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SELF-COMPACTING CONCRETE WITH RECYCLED CONCRETE AGGREGATE AS ECOLOGICAL MATERIAL

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Abstract
The concept of sustainable development, which in addition to social and economic aspects, includes energy saving, environmental protection and the conservation of exhaustible natural resources, is a strategic goal of many economic sectors including the particular contribution expected from the construction. 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 and hardened state, made with various mineral additives: lime, fly ash, and silica fume, wherein the aggregates used, are both natural and recycled aggregates.

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 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. Materials

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. 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 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].
Silica fume is formed during melting quartz at high temperature in an electric arc furnace, wherein silicon or ferrosilicon occurs. 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. 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. 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.
The use of **recycled aggregates** in structures is not 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].

3. Experimental research

For the purposes of the experimental work, nine three-fraction concrete mixes have been made. Cement PC 42.5 has been used as well as mineral additives: lime (120 kg/m^3), fly ash (from the power plant, 120 kg/m^3), and silica fume (52 kg/m^3); natural aggregate, recycled aggregate obtained by crushing demolished retaining wall. 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. 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. 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.

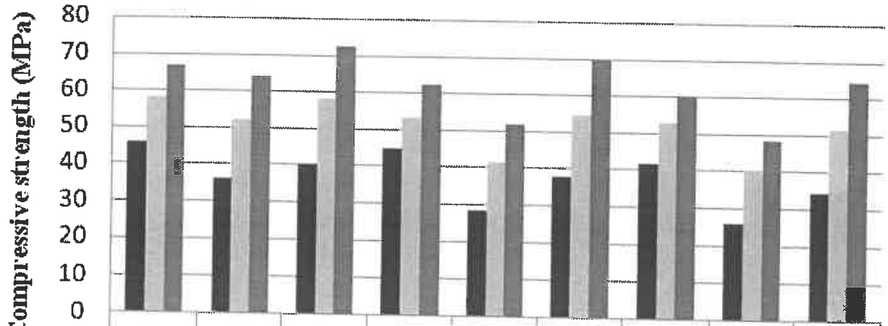
3.1 Test results

The test results for concrete in the fresh state are shown in Table 1.

Table 1: 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

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.



	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

Figure 1: Compressive strength.

Shrinkage test was done on the samples of dimensions 12x12x36cm. 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. 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 2.

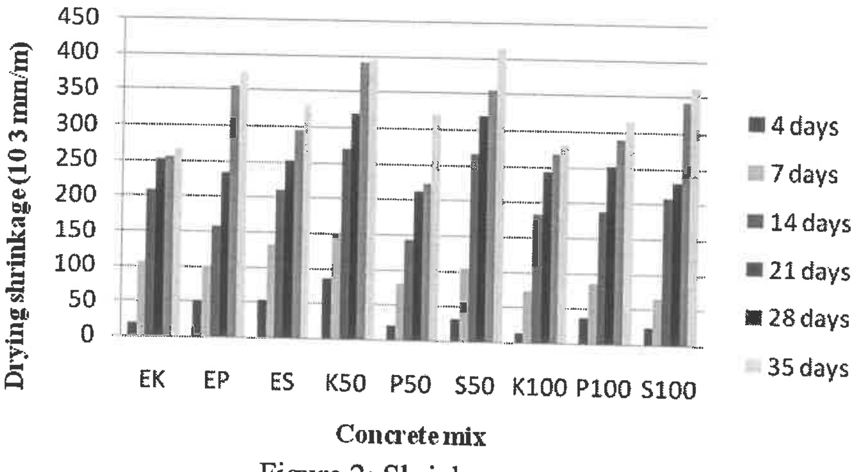


Figure 2: Shrinkage.

Scanning electron microscopy (SEM analysis) enables to "look into" the structure of concrete made and to better explain the results obtained by testing (Figure 1). Water absorption test was done on the samples of dimensions 12x12x36cm, by the method of gradual immersion. The results are 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%.

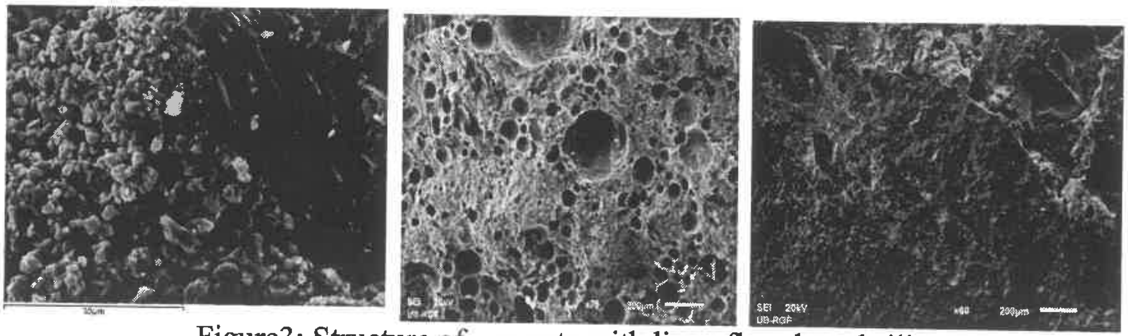


Figure3: Structure of concrete with lime, fly ash and silica fume

4. Discussion

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 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: 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.

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. Slower early strengths of concrete with fly ash prevent its application where high early strength is expected, which can be solved by using accelerator.

The effect of lime: 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. Available data from the literature, like 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. The main problem of using recycled aggregate is its increased porosity, caused by the remained old cement paste on aggregate grains. 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.

5. Conclusion

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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