	221	5.08
S100	400	0	0	52	809.14	306.28	505.43	208.6	5.08

5.2 Test results

The test results for concrete in the fresh state are shown in Table 2.

Table 2: Test results for concrete in the fresh state

Concrete mix	Density kg/m3	Slump-flow cm	T500 s	L-box H1/H2	Sieve segregation %
EK	2418	73	4	1	12.4
EP	2288	70	4	0.94	11
ES	2416	66	6	0.91	6.8
K50	2362	70	5	0.96	12
P50	2279	70	5	0.95	7.8
S50	2324	67	5	0.94	5.2
K100	2347	69	5	1	10
P100	2298	66	6	0.91	5.5
S100	2359	66	6	0.92	7.5

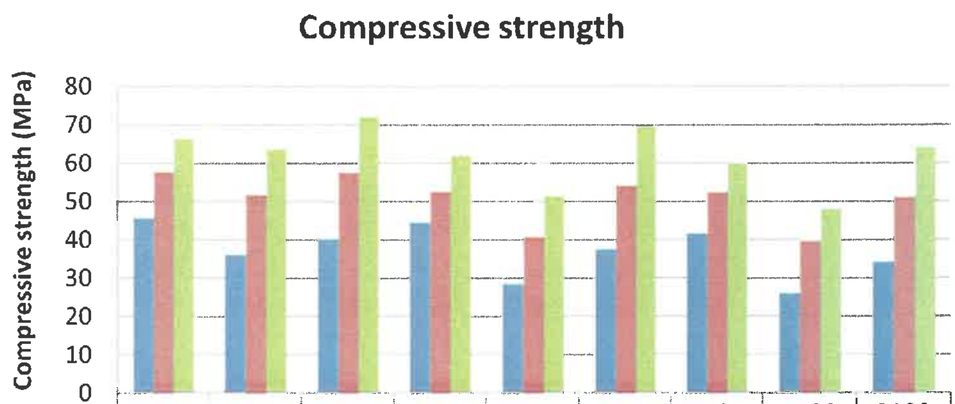
The test results for density of concrete in the hardened state, according to SPRS EN 12390 – 7:2010, after 2,7 and 28 days are shown in Table 3.

Testing compressive strength was carried out on the cubes with edges of 15cm. The test results for compressive strength after 2,7 and 28 days are shown in Chart 1.

Testing tensile strength by bending was done after 28 days on the samples of dimensions 12x12x36cm. The results are shown on Chart 2.

Table 3: Test results for density (kg/m3)

	EK	EP	ES	K50	P50	S50	K100	P100	S100
2 dana	2396	2262.4	2366.4	2356.5	2313.5	2313	2363.5	2284.2	2312
7 dana	2469.2	2289.7	2361.8	2370	2315.5	2315.8	2352.9	2292.5	2338.6
28 dana	2426.7	2306.2	2376.3	2401.7	2314	2325	2357	2303.3	2333



	EK	EP	ES	K50	P50	S50	K100	P100	S100
2 days	46	36.34	40.4	44.82	28.68	37.75	41.86	26.2	34.38
7 days	58.24	52.18	58.05	53.12	41.24	54.67	52.86	40.18	51.59
28 days	66.68	64	72.31	62.17	51.7	69.7	60.3	48.2	64.5

