DIMK

DRUŠTVO ZA ISPITIVANJE I ISTRAŽIVANJE MATERIJALA I KONSTRUKCIJA SRBIJE

SOCIETY FOR MATERIALS AND STRUCTURES TESTING OF SERBIA

MEĐUNARODNI SIMPOZIJUM

O ISTRAŽIVANJIMA I PRIMENI SAVREMENIH DOSTIGNUĆA U GRAĐEVINARSTVU U OBLASTI MATERIJALA I KONSTRUKCIJA

INTERNATIONAL SYMPOSIUM

ON RESEARCHING AND APPLICATION OF CONTEMPORARY ACHIEVEMENTS IN CIVIL ENGINEERING IN THE FIELD OF MATERIALS AND STRUCTURES

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DRUŠTVO ZA ISPITIVANJE I ISTRAŽIVANJE MATERIJALA I KONSTRUKCIJA SRBIJE
SOCIETY FOR MATERIALS AND STRUCTURES TESTING OF SERBIA

XXVI KONGRES – Vrnjačka Banja 29-31. oktobar 2014.
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FIBER REINFORCED SELF-COMPACTING CONCRETE MADE WITH FLY ASH – A CONTRIBUTION TO THE SUSTAINABLE CIVIL ENGINEERING

Summary: *Possible applications of fly ash in civil engineering, with respect to its origin are discussed in the paper. Also, rate of production and quantities of this material both in Europe and in Serbia are given and commented. Considerable experimental research was conducted in the Laboratory for materials at the Faculty of Civil Engineering, University of Belgrade. The testing, performed on Steel fiber reinforced Self Compacting Concrete (SCC) specimens showed satisfactory results concerning possible application of fly ash as admixture for this kind of concrete. Fly ash was used as a partial replacement of aggregate (filler). A number of investigations regarding fresh and hardened SCC properties are presented and analyzed in the paper.*

Key words: *Cement, SCC, fly ash, superplasticizer, filler, steel fibers*

MIKROARMIRANI SAMOZBIJAJUĆI BETONI SPRAVLJANI SA ELEKTROFILTERSKIM PEPELOM – DOPRINOS ODRŽIVOM GRAĐEVINARSTVU

Rezime: *U ovom radu prikazane su mogućnosti primene letećeg pepela u građevinarstvu, sa osvrtom na njegovo poreklo. Takođe, dati su i komentarisani podaci u vezi sa proizvodnom i količinama ovog materijala, kako u Evropi, tako i u Srbiji. Značajna eksperimentalna ispitivanja sprovedena su u Laboratoriji za materijale Građevinskog fakulteta Univerziteta u Beogradu. Ispitivanja sprovedena na samozbijajućim betonima (SCC) mikroarmiranim čeličnim vlaknima pokazala su zadovoljavajuće rezultate u vezi sa mogućnošću primene elektrofilterskog pepela u svojstvu dodatka kod ove vrste betona. Elektrofilterski pepeo je upotrebljen kao delimična zamena agregata (filera). Veliki broj ispitivanja u vezi sa svojstvima SCC u svežem i očvrslom stanju je prikazan i analiziran u okviru ovog rada.*

Ključne reči: *Cement, SCC, elektrofilterski pepeo, superplastifikator, filer, čelična vlakna*

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1. INTRODUCTION

There is an ongoing development of building industry, especially concrete structures, which in turn stimulates the production of cement for cementitious composites (concrete, mortar, etc.). Cement is undoubtedly a basic material in building industry, because it is necessary for construction of residential, commercial and industrial structures, roads, tunnels and bridges, underground structures, etc. In the last several years, substantial changes occurred, both in EU and in Serbia, regarding the types and strength classes of produced cement types. According to [1], more than 80% of the total production of cement in Serbia represents Portland composite cement.

Nowdays, annual production of cement in the world exceeds 3.8 billion tons, according to the investigations [2] from 2013. Also, China was the biggest producer of concrete and cement in the world (Figure 1). This huge production is accompanied with environmental hazard. Namely, approximately 0.92 tons of CO_2 are produced in the process of cement production, for every ton of cement clinker produced. This CO_2 emission is mostly a result of de-carbonation of limestone and the use of carbon based fuels.

