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POTENTIAL FOR APPLICATION OF WASTE MATERIALS AS MINERAL ADMIXTURE FOR MAKING OF SELF-COMPACTING CONCRETES

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SUMMARY: The basic principle of sustainable construction is usage of building materials which will not have negative effects on the environment, as well as proper management of waste materials generated during construction or demolishing of structures. Rapid technological and industrial development in the recent decades caused big environmental problems, and one of the most significant is, undoubtedly, disposal and recycling of waste materials and by-products of industrial production. Since concrete is a composite material, waste materials can suitably be used in its composition. Waste materials in concrete can be used as partial substitution of cement, partial substitution of aggregate or as reinforcement of concrete composite. In this paper, the research of effects of milled recycled glass from cathode tubes, flotation tailings from a copper mine, fly ash, red mud and limestone filler as mineral admixtures on properties of fresh and hardened self compacting concrete was presented. The test results indicated that addition of such materials does not cause a drop in performance quality of self-compacting concretes in fresh and hardened states, and they even improve certain properties of concrete. Waste materials such as fly ash and recycled glass of cathode tubes exhibit a pozzolanic activity, so the performances of the concretes with these admixtures proved to be better after ageing than the concretes with other admixtures.

POTENCIJAL PRIMJENE OTPADNIH MATERIJALA KAO MINERALNOG DODATNOG SASTOJKA PRI IZRADI SAMOZBIJAJUĆIH BETONA

SAŽETAK: Osnovno načelo održive gradnje upotreba je građevnih materijala koji neće imati negativne učinke na okoliš i odgovarajuće upravljanje otpadnim materijalima koji nastaju pri gradnji i rušenju građevina. Brzi tehnološki i industrijski razvoj posljednjih desetljeća prouzročio je velike probleme za okoliš. Jedan od najvažnijih bez sumnje je odlaganje i recikliranje otpadnih materijala koji su nusproizvodi industrijske proizvodnje. Kako je beton kompozitni materijal prikladno je u njegovu sastavu upotrijebiti otpadne materijale. Otpadni se materijali u betonu mogu upotrijebiti kao djelomična zamjena cementa, djelomična zamjena agregata ili za armiranje cementnoga kompozita. U radu je prikazano istraživanje učinaka reciliranog mljevenog stakla iz katodnih cijevi, jalovine nakon flotacije iz rudnika bakra, letećeg pepela, crvenoga mulja i vapnenačkog filera kao mineralnih dodataka na svojstva svježega i očvrsnuloga samozbijajućeg betona. Rezultati ispitivanja pokazuju da dodavanje takvih materijala ne uzrokuje pad kvalitete samozbijajućih betona u svježem i očvrsnulom stanju nego da su neka svojstva betona čak i poboljšana. Otpadni materijal kao što su leteći pepeo i reciklirano staklo iz katodnih cijevi pokazuju pucolansku aktivnost pa će svojstva betona s tim dodacima biti bolja tijekom vremena nego li kod betona s drugim dodacima.

1. INTRODUCTION

The basic principle of sustainable construction is usage of building materials which will not have negative effects on the environment, as well as proper management of waste materials generated during construction or demolishing of structures. Increasing attention is paid to the rapid technological and industrial development in the recent decades which caused big environmental problems, and one of the most significant is, undoubtedly, disposal and recycling of waste materials and by-products of industrial production. On the other hand, concrete, being a composite and frequently used building material is fitting for usage of waste materials as components in its composition. Waste materials in concrete can be used as partial substitution of cement, partial substitution of aggregate or as reinforcement of concrete composite. Exactly integration of those materials into concrete itself can, to a considerable extent, contribute to solving the problem of their disposal. However, in order to achieve this goal, it is important to establish how these materials affect the concrete properties, and what quantities of them can be added without compromising strength and durability of concrete which make it such a suitable building material.

In this paper, the research of effects of milled recycled glass from cathode tubes, flotation tailings from a copper mine, fly ash, red mud and limestone filler as mineral admixtures on properties of fresh and hardened self compacting concrete was presented. The composition of self-compacting concrete can be designed in multiple ways, but one must take care to achieve certain adequate rheological properties of fresh concrete, such as fluidity, viscosity, resistance to segregation [1]. Each of the mentioned materials has a characteristical impact on concrete, so it is necessary to individually examine each one prior to making concrete.