Chart 1: Compressive strength

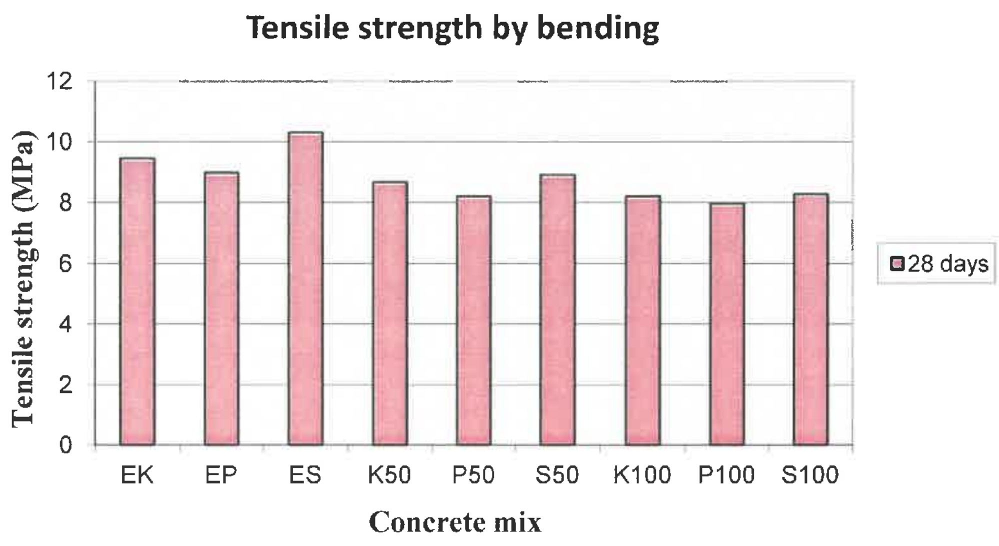


Chart 2: Tensile strength by bending

Shrinkage test was done on the samples of dimensions 12x12x36cm, all in accordance with SRPS UM1.029. 72 hours after the samples are made they are taken out from the water and exposed to thermo hygrometric conditions. We chose it to be 70 ± 5 % air humidity and a constant temperature of 20± 4 °C, which is the standard prescribed for structures and elements located in free space. First measurement was done 72± 0.5 h hours after the samples were made, and then after 4 and 7 days. After this, further measurements were done after every seven days, until the process stabilized. The results of shrinkage tests after 4, 7, 14, 21, 28, and 35 days, are shown in Chart 3.

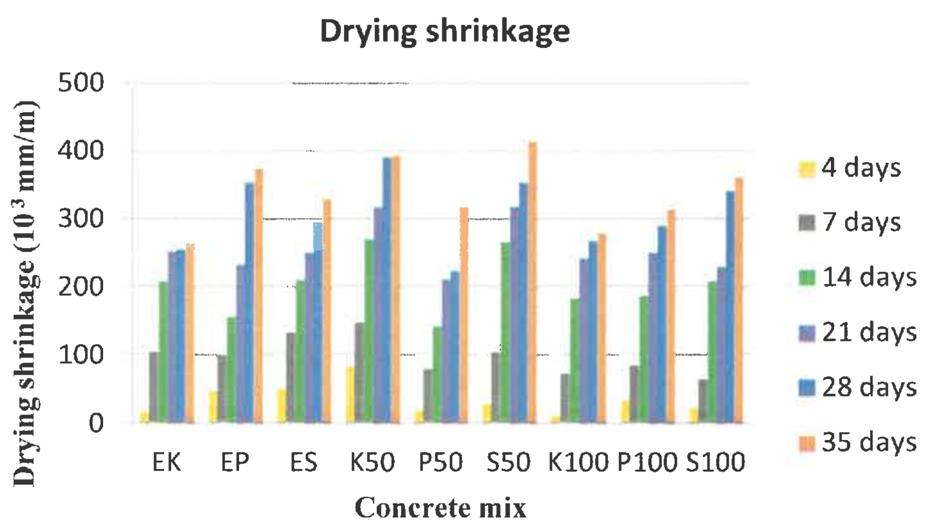


Chart 3: Shrinkage

Water absorption test was done on the samples of dimensions 12x12x36cm, by the method of gradual immersion. The test results for water absorption after 28 days are shown in Chart 4.