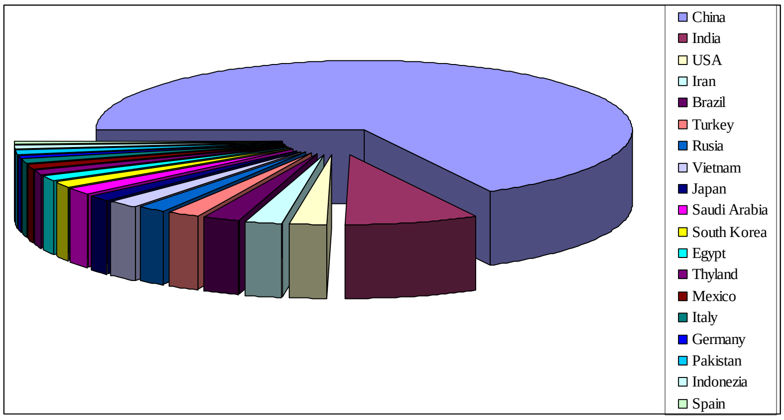

Figure 1. *Worldwide cement production in 2013.*

One of the ways of decreasing this evident threat is incorporated in production of cement. It is the use of pozzolanic materials, such as fly ash and slag. Through the use of such materials, the need for production of cement clinker (as a main component of cement) reduces, and with that reduces the need for energy consumption and CO_2 emission. This is only one of the possible applications of fly ash, which is regretfully used very poorly in Serbia, and represents a great potential. In this paper, several topics of interest will be discussed and illustrated, regarding fly ash and its use in building industry.

Usually the term "fly ash" is attributed to a fine material that is deposited on the filters of the exit gases, as a result of the coal combustion in thermal power plants. The amount of this ash varies widely: from about 1 ton per day, to several tons a minute, depending on a power plant [3]. On the basis of the relevant assessment [4], it is estimated that there is more than 200 million tons of deposited ash and slag in Serbia today - as a result of decades of disposal of these by-products in the power plants. Additional 6 million tons of the waste is the amount added to the previous on an annual basis. Despite the constant control and monitoring, deposited fly ash and slag in Serbia occupy an area of about 1600 hectares, producing many environmental problems such as: pollution of air, soil, surface and groundwater, destruction of vegetation cover and disturbance of ecosystems, damage to human health, etc.

Given the fact that fly ash has pozzolanic properties and relatively high fineness (its particle diameter is usually within limits of 1 - 150 microns), the powder material can be used as a mineral supplement in cement production, or as a partial replacement for Portland cement in cementitious composites. In this way, significant savings in the consumption of non-renewable resources (limestone, clay) can be achieved, as well as in the energy required for the production of cement. This also provides reduction of the CO_2 emissions (cement industry is responsible for the emission of at least 5-7% of the total CO_2 in atmosphere [5]). Numerous international experiences show that fly ash and slag can be used as cement admixtures, as a substitute for aggregates and fillers for concrete and asphalt, for the production of lightweight concrete masonry elements, gas concrete, bricks, etc. Also, geopolymers can be obtained through alkaline activation of the fly ash; geopolymers present a promising alternative to cement composites. In this sense, application possibilities and synthesis of geopolymers have been studied at the Faculty of Civil Engineering, University of Belgrade.

2. EXPERIMENTAL RESEARCH

Self Compacting Concrete (SCC) is a modern composite material, which is becoming more and more accepted in the construction industry in the world - primarily for its good technological properties in the fresh state (consistency, workability, pumpability, etc.). The most commonly used definition of SCC is that it is a concrete with liquid consistency, a concrete that is capable of completely flowing through the most complex re-bar formations, filling complex sections of formwork and passing through narrow segments of formwork, without the occurrence of segregation and without the need for any mechanical compaction. The use of such concrete offers multiple benefits, both in engineering, but also in economic and environmental terms. These benefits are even more pronounced in the case when fly ash is used as a component for SCC.

River aggregate "Moravac" was used, separated in three different fractions: I (0/4), II (4/8) and III (8/16). Grain size distribution curves of the used fractions, together with the distribution curve of mixture of aggregate, are shown in Fig. 2. This mixture contained 50% of fraction I (0/4), 25% of fraction II (4/8) and 25% of fraction III (8/16). Gravity of aggregate was 2.682 g/cm^3, 2.645 g/cm^3 and 2.655 g/cm^3 for fractions I, II and III, respectively.

Pure cement PC 42.5R "Lafarge" Beocin was used, with gravity of 3.0 g/cm^3. Fly ash, originated from TE Kolubara was used, with density of 2.180 g/cm^3. Results of sieve analysis of fly ash are given in Table 1, and chemical composition in Table 2 [8], [9]. Polycarboxilate based superplasticizer (HRWR admixture) Glenium Sky 690 BASF, USA was used for this investigation also. Limestone powder was used produced by "Rujevac" BA, "Granit Pescar" AD Ljig.

