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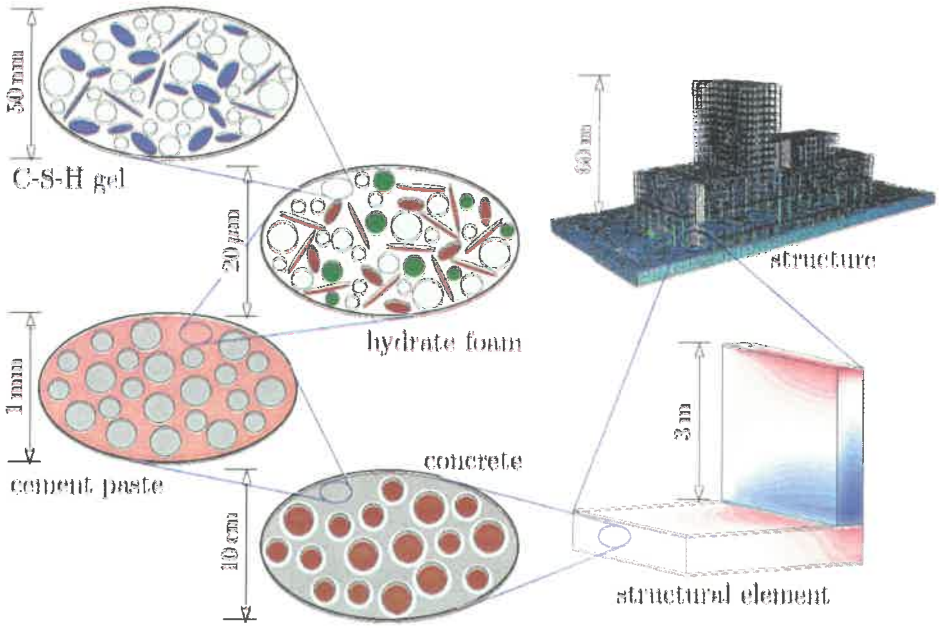

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Influence of different mineral additives and recycled concrete aggregates on the properties of self – compacting concrete in the fresh state

Iva Despotović *[a], Ksenija Janković[b],
[a]Belgrade University College of Applied Studies in Civil Engineering and Geodesy, Serbia
[b]IMS Institute, Belgrade, Serbia

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. Self-compacting concrete 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 the properties and technology of self-compacting concrete in the fresh state, 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.

Keywords: 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. 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. 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 [1,2].

One of the solutions of the mentioned problems is recycling deposited building materials, primarily concrete. 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 [3,4,5].

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 [6].

The research subject presented in this paper are properties and technology of self-compacting concrete in the fresh state, 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.

*ivickad@gmail.com; phone 0038164 1918 539

2. EXPERIMENTAL RESEARCH

2.1 Materials used in experiment

Fly ash - 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. In the reactions of Portland cement and water, hydrated lime ($CaOH_2$) is formed first, in the space between particles, because of its limited solubility. In the presence of water, lime reacts pozzollanic with fly ash to form new hydration products with fine pore structures. Particles smaller than 50—are generally spherical (Figure 1), while larger particles may be irregularly shaped [7].

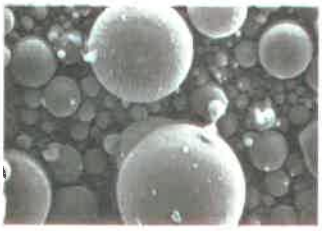

Figure 1. Fly ash particle (SEM picture) [7]

Silica fume is formed during melting quartz at high temperature in an electric arc furnace, wherein silicon or ferrosilicon occurs (Figure 2). 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. In terms of placeability, it should be noted that fresh concrete with silica fume has less spreading (slump values) because of greater cohesion. Besides the lack of segregation and filling the main cavities, in concrete with silica fume, there is no separation of water. That is why, immediately after placement, it is necessary to begin with appropriate curing.