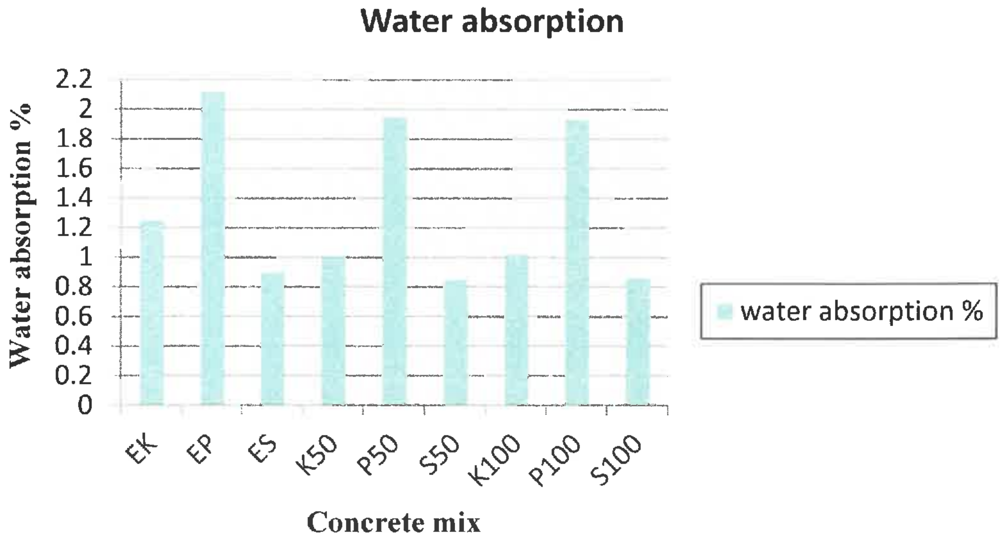


Chart 4: Water absorption

Water permeability testing was done on the samples of dimensions 200x200x-150mm, in concrete at an age of 28 days, all in accordance with SRPS U.M1.015:1998. The samples were exposed to water under pressure of 1 bar for 24 hours; then the following 48 hours of 3 bars and finally, the last 24 hours of testing, under pressure of 7 bars. After this, they were broken and the depth of water ingress is measured. With the samples with lime and silica fume, ingress of water of about 2cm was recorded, while with the samples with fly ash, ingress of water was 8 – 10cm.

Scanning electron microscopy (SEM analysis) enables to „look into" the structure of concrete made and to better explain the results obtained by testing (Figures 1 – 3).