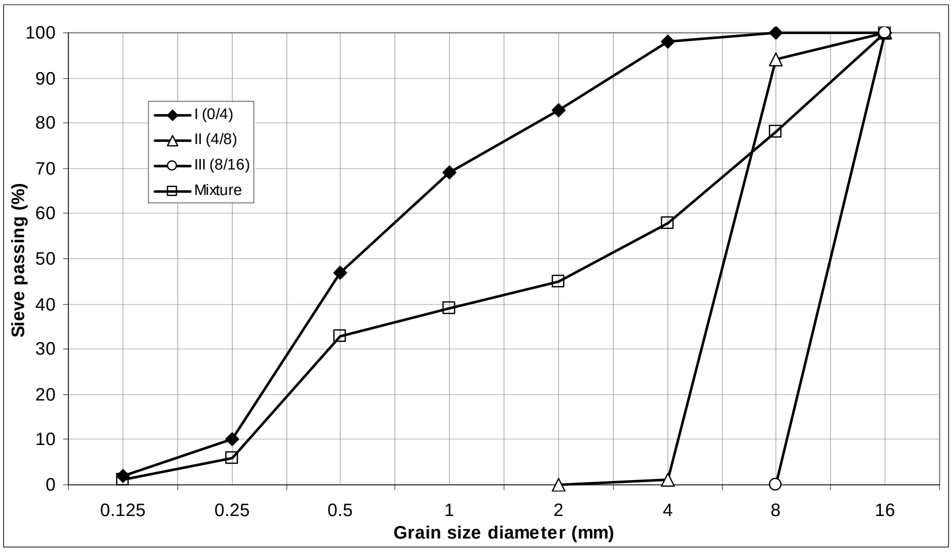

Figure 2. *Grain size distribution curves of the fractions and the used mixture of aggregate*

d (mm)	0,003	0,005	0,009	0,015	0,026	0,045	0,056	0,063
Y (%)	9,63	11,82	15,32	27,14	39,45	51,30	58,00	60,70
d (mm)	0,090	0,200	0,315	0,500	0,710	1,000	2,000	-
Y (%)	69,10	92,20	96,40	98,60	99,00	99,66	100,00	-

Table 1. Fly ash sieve analysis results

Oxides content (%)											
SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	P_2O_5	SO_3	Na_2O_3	K_2O	MnO	CO_2
58.32	*18.88*	*6.75*	*0.57*	*8.71*	*2.3*	*0.025*	*1.29*	*0.5*	*1.16*	*0.026*	*0.11*
Microelements (mg/kg)											
Pb	Cd	Zn	Cu	Ni	Hg	As	Ba	Sb	Se		
24.4.	*0.2*	*56.6*	*36*	*135.1*	*0*	*182*	*86.2*	*1.1*	*1.4*		

Table 2. Chemical composition of fly ash

The content of cement was constant in these series, and the quantities of filler – limestone powder (m_f) and fly ash (m_{fa}). Steel fibers were used with properties presented in the Table 3.

Designation	Length [mm]	Diameter [mm]	Shape factor L/d	Cross section	Tensile strength N/mm^2
ZS/N 1.05x50	50±10%	1.05±10%	47.6	circle	1100-2700

Table 3. Steel fiber properties

To verify the above-mentioned quotes, four SCC mixtures were made, with the addition of fly ash and with different amounts of steel fibers. The aim was to obtain a class of SCC concrete SF2 (710 mm < Flow diameter < 780 mm). The four mixtures were designed in a following manner:

– Mixture SCC1 – reference concrete mixture, with usual components (aggregate, cement, filler, water and superplasticizer)

– Mixture SCC2 - concrete mixture, made with fly ash in a quantity of 34% of total amount of filler (52% of the used limestone powder), with other components (aggregate, cement, water and superplasticizer) in the same quantities as in mixture SCC1

– Mixture SCC3 - concrete mixture, made with fly ash in a quantity of 34% of total amount of filler (52% of the used limestone powder), with other components (aggregate, cement, water and superplasticizer) in the same quantities as in mixture SCC1. This mixture was steel fiber reinforced, with 30 kg/m^3 of fibers.

– Mixture SCC4 - concrete mixture, made with fly ash in a quantity of 34% of total amount of filler (52% of the used limestone powder), with other components (aggregate, cement, water and superplasticizer) in the same quantities as in mixture SCC1. This mixture was steel fiber reinforced, with 60 kg/m^3 of fibers.

Mix compositions of all the described mixtures are presented in Table 4.

Series	SCC1	SCC2	SCC3	SCC4
Cement PC 42.5R	260	260	260	260
Filler (limestone powder)	304	200	200	200
Fly ash	0	104	104	104
Water	190	190	190	190
I (0<d<4 mm)	840	840	840	840
II (4<d<8 mm)	420	420	420	420
III (8<d<16 mm)	420	420	420	420
Superplasticizer	10.92	10.92	10.92	10.92
Steel fibers	0	0	30	60

Table 4. Composition of SCC series

Properties of the fresh mixtures are shown in Table 5, including: density, slump-flow, time t_{500} and L-box test.