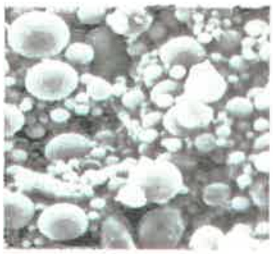

Figure 2. Silica fume (SEM picture) [8]

Lime - 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 (Figure 3).

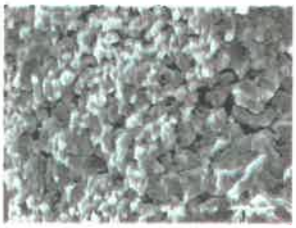

Figure 3. Lime (SEM picture)

Recycled concrete aggregate - 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 [9,10].

2.2 Concrete mixtures

For the purposes of the experimental work, nine three-fraction concrete mixtures have been made (Table 1).

Table 1. Composition of concrete mixtures.

	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)
EL	400	120	0	0	770.86	306.28	532	170.8	4.94
EF	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
L50	400	120	0	0	809.14	306.28	505.43	182.86	5.08
F50	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
L100	400	120	0	0	809.14	306.28	505.43	189.5	5.08
F100	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

Cement PC 42.5R has been used as well as mineral additives: lime, fly ash and silica fume (product of Sikafume , a manufacturer of building chemicals SIKA); natural aggregate, recycled aggregate obtained by crushing demolished retaining wall in the quarry. Control concrete was made with each of the additives and a natural aggregate; in mixtures L50, F50 and S50, fraction 8/16mm was replaced by the recycled aggregate, and in mixtures L100, F100 and S100, both coarse fractions (4/8 and 8/16) were replaced by recycled fractions. In all the mixtures, superplasticizer has been used, which was dosed according to the manufacturer. The criterion in the designing mixtures 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(Figure 4).

Figure 4. Testing of fresh concrete

3. 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 mixture	Density kg/m3	Slump-flow cm	T500 s	L – box H1/H2	Sieve segregation %
EL	2418	73	4	1	12.4
EF	2288	70	4	0.94	11
ES	2416	66	6	0.91	6.8
L50	2362	70	5	0.96	12
F50	2279	70	5	0.95	7.8
S50	2324	67	5	0.94	5.2
L100	2347	69	5	1	10
F100	2298	66	6	0.91	5.5
S100	2359	66	6	0.92	7.5

Fresh concrete was spread from 66 to 73 cm which designed mixtures of class SF2 which fits in most common use of concrete in construction. Mixtures with silica fume had the slightest mobility, as well as mixtures 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 mixtures with silica fume and coarse recycled aggregate, and in mixtures with fly ash and coarse recycled aggregate – 66 cm.

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 mixture; the recommended interval for class SF2 is from 3.5 to 6.0s, and all mixtures "fit" into it. The results are in the range of 4 – 6s, wherein concrete mixtures with silica fume were the slowest. Time longer than 2s puts them in viscosity class VS2.

All mixtures 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 mixtures with lime achieved the best results (nearest to 1.0). The biggest difference at the ends of L box was measured in mixtures with silica fume, which is a logical consequence of its minimum spreading. Blocking of aggregate grains between reinforcement bars was not recorded in any case.

Sieve test shows that all mixtures 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, mixtures 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 mixtures, 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 mixtures 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 mixtures 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 mixture with III recycled fraction 31.42 kg (17.2%) compared to the appropriate mixture with lime and in the mixture 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 mixtures with lime and recycled aggregate. The required class of consistency was obtained at the lowest water-cement ratio in mixtures with lime, while the highest amount of water was needed in mixtures 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 mixtures with fly ash and both two coarse recycled fractions – 0.46. It is necessary to point out that concrete mixtures with lime, at the lowest content of water compared to other mixtures, had the largest diameters of spreading and the best properties of self-compacting.

4. CONCLUSIONS

Properties of self-compacting concrete in the fresh state 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 mixtures 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% and increasing the amount of water and superplasticizer, in order to achieve the desired consistency.

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