MALTERI SA RECIKLIRANIM AGREGATOM OD RECIKLIRANOG BETONA I LETEĆIM PEPELOM

RECYCLED AGGREGATE MORTAR MADE WITH THE RECYCLED CONCRETE AGGREGATE AND FLY ASH

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U cilju održivog razvoja građevinske industrije trenutno se obavlja veliki broj teorijskih i praktičnih istraživanja o mogućnostima upotrebe različitih recikliranih materijala u cementnim kompozitima. U radu je prikazana jedna mogućnost projektovanja sastava kompozita tipa maltera spravljenog sa recikliranim agregatom i letećim pepelom. U cilju poboljšanja svojstava recikliranog agregata, upotrebljeno je vodeno staklo. Istraživana svojstva obuhvatila su u svežem stanju: zapreminsku masu i konzistenciju merenu metodom potresnog stola, a u očvrslom stanju: zapreminsku masu, čvrstoću pri savijanju i čvrstoću pri pritisku. Mešavina spravljena sa vodenim staklom i sa recikliranim agregatom pokazala je najnižu zapreminsku masu u svežem stanju i najkruću konzistenciju. U očvrslom stanju, navedena mešavina je posedovala najviše vrednosti čvrstoće pri savijanju i čvrstoće pri pritisku, uz najnižu vrednost zapreminske mase.

Ključne reči: *malteri, reciklirani agregat, leteći pepeo, vodeno staklo, fizičko-mehanička svojstva.*

With the aim of sustainable development of the construction industry, a large number of theoretical and practical research is currently being carried out on the possibilities of using various recycled materials in cement composites. The paper presents one possibility of designing the composition of a mortar-type composite made with recycled aggregate and fly ash. In order to improve the properties of the recycled aggregate, sodium silicate was used. The investigated properties included in the fresh state: density and consistency, measured by the flow-table method, and in the hardened state: density, flexural strength and compressive strength. The mixture made with sodium silicate and with recycled aggregate showed the lowest bulk density in the fresh state, and the stiffest consistency. In the hardened state, the mentioned mixture had the highest values of flexural strength and compressive strength, with the lowest value of density.

Key words: *mortars, recycled aggregate, fly ash, water glass, physical-mechanical properties.*

1 Introduction

I n the 21st century, there is a great human need for a more rational use of natural resources in order to achieve sustainable development of the planet. Sustainable development implies such development of society that meets human needs with available resources, without endangering natural systems and the environment, thereby ensuring the long-term existence of human society and its environment [1]. That is why there is an effort towards the production of "green" materials that will partially or completely replace traditional materials, the production of which is limited by the natural resources on the planet as well as by the great pollution that occurs during the technological production process.

Cement composite materials, such as concrete and mortar, are still the main "carriers" of the construction industry. The annual production of cement at the global level is more than 3000 Mt and causes the non-negligible risk to the environment [2]. In addition to pollution, the production of the mentioned construction materials leads to a serious depletion of natural resources [3].

A group of scientists from Lisbon [4] analyzed the effects of incorporating a high content of fly ash and recycled concrete aggregate in composites. The focus was on the properties of fresh and hardened concrete in which fine and coarse RCA were used as a partial or complete replacement of fine and coarse natural aggregate. Several mixtures were made in which the natural aggregate was partially or completely replaced by recycled, with the best results obtained when the coarse natural aggregate was completely replaced by coarse recycled aggregate with the addition of fly ash. The worst result was obtained on samples made by replacing fine natural aggregate with fine river aggregate, without replacing coarse aggregate, and without adding fly ash.

Recycled aggregate consists of natural aggregate, cement paste and mortar that envelops the grains [5,6,7]. Compared to natural, recycled aggregate is of lower quality. Cement paste is a more porous material compared to the grain of natural aggregate, and the porosity depends on the water-cement factor of the recycled concrete. Recycled aggregate has a cracked surface, which means that there is a greater permeability of water and air between the cement paste and the aggregate. It is obvious that fine recycled aggregate has worse properties than the coarse, and that the use of this size fraction is a challenge.

Three mixtures were made in order to investigate the effect of incorporating recycled aggregate, sodium silicate and fly ash in mortars (in these composites the aggregate size is less than 4 mm), by testing the change of basic properties in fresh and hardened state with the change in composition.