Fly ash is very frequently used as admixture when making self-compacting concrete. The research established that addition of fly ash reduces slump time T_{500} [2], porosity [3] as well as shrinking and creeping [4]. The spherical shape of ash particles increases mobility and workability of concrete. Presence of fly ash retards alite reaction, so early concrete strengths are lower in comparison with the usual values of SCCs without mineral admixtures. However, in time the strength increases and after 90 days, it is equal to the corresponding reference concrete. Because of the reduced porosity, concretes with the admixture of fly ash achieve, in general, higher terminal strengths [5], but this impact considerably depends on the amount of added ash. Excessive quantity of fly ash in concrete can lead to reduction of its strength [6-8].

In the copper production process, large quantities of waste material are generated whose disposal represents large environmental issue. Flotation tailings, as one of the by-products of copper production, are rich in iron oxides and silicates, and thus it is suitable for production of concrete and mortar. Depending on its chemical composition, they can be used either as an admixture to ordinary Portland cement, or as a replacement of fine aggregate particles. This method may solve this large metallurgical environmental issue and bring a great financial benefit, while simultaneously leading to reduction of gases emission and energy consumption related to production of the same quantity of materials whereby natural resources remain preserved [9]. Onuaguluchi and Eren in their researches demonstrated that concretes with admixture of flotation tailings possess improved mechanical characteristics in comparison to vibrated concrete. Compressive, tensile shear and flexural strengths of SCCs with the mineral admixture of flotation tailings are increased. Also, an increased resistance to abrasion and lower chloride penetration depth were observed. Such improved characteristics are more prominent in cases when 5% of flotation tailings are used and when water/cement ratio is high (water absorption is increased, when flotation tailings are used) [10]. They also tested chemical action on concretes comprising flotation tailings, and on their basis they determined that the increase of presence of flotation tailings in concrete increases acid action resistance, but simultaneously reduces resistance to destructive sulphate expansion [11].

In the Bayer alumina production process, red mud created as a waste is composed mostly from hematite, goethite, quartz, boehmite, calcite, tricalcium aluminate, zinc and magnesium oxide, sodium hydroxide etc. What makes red mud a a dangerous polluter of land, ground and surface waters is alkaline liquid phase which filters down from disposal sites into ground waters carrying with it a still high content of sodium [12-13]. A large number of studies done in the world relate to the various aspects of implementation of red mud as a composite element of mortars and concretes: as cement replacement, partial replacement of fine aggregate in mortars, integral part of geopolymers, etc. On the basis of the tests performed on SCC, it was established that red mud admixture increases viscosity, reduces fluidity and considerable reduces segregation and concrete bleeding, i.e. water separation. On the other hand, porosity of SCC increases, but shrinking reduces [14]. Density of hardened concrete also reduces with the admixture of red mud. Compressive strength yields higher values in relation to the reference SCC after 90 days. Flexural and tensile splitting strengths are considerably higher in comparison with the reference self-compacting concrete made without red mud [14-15].

Limestone filler in SCC contributes to increase of fluidity and viscosity and to reduction of concrete porosity [16-17]. Fluidity of SCC made with milled limestone increases with the fineness of the admixture particles. In comparison to the SCC wit fly ash, concrete with milled limestone has a higher water permeability and lower frost resistance [18]. Limestone contributes to creation of large pores in concrete which are formed around larger particles, which acts as hydration inhibitor in an early hardening stage [17].

There were numerous tests of application of recycled glass as a partial replacement of fine aggregate for making of SCC. [19-20]. The test results showed that with the increase of recycled glass content in concrete, fluidity and air content increase, but mechanical strengths and static elasticity model are reduced. When SCC with limestone filler was tested, it was established that compressive strength and ultrasound velocity increase with the increase of recycled cathode ray tube glass content [21].