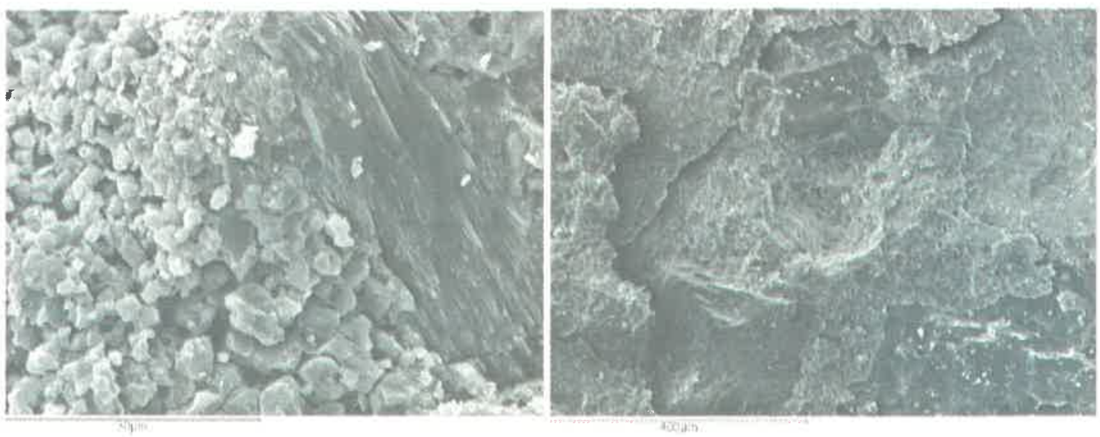


Figure 1: Microstructure of the concrete with lime

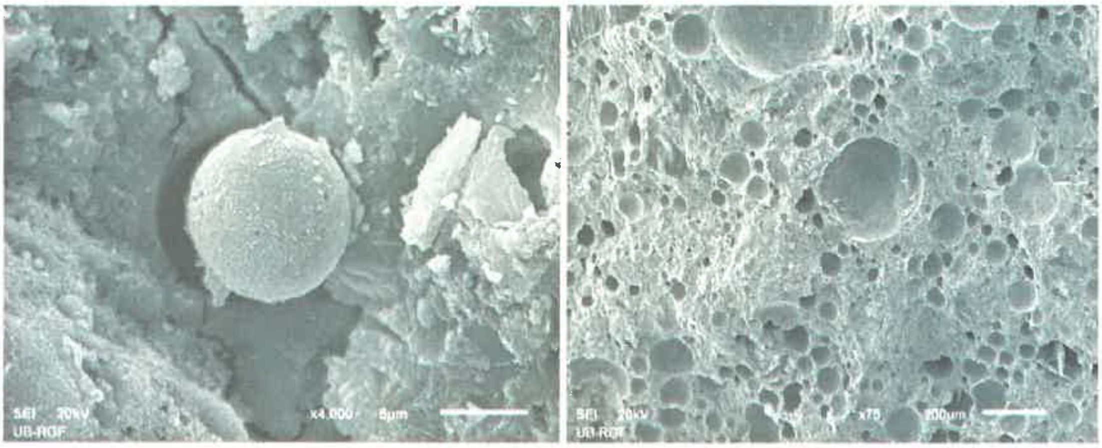


Figure 2: Microstructure of the concrete with fly ash

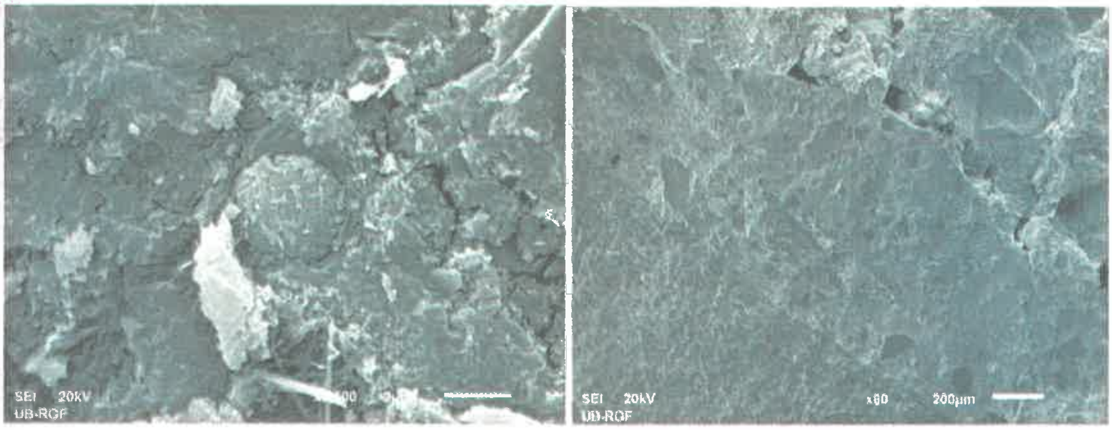


Figure 3: Microstructure of the concrete with silica fume

6. THE RESULTS ANALYSIS

Fresh concrete was spread from 66 to 73cm which designed mixes of class SF2 which fits in most common use of concrete in construction. Mixes with silica fume had the slightest mobility, as well as mixes with recycled aggregate, because grains with sharp edges were more difficult to „move" while levelling concrete. The largest spreading was recorded in control concrete with lime - 73cm, and the smallest in control concrete with silica fume, in mixes with silica fume and coarse recycled aggregate, and in mixes with fly ash and coarse recycled aggregate - 66.

T500 is the time that concrete reaches 500mm, and it is measured when doing slump-flow test. It represents a check of viscosity of the mix; the recommended interval for class SF2 is from 3.5 to 6.0s, and all mixes „fit" into it. The results are in the range of 4 – 6s, wherein concrete mixes with silica fume were the slowest. Time longer than 2s puts them in viscosity class VS2.

All mixes meet the criterion that height ratio of concrete at the ends of L-box is at least 0.8 and their class is PA2 as the testing was done with three reinforcement rods which is a requirement for thicker reinforced construction. The test scores are in the range of 0.91 – 1.0, wherein mixes with lime achieved the best results (nearest to 1.0). The biggest difference at the ends of L box was measured in mixes with silica fume, which is a logical consequence of its minimum spreading. Blocking of aggregate grains between reinforcement rods was not recorded in any case.

Sieve test shows that all mixes are resistant to segregation and they belong to class SR2 (<15%), while larger spreading means lower resistance to segregation.

Control concrete with lime had the highest density in the fresh state, 2418 kg/m^3, nearly the same as the control concrete with silica fume (2416 kg/m^3, i.e. 0.08 lower), while minimum density was found in the mix P50 (fly ash and recycled III fraction) 2279 kg/m^3, 5.7% lower. Generally speaking, mixes with fly ash had the lowest density, about 70 kg/m^3 lower, compared to the corresponding mixes with lime and silica fume.