2 Materials and methods

Natural river aggregate, Dunavac in the first fraction I (0/4) mm, and recycled aggregate obtained by crushing in a crusher, also in the first fraction I (0/4) mm, were used for the production of mortar for the purposes of the experiment. The recycled aggregate was obtained by crushing concrete samples in the "RETSCH JAW CRUSHER BB 300" machine in the Laboratory for materials of the University of Belgrade Faculty of Civil Engineering (Figure 1). Densities of natural (river) and recycled aggregate were 1590 kg/m^3 and 1269 kg/m^3 in loose state, while in compacted state they were 1662 kg/m^3 and 1394 kg/m^3. Gravity of the river aggregate was 2.7 and in the case of recycled concrete aggregate it was 2.4. The water absorption values were 1.1% and 7.0% for river and recycled aggregate, respectively. Fines content (under 0.09 mm in size) was 1.4% and 6.2% for river and recycled aggregate, respectively.

Figure 1. River sand (left) and recycled fine aggregate (right) used in this study

Cement PC 20M (S-L) 42.5R Holcimlafarge from Beočin was used in the study of mortars. Based on the laboratory tests on standard cement mortars, flexural and compressive strengths at the age of 28 days were 7.75 MPa and 49.4 MPa, respectively. Fly ash form the thermal power-plant "Nikola Tesla B" had been tested in terms of pozzolanic activity and had values of flexural and compressive strength of 2.2 MPa and 9.1 MPa, respectively were obtained after the testing on mortars with referent composition. These values classify the used fly ash among pozzolans of average performance. Densities of fly ash in the loose and compact state were 690 kg/m^3 and 910 kg/m^3, while gravity was 2.2.

In construction, the much cheaper sodium silicate Na2O·nSiO2 is most often used, and theferfore this study was conducted with this material, provided from "Galenica", which contains SiO_2 and Na_2O in a ratio of 2.97 in favor of SiO_2. Sodium silicate was used as the water solution (every 1 l of the solution used was made of 92 ml of water glass and 908 ml of water). Drinking (tap) water was used for the production of the mortar series.

Tests included basic fresh [8] and hardened mortar properties based on SRPS EN 1015-3:2008 and SRPS EN 196-1:2017 [9].

3 Mixtures and results

A total of three mixes were made using natural or recycled aggregate, with the presence of sodium silicate, or fly ash depending on their combinations. Table 1 defines the composition of each mixture. The first mixture (1) consisted of natural aggregate, cement and water. The second mixture (2) consisted of recycled aggregate, cement, sodium silicate and water. The third mixture (3) consisted of recycled aggregate, cement, fly ash, sodium silicate solution and water.

Table 1. Composition of mortar series

Mixture	Aggregate (kg/m^3)		Cement (kg/m^3)	Fly ash (kg/m^3)	Sodium silicate solution in water (kg/m^3)	Additional water (kg/m^3)
	Natural	Recycled				
1	1758	/	586	/	/	293
2	/	1758	593	/	386	/
3	/	1758	593	59	267	119

The results of tests in fresh and hardened state are presented in table 2.

Table 2. Results of fresh and hardened tests of the mortars

Mixture	Fresh mortar density (kg/m^3)	Flow value (consistency) (mm)	Hardened mortar density (kg/m^3)	Flexural strength, 28d (MPa)	Compressive strength, 28d (MPa)
1	2223	12.6	2282	7.9	49.6
2	2205	10.2	2249	9.6	64.4
3	2224	11.2	2285	8.9	50.2

4 Conclusions

One of the most important scientific focuses nowadays is investigation of sustainable construction materials, that would aid overall sustainability of mankind and improve energy sustainability end efficiency at the same time.

Fresh and hardened mortar densities were lined in the same order, being the lowest for the mixture with the sodium silicate, and the highest for the mixture with natural aggregate. Flow values of the series showed the stiffest consistency of the mortar with sodium silicate and the most fluid for the river aggregate, as expected. Flexural and Compressive strengths were highest for the series with sodium silicate and very close with the series with natural only and the series with recycled aggregate, sodium silicate and fly ash.

The results of mortar series testing shown in this paper, as a part of wider study, show that the properties of recycled materials can be improved, for instance by use of sodium silicate, as in this study. Although it didn't reduce the properties in comparison to the referent series, fly ash didn't induce improvement of the most important properties.

5 Acknowledgements

The research presented in this paper was done with the financial support of the Ministry of Education, Science and Technological Development of the Republic of Serbia, within the funding of scientific research work at the University of Belgrade, Faculty of Civil Engineering (No. 200092).

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