2. EXPERIMENTAL RESEARCH

2.1. USED MATERIALS

The cement used for making of concrete mixtures was manufactured by „CRH“ CEM I 42,5 R, whcih complies with all the quality requirements prescribed by SRPS EN 197-1 standard. Three fractions of river aggregate used (0/4 mm, 4/8 mm i 8/16 mm) originate from the South Morava river, and they comply with all the quality requirements prescribed by SRPS EN 206-1 and EN 12620 standard. Limestone filler was obtained by milling stone from the „Babin Kal“ quarry near Bela Palanka, fly ash is from the Kostolac B coal-fired power plant, flotation tailings are from the Mining and Smelting Combine Bor, red mud is from the Aluminum Plant Podgorica created in the Bayer process of aluminum production. Recycled cathode ray tube glass was taken from the company „E-reciklaža“ Niš and milled in the laboratory mill. The superplasticizer Sika Viscocrete 5380 was used as chemical admixture in the mixtures.

2.2. CONCRETE MIXTURE COMPOSITION

A total of five different mixtures of SCCs were made for the requirements of the experimental research, those being: mixture with the mineral admixture of limestone filler (mixture designated LF), mixture with te admixture of powdered recycled glass of cathode ray tubes (RS), mixture with the admixture of fly ash (EP), mixture with the admixture of flotation tailings (FT) and mixture with the admixture of red mud (RM). Concrete mixtures differ only in terms of the implemented powder admixtures type. All these admixtures are finer than 0,125 mm, because they were passed through an adequate sieve. The percentage share of component volume in 1 m^3 of concrete is the same for all the concrete mixtures. All the concrete mixtures were made so as to have a similar spreading (around 650 mm) when concrete fluidity is tested. This condition is met by varying the superplasticizer quantity. Compositions of concrete mixtures for 1 m^3 of concrete are given in Table 1.

Table 1 Composition of 1m^3 of concrete mixtures used in the experiment

Kinds of materials			Percentage of volume in 1m^3 [%]		Volume in 1m^3 [m^3]	Density [kg/m^3]	Mass in 1m^3 [kg]
Cement			12.7		0.127	3150	400
Water			18.15		0.1815	1000	181.5
Fine aggregate	0/4 mm		29.62		0.2962	2620	776
Coarse agregat	4/8 mm		31.69	11.58	0.1158	2650	307
	8/16 mm			20.11	0.2011	2650	533
Assumed air content			2.0		0.02	–	–
Designation of the mixture	LF	Limestone filler	5.5		0.055	2720	150
		Superplasticizer	0.45		0.0045	1100	4.95
	RG	Recycled glass	5.5		0.055	2840	156
		Superplasticizer	0.40		0.0040	1100	4.40
	FA	Fly ash	5.5		0.055	2130	117
		Superplasticizer	0.50		0.0050	1100	5.50
	FT	Flotation tailings	5.5		0.055	3150	173
		Superplasticizer	0.43		0.0043	1100	4.68
	RM	Red mud	5.5		0.055	2710	149
		Superplasticizer	0.80		0.008	1100	8.80

2.3. TYPES OF TESTS INVESTIGATED ON THE FRESH AND HARDENED CONCRETE

The following tests were conducted on the fresh concrete: density according to SRPS EN 12350-6:2010 standard, air content in concrete according to SRPS EN 12350-7:2010, slump flow test and T_{500} spreading test according to SRPS EN 12350-8:2012 standard, workability using L-box test according to SRPS EN 12350-10:2012 standard and the segregation test using sieves according to SRPS EN 12350-11:2012 standard.

The tested physical properties of the hardened concrete were the density of water saturated concrete according to SRPS EN 12390-7:2010 standard, using the specimen cubes having sides of 15cm at the age of 2, 7, 28 and 90 days. Also tested were mechanical properties of concrete, the most important being compressive strength. This characteristic was tested according to SRPS EN 12390-3:2010 standards, on cube shaped specimens having sides of 15cm at the age of 2, 7, 28 and 90 days. The flexural strength test was performed on the prism shaped specimens, having dimensions 10×10×40 cm at the age of 28 and 90 days according to SRPS EN 12390-5:2010 standard. Also, the splitting tensile strength test (Brazilian test) was performed on cylindrical specimens having diameter Ø15 cm and length 30 cm at the age of 28 and 90 days according to SRPS EN 12390-6:2012 standard. „Pull-off" strength test was performed on the cubes having sides 15 cm at the age of 28 and 90 days according to SRPS EN 1542:2010 standard.