While designing concrete mixes, in order to obtain the same consistency because of the use of recycled aggregate, it was necessary to intervene in two directions: to increase the amount of water and to reduce the amount of III fraction by 5%, simultaneously increasing the amount of sand by 5%. Without these interventions in the composition, it was impossible to achieve self-compacting of mixes because of the sharp-edged grain shape of recycled aggregates and granulometric composition itself (recycled aggregate had 7% of oversized grains). The greatest change of the water- cement ratio was found in concrete mixes with fly ash; at the same amount of mineral additive (and all other components), 21.86 kg (12.8%) of water was added into the control concrete with fly ash compared to the control concrete with lime; in the mix with III recycled fraction 31.42 kg (17.2%) compared to the appropriate mix with lime and in the mix with I and III fraction 31.5 kg (16.6%). Silica fume has much smaller particles than lime and fly ash, so that its dosage was 52 kg/m3 of concrete, i.e. 13% by the mass of cement (the usual dosage is 10 – 15%). We added 14.91 kg (8.7%) of water into the control concrete with silica fume compared to the control concrete with lime and 14.28 kg (7.8%) and 19.1 kg (10.11%) compared to mixes with lime and recycled aggregate. The required class of consistency was obtained at the lowest water-cement ratio in mixes with lime, while the highest amount of water was needed in mixes with fly ash. The lowest water-cement ratio was recorded in the control concrete with lime – 0.43 (at the same time the lowest water-cement ratio – 0.33), and the highest in mixes with fly ash and both two coarse recycled fractions – 0.46. It is necessary to point out that concrete mixes with lime, at the lowest content of water compared to other mixes, had the largest diameters of spreading and the best properties of self-compacting.

The highest density in the hardened state after two days was recorded in the control concrete with lime, and the lowest in the control concrete with fly ash (the difference 133.6 kg/m^3 i.e.5.6%). This trend was held even after 7 days excepting that the difference amounted 179.5 kg/m^3 (7.3%). After 28 days, control concrete with lime had the highest density, 2426.7 kg/m^3, 123.4 kg/m^3 (5.1%) higher than the mix with fly ash and both two coarse recycled fractions, and 120.5 kg/m^3 (5%)

higher than control concrete with fly ash. Density in the hardened state in mixes with silica fume ranged from 2312 kg/m^3 (S100, 2days) to 2366.4 kg/m^3 (ES, 28days); those are the values „between" the corresponding values in lime and fly ash. It should be borne in mind that, for making concrete mixes, we used 52 kg of silica fume and 120 kg of lime and120 kg of fly ash.

The highest value of the compressive strength after 2 days was recorded in the control concrete with lime, and the lowest in the mix with fly ash and both two coarse recycled fractions – P100. The difference was 19.8 MPa (43%). After 7 days, control concrete with lime and control concrete with silica fume had nearly the same compressive strength (58MPa), while the mix P100 reached 40.18 MPa (the difference 17.82 MPa, i.e.30.7%). After 28 days, the highest value of strength was found in the control concrete with silica fume, 72.31 MP, and the lowest in the mix P100, 47.2 MPa (the difference 25.11 MPa, i.e. 34.7%). Considering mixes with lime, it can be concluded that the differences in the obtained strength, when using natural and recycled aggregate, are relatively small, 4.51 MPa (6.8%) and 6.38 MPa (9.6) – comparison of control concrete with mixes in which one or both coarse fractions are replaced. In mixes with fly ash, the difference is 12.3 MPa (19.2%) and 16.8 MPa (26.2%). Greater difference in strength among mixes with fly ash can be explained by the uneven quality of recycled aggregate, which represents a major problem of their application. In the group of mixes with silica fume, the difference between the control concrete mix and other two mixes was 2.61 MPa (3.6%) and 7.81 MPa (10.8%). The fastest increment of strength was found in mixes with silica fume. In all concrete mixes with natural aggregate, a failure was recorded through cement paste, while in mixes with recycled aggregate, the failure was found through aggregate, no matter which mineral additive was used.

Differences in the results of tensile strength by bending are not great. The values of strength by bending are in the range of 7.97 MPa (P100) to 10.31 MPa (ES). The difference between these values is 2.34 MPa (22.7).