Series		SCC I	SCC II	SCC III	SCC IV
Density SRPS EN 12350-6 [kg/m^3]		2340	2310	2320	2380
Slump-flow SRPS EN 12350-8	value[mm]	780	730	720	710
	class	SF3	SF2	SF2	SF2
Time t_{500} SRPS EN 12350-8	value [s]	1.60	5.80	7.21	7.59
	class	VS1	VS2	-	-
L-box SRPS EN 12350-10	value [-]	1	1	1	0.86
	class	PA2	PA2	PA2	PA2

Table 5. Fresh SCC properties

This concrete was poured in the molds without vibration and then cured in a customary manner under laboratory conditions. Testing of compressive strength (f_c) of SCC was performed on 15 cm cubes, at the age of 28 and 90 days. The investigation also included the adhesion strength test (f_a), carried out on 40×40×5cm plates using ″Pull-off″ apparatus, and splitting tensile test (f_{st}) made on cylinders of diameter and height of 15 cm, at the age of 28 days [16]. The average values of the mechanical properties are given in the Table 6.

Series	SCC 1	SCC 2	SCC 3	SCC 4
Compressive strength, $f_{c,28d}$ [MPa]	28.08	47.08	43.48	48.56
Compressive strength, $f_{c,90d}$ [MPa]	36.2	59.6	53.6	62.9
Tensile splitt. strength, $f_{st,28d}$ [MPa]	1.92	3.06	3.68	3.74
Flexural strength, $f_{fl,28d}$ [MPa]	5.08	6.64	6.90	8.07
Adhesion, $f_{a,28d}$ [MPa]	2.82	4.77	5.10	5.62

Table 6. Hardened SCC properties

3. CONCLUSIONS

It is important to stress out that fly ash represents the most common waste material in our country, as well as secondary raw material that can be used primarily in the construction industry. Therefore, a package of legislation that deals with the issue of environmental protection came into force in 2004, as part of efforts to harmonize national with the EU legislation. In this regard, public company "Elektroprivreda Srbije" (EPS) is bound to harmonize the work of its plants with the provisions of the Law on Integrated Pollution Prevention and Control, by the end of 2015. This means that the EPS is bound to apply modern safety measures, such as plant fuel gas desulphurization, high efficiency electrostatic or facilities for waste treatment, both in the new objects and in the old objects to be reconstructed (revitalized).

Currently, fly ash is utilized practically only in cement plants, and to a lesser amount, for brick manufacture. Only a few percents of the total annual production of fly ash are used this way [1]. Given the market potential, there is a strong possibility to significantly increase the degree of utilization of this resource. Regarding the legislation in Serbia, there is a set of laws, standards and other documents covering this topic of fly ash. For instance, there are standards about the use of fly ash in concrete, designated as SRPS EN 450-1 and SRPS EN 450-2, [13], [14].

Based on the performed experimental studies, conclusion can be drawn that fly ash can be successfully applied for cementitious composites, such as mortar and concrete. Also, the replacement levels of cement with fly ash, as well as the properties of fly ash, depend on the physical and mechanical properties of the composite in design - both in fresh and in the hardened state. In order to eliminate the influence of the type of cement on the investigated properties of mortar and concrete made with the addition of fly ash, ″pure″ Portland cement should be used, instead of composite cements, whenever possible.

Generally, the increase in water content was necessary in order to achieve the same consistency of the composites with fly ash, which is in correlation with relatively large fineness of fly ash. This usually leads to a decrease in density of the composite, as well as to a reduction of the early strength, as compared to the reference (composites made without the addition of fly ash). This is fully in line with the results of other authors [3], [6]. On the other hand, due to its pozzolanic properties, fly ash contributes to the improvement of mechanical properties of mortar and concrete at ages greater than 28 days.

Regarding the replacement of limestone filler (as the usual type of filler in Self Compacting Concrete) with fly ash as an alternative, conducted studies have shown that the addition of fly ash contributes significantly to the rise of the mechanical properties (compressive strength, tensile strength, flexural strength and adhesion). Namely, these composites, made with low amount of cement (260 kg/m^3) and with the addition of limestone powder and fly ash, in the presence of steel fibers, showed 28 days compressive strength 72% higher than in the case of reference SCC1 (made with limestone powder only). Adhesion was approximately 2 times higher then reference. The presence of steel fibers as reinforcement was also beneficial, showing flexural strength to be 50-60% higher on SCC4 series than reference SCC1.

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