The primary goal of this research is testing potential for application of waste materials as mineral admixture for making of SCC. For that reason, the concrete mixture with limestone filler (LF) can be considered a reference mixture used for comparison with other mixtures which contain admixtures of recycled cathode ray tube glass, fly ash, flotation tailings and red mud.

The previous tests according to SRPS B.C1.018 standard established that only fly ash and pulverized recycled ray tube glass exhibit puzzolanic activity. Other powder admixtures can be considered inert.

3. RESULTS OF EXPERIMENTAL RESEARCH

The test results of fresh and hardened concrete are provided in Tables 2 and 3. The tables provide mean values of the obtained test results.

Table 2 Characteristic concrete in fresh state

Properties	Unit	Test results				
		LF	RG	FA	FT	RM
Density	kg/m^3	2375	2390	2340	2385	2365
Air content	%	2.0	0.8	2.9	2.8	2.6
Test T_{500} time	s	3.5	4.5	7.0	6.0	6.5
Slump flow test	mm	650	660	640	660	640
Tests using the L - box H_2/H_1	(mm/mm)	0.94	0.95	0.91	0.92	0.87
Testing segregation using sieves	%	14.0	12.8	5.6	6.8	6.0

Table 3 Characteristic concrete in hardened state

Properties	Unit	Age of samples	Test results				
			LF	RG	FA	FT	RM
Density of water saturated specimen	kg/m^3	2 days	2375	2390	2340	2385	2365
		7 days	2372	2388	2338	2382	2363
		28 days	2370	2385	2336	2380	2359
		90 days	2370	2383	2335	2378	2356
Compressive strength	MPa	2 days	39.6	38.7	44.6	36.6	41.2
		7 days	49.1	47.7	51.0	46.2	45.0
		28 days	56.3	59.0	59.6	59.7	54.0
		90 days	65.1	72.2	69.3	64.7	57.0
Flexural strength	MPa	28 days	6.3	6.4	5.6	5.3	7.3
		90 days	7.0	7.7	7.8	6.3	8.4
Tensile splitting strength	MPa	28 days	4.4	4.2	4.8	4.0	4.0
		90 days	4.7	5.5	5.1	4.2	4.3
Bond strength by Pull-off test	MPa	28 days	3.7	4.2	4.4	4.0	3.8
		90 days	4.0	4.9	4.8	4.3	4.1

4. DISCUSION OF RESULTS AND CONCLUSION

Based on the test results of fresh concrete density, Table 2, it can be concluded that it primarily depend on the specific mass of the used mineral admixture, but also on the air content in concrete which is noticeable in the case of concrete mixture with cathode ray tube glass admixture (the mixture designated with RG). The highest density is demonstrated exactly by the mixture having the RG designation, which has 15 kg/m^3 more than the reference concrete with limestone filler, and the least density is demonstrated by the mixture with fly ash having FA designation, which has 35 kg/m^3 less than the reference concrete.

In terms of air content in fresh concrete, the mixture designated with RG had the lowest value, i.e. 0,8%, and the mixture designated with FA had the highest value (2,9%). Almost all concrete mixtures with the exception of RG have the approximately same air content and they have similar values to the reference LF, Table 2.

As it was already said, all the concrete mixtures were made to have approximately same spread (around 650 mm) on the event of testing concrete fluidity, Table 2, which was achieved by implementing superplasticizer. T_{500} test indicates viscosity of concrete mixture, and represents the time in which the concrete achieves the spread of 500 mm when testing fluidity. Based on the test results in the Table 2, it can be concluded that all concrete mixtures with the admixture of waste materials have higher values of T_{500} test than the reference concrete. The FA mixture had the highest spread time for 500 mm, the mixtures RM and FT were similar, while the RG mixture had a similar value as the LF reference concrete.

Filling ability was determined using L-box test, and other methods can be implemented as well: U – box, J – ring and Kajima box. On the basis of the test results from the Table 2, it can be concluded that RG mixture has the best filling ability while the RM mixture has the lowest ability in comparison to the other mixtures. FA and FT mixtures had mutually similar values, but lower than the reference, LF mixture.