Available data from the literature, like my own previous researches [7] show that it is difficult to predict or find regularities when shrinkage of concrete is in question. The measurements done show that the largest shrinkage was found in the concrete mix with silica fume and III recycled fraction, S50, and the smallest in the control concrete with lime EK, wherein the difference is 56%. No regularities can be drawn from these results: mixes with III recycled fraction had greater shrinkage than mixes with II and III recycled fraction, wherein differences in lime and silica fume were more pronounced than in concrete with fly ash. If classification of concrete is done according to the mineral additive, the largest shrinkage was found in mixes with silica fume; if the criterion is aggregate, the largest shrinkage among control concrete mixes, was found in the control concrete with fly ash (29% more than in the control concrete with lime and 11.7% more than in the control concrete with silica fume); among mixes with III recycled fraction S50 (4.8% more than in mixes with lime and 22.8% more than in mixes with fly ash), and among mixes with II and III recycled fraction S100 (22.8% more than in mixes with lime and 13.2% more than in mixes with fly ash).

Water absorption is in the range of 0.85% (mix S50) to 2.12% (mix EP). The highest water absorption was recorded in the mixes with fly ash, and the lowest in the mixes with silica fume, which is absolutely in accordance with the achieved concrete structure, which was, according to SEM analyses, the most porous in concrete mixes with fly ash. Average water absorption in mixes with silica fume was 0.9%, in mixes with lime 1%, and in mixes with fly ash 2%. When testing water impermeability, the ingress of water into the concrete with lime and silica fume, was very small, about 2cm, so as these mixes were practically impermeable, while in the mixes with fly ash, larger ingress of water was noted, about 10cm, which is the consequence of the increasing porosity of these concretes and, according to the criterion, that penetration of water must not be larger than 4cm [8], concretes with fly ash can be considered permeable.

7. CONCLUSIONS

Properties of self-compacting concrete are affected both by a kind of mineral additive and a kind of the applied aggregate. Best properties of self-compacting are achieved by using lime. These concrete mixes had the best fluidity and viscosity, after passing through reinforcement they were absolutely horizontal, but because of the largest spreading, they had minimum segregation resistance. Mixes with fly ash had the best ratio of diameter of spreading (fluidity) and segregation resistance. Since they are very small (about 100 times smaller than cement or ash grains), and have very large area of grain (15 000 to 20 000 m^2/kg), particles of silica fume significantly increase concrete cohesion and adversely affect the fresh concrete self-compacting. Use of recycled aggregates, due to a sharp-edged shape of grains which increases adhesion, also adversely affects the properties of self-compacting concrete, so it was necessary to intervene in the sense of reducing III or increasing I fraction by 5%, in order to achieve the desired consistency.

Effect of silica fume on the compressive strength of concrete: silica fume is pozzolan which is activated by calcium hydroxide. Calcium hydroxide is formed in the process of cement hydration so that silica fume can be activated only when cement begins to react. As concrete starts to bind and harden, pozzolanic activity of silica fume becomes the dominant reaction. Due to the high specific area and higher content of silicon dioxide, silica fume is much more reactive than fly ash. This increased reactivity will initially significantly intensify hydration rate of C_3S cement fraction, but after two days the process becomes normal. As silica fume reacts and forms calcium silicate hydrates, voids and pores in the concrete are filled, wherein crystals formed connect the space between cement particles and aggregate grains. If this effect is added by the physical presence of silica fume in the mix, it is clear that the concrete matrix will be very homogenous and dense, resulting in improved strength and impermeability, which is clearly seen in SEM pictures. Besides, owing to their size, silica fume particles can cause "micro filler" effect, additionally filling transit zone of concrete.

Effect of fly ash on the compressive strength of concrete: when fly ash is added to concrete, there is pozzolanic reaction between the silicon dioxide (SiO_2) and calcium hydroxide ($Ca(OH)_2$) or lime, which is a by-product of hydration of Portland cement. Weak pozzolanic reaction occurs during the first 24 hours at a temperature of 20°C. That is why, for a given amount of cement, with increasing fly ash content, lower early compressive strength is achieved. The presence of fly ash slows the reaction of alite in Portland cement at an early stage. Meanwhile, production of alite later accelerates thanks to the creation of cores of hydration on the surface of fly ash particles. Calcium hydroxide is pressed in the surface of the glassy particles, reacting with SiO_2 or Al_2O_3-SiO_2 grid. Slower early strengths of concrete with fly ash prevent its application where high early strength is expected, which can be solved by using accelerator. Therefore, the available literature refers to the design and monitoring of the 90 day compressive strength of concrete. SEM analyses evidently show extremely spongy, i.e. porous structure of the concrete with fly ash, no matter which aggregate is used.