Segregation resistance is expressed as the percentage of the amount of concrete which passed through the sieve with 5 mm openings in comparison with the total mass. Based on the results from the Table 2, it can be concluded that all the mixtures with waste materials have a higher resistance in respect to the reference concrete LF, whereby the best resistance was demonstrated by the FA mixture, followed by RM, FT and RG mixtures, respectively.

As for the properties of hardened concrete, densities of water saturated concrete at the age of 2, 7, 28 and 90 days are coordinated with the density of fresh concrete, Table 3. As well as in the case of fresh concrete, differences occur due to the various specific masses of mineral powder admixtures and air content in concrete.

Compressive strengths of concretes, as one of the most important characteristics of concrete, are mutually similar at corresponding age of concrete, Table 3. At the age of 2 days, the highest strength was exhibited by the FA mixture which is 12,6% higher than LF reference concrete, and the lowest by the FT mixture which is 7,6% lower than LF. At the age of concrete of 7 days, the highest strength was demonstrated by the FA mixture which is 3,9% higher than the LF reference, and the lowest was demonstrated by the RM mixture which is 8,4% lower than LF. At the age of 28 days, the highest compressive strength increase was demonstrated by the FT mixture. It simultaneously had the highest compressive strength, as well, which is 6,0% higher than the LF, while the lowest value was exhibited by the RM which was 4,1% lower than the LF. At the age of 90 days, the highest increase and highest value of compressive strength was exhibited by the RG mixture, while the FA mixture exhibited a slightly lower increase, followed by the LF and FT mixtures, while the lowest mixture was exhibited by the RM mixture. Compressive strength of the RG mixture was 10,9% higher than LF, while compressive strength of the RM mixture is 12,4% lower than the LF. This was expected, since among all the mineral admixtures, only fly ash and pulverized recycled glass demonstrated puzzolanic activity.

The highest value of flexural strength at the age of 28 days was demonstrated by the RM mixture which contained red mud admixture, which was 15,9% higher than the LF reference value, and the lowest value was demonstrated by the FT mixture which contained flotation tailings, which was 15,9% lower than EF. The mixture containing recycled glass from cathode ray tubes had a flexural strength similar to the LF mixture, while the mixture containing fly ash admixture had 11,1% lower value than the LF reference. At the age of 90 days, the highest increase of flexural strength was exhibited by the RM mixture, whose value is 20,0% higher than the LF mixture. The FT mixture had the lowest value of flexural strength, which was 10,0% lower than the LF, while the RG and FA mixtures had 10,0% and 11,4% higher flexural strength, respectively, than the LF mixture.

In terms of tensile splitting strength at the age of 28 days, all the concrete mixtures had the similar strength values. All the concrete mixtures made with waste materials, except the FA mixture with fly ash had the lower tensile split values than the LF reference. The highest value was exhibited by the FA mixture which is 9,1% higher than the LF, and the lowest by the FT and RM mixtures, 9,1% lower than the LF. At the age of 90 days, the highest tensile splitting strength increase was exhibited by the RG mixture, whose value was 17,0% higher than the LF mixture. The lowest value of tensile splitting strength was exhibited by the FT mixture which was 10,6% lower than the LF. The RM mixture had a s similar value, while the FA mixture had 8,5% higher tensile splitting strength than the LF mixture.

In case of the bond strength Pull-off tests, all the concrete mixtures had the similar strength values. At the age of 28 and 90 days, all the concrete mixtures made with waste materials, had the higher bond strengths in comparison with the LF reference. At the age of 28 days, the highest value was exhibited by the FA mixture which was 18,9% higher than the LF reference, and the lowest value of all the waste material mixtures by the RM mixture which was 5,4% higher than the LF. At the age of 90 days, the highest value was exhibited by the RS which was 22,5% higher than the LF reference. The FA mixture had the similar value, while the lowest value was shown by the RM mixture which was 2,5% higher than the LF.

Based on the test results of SCC with the admixture of waste materials, it can be concluded that addition of these materials does not considerably reduce the quality of fresh and hardened concrete performances. It can be said that they even contribute to the increase of certain concrete properties presented in this paper. A special attention must be paid to the durability of concrete mixtures containing admixture of waste materials such as cathode ray tube recycled glass, fly ash, flotation tailings and red mud. Further research should be focused on that aspect, since proofs of unaffected durability would complete the study of potential application of these materials for making of concrete.

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