The effect of lime on the compressive strength of concrete: SEM analyses show the presence of lime particles in concrete even after 28 days, and on the other hand, two day increment of strength confirms that these particles constitute the core for hydration C_3S and C_2S, so that they accelerate the reactions of hydration, which supports the thesis that lime is chemically inert.

The main problem of using recycled aggregate is its increased porosity, caused by the remained old cement paste on aggregate grains. This is the main reason for uneven quality of aggregates and it causes a decrease in the compressive strength of concrete. The amount of recycled aggregate affects the absorption of water in the sense that with increasing the amounts of recycled aggregates, the percentage of water absorption is also increased, as a consequence of greater porosity.

Using all three tested mineral additives, high performance self-compacting concretes can be obtained. Silica fume is ahead, but having in mind economic and ecological component of fly ash, as well as relatively small difference in the obtained results, fly ash should necessarily be taken into account. Besides, the use of recycled aggregates (with increased testing) makes these concretes ecological rightly considered. Insufficient research in this area opens up a wide range of options for further testing, in terms of variations in the amount of cement, combining different additives, etc.

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ACKNOWLEDGEMENTS

The work reported in this paper is a part of the investigation within the research project TR 36017 "Utilization of by-products and recycled waste materials in concrete composites in the scope of sustainable construction development in Serbia: investigation and environmental assessment of possible applications", supported by the Ministry for Science and Technology, Republic of Serbia. This support is gratefully acknowledged.

И. Деспотовић

САМОУГРАЂУЈУЋИ БЕТОН СА ОТПАДНИМ МАТЕРИЈАЛИМА КАО НОВ ЕКОЛОШКИ МАТЕРИЈАЛ

Апстракт: Грађевинска индустрија исцрпљује природне ресурсе истовремено производећи значајне количине грађевинског отпада те на тај начин утиче на природну средину. Годишња производња бетона у свету је достигла 10 милијарди тона годишње, сврставајући бетон у најчешће коришћен грађевински материјал. Имајући у виду чињеницу да 70% бетона чини агрегат, јасно је колике су потребе за речним и дробљеним агрегатом.

Самоуграђујући бетон, и сам иновација на пољу технологије бетона, садржи одређену количину прашкастог материјала – филера. Постоје различите могућности за избор ове компоненте, при чему примена индустријских нус – продуката попут летећег пепела или силикатне прашине решава проблем њиховог одлагања на депонију, а бетон чини еколошким материјалом.

Предмет рада су карактеристике и технологија самоуграђујућег бетона са различитим минералним додацима: млевеним кречњаком, летећим пепелом и силикатном прашином, при чему су коришћени речни и рециклирани агрегат, добијен рушењем потпорног зида, чија количина је варирана у бетону.

Кључне ријечи: самоуграђујући бетон, рециклирани агрегат, летећи пепео, силикатна прашина, кречњак.

Издавач
АКАДЕМИЈА НАУКА И УМЈЕТНОСТИ
РЕПУБЛИКЕ СРПСКЕ

ЗА ИЗДАВАЧА
Академик Рајко Кузмановић

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ГРАФОМАРК
ЛАКТАШИ

ЗА ШТАМПАРИЈУ
Јелена Милинчић

ТИРАЖ
300 КОМАДА

Бања Лука, 2017

CIP - Каталогизација у публикацији
Народна и универзитетска библиотека
Републике Српске, Бања Лука

620.1(082)

МЕЂУНАРОДНИ научни скуп Савремени материјали (9 ; 2016 ; Бања Лука)

Савремени материјали : [зборник радова] / [Међународни научни скуп], Бања Лука, [4-5. септембра 2016. године] ; главни уредник Рајко Кузмановић ; одговорни уредник Драгољуб Мирјанић ; редакциони одбор Рајко Кузмановић... [и др.]. - Бања Лука : Академија наука и умјетности Републике Српске, 2017 (Лакташи : Графомарк). - 606 стр. : илустр. ; 24 cm. - (Научни скупови ; књ. XXXIX. Одјељење природно-математичких и техничких наука ; књ. 33)

На спор. насл. стр.: Contemporary Materials. - Текст ћир. и лат. - Текст на срп. и енгл. језику. - Библиографија уз сваки рад. - Abstract.

ISBN 978-99938-21-89-2

COBISS.RS-ID 6316568