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Properties modeling of cement composites made of fly ash

There is a number of advantages when using fly ash in cement composites. Fly ash is known for decades for its' pozzolanic properties, and thus it is mostly used as an mineral admixture in the process of production of cement. This way benefits like saving energy and reduction of CO2 emission are obtained. This paper presents the results of research conducted on cement composites made with fly ash from Serbia, added as a partial substitute for cement. The properties of fresh and hardened cement composites were studied with replacement of different mass quantites of cement. Studies have shown that with the moderate amount of fly ash (up to 30%) it is possible to obtain satisfactory physical and mechanical properties of cement composites, both in fresh and hardened state.

Key words: *fly ash, mortars, cement, physical and mechanical properties*

INTRODUCTION

Billions of tons of fly ash are produced annually all over the world, as a by-product of the combustion of coal in thermal power plants. This huge generation of fly ash caused formation of landfills near the largest power plants, over the years. In Serbia, the biggest landfills are located near the main power plants, Nikola Tesla in Obrenovac and one in Kostolac.

Fly ash, as a building material, can be defined as fine powder of mainly spherical, glassy particles, derived from burning of pulverized coal, with or without co-combustion materials, which has pozzolanic properties and consists essentially of SiO_2 and Al_2O_3, the content of reactive SiO_2 as defined and described in EN 197-1 being at least 25 % by mass [1,2]. The amount of fly ash collected from chimneys on a single site can vary from less than one ton per day to several tons per minute [3].

Fly ash is a very variable material, because of several factors. Among these are the type and mineralogical composition of the coal, degree of coal pulverization prior to burning, type of furnace and oxidation conditions, and the manner in which fly ash is collected, handled and stored before use. Also, the quantity of coal used in the process has to exceed 80% of the material burned, and co-combustion materials (vegetables, wood, municipal sewage and paper sludge, virtually ash free liquid and gaseous fuels) quantity should be taken into account and also limited whenever possible in order to have some kind of control over the composition of the resulting fly ash. Within the same power plant, properties of fly ash vary due to load conditions over a twenty four hour period. Non uniformity of fly ash is a serious disadvantage and sometimes the main barrier for its use.

In Serbia, only 2.3% of the ash is used in the construction industry, in contrast to European practice, which uses almost the entire amount of ash produced [4]. In order to enable better use of fly ash, a number of related legislation and technical requirements are being published in Serbia. According to [1], a production plant is defined as a facility used by a producer for the production of fly ash and it should be power plant with one(several) boiler(s), and a processing plant, for example for the classification, selection, sieving, drying, blending, grinding and/or carbon reduction of fly ash(es).

In the production plant equipment has to be used which is suitable for production of fly ash including the necessary silo capacity for the storage and dispatch of the fly ash produced, and equipment to test, evaluate and control the fly ash production. This equipment and the production control applied allow the control of production with sufficient accuracy to ensure that the requirements of EN 450-1 are met.

MATERIALS

In order to investigate the suitability of non-treated (non-ground) fly ash, as a partial replacement of cement in cement based composites, four mixtures of mortar were designed. The goal of the experimental research was to obtain cement based composites with acceptable physical and mechanical properties (density, compressive strength, tensile strength, flexural strength and

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modulus of elasticity). The research was done in the Laboratory for materials, Institute for materials and structures, Faculty of Civil Engineering, University of Belgrade.

Fly ash characterization

Conformity criteria according to [1] and [2] set a number of requirements for fly ash, in order for it to be used in mortar and concrete composites.

Table 1 – Limit values for fly ash [1]

	Property	Single result limit values
1	Loss on ignition	≤5.0% by mass (category A) 2.0-9.0% by mass (category B) 4.0-9.0% by mass (category C)
2	Fineness (upper limit value)	40% by mass (category N) 12% by mass (category S)
3	Fineness variation (lower and upper limit values)	± 10 percentage points from declared value (category N only)
4	Chloride (upper limit value)	0,10 % by mass
5	Free calcium oxide (upper limit value)	2,5 % by mass
6	Reactive calcium oxide (upper limit value)	10,0 % by mass
7	Reactive silicon dioxide (lower limit value)	25 % by mass
8	Sulfuric anhydride (upper limit value)	3,0 % by mass
9	Silicon dioxide + aluminum oxide + iron oxide (lower limit value)	70 % by mass
10	Total content of alkalis (upper limit value)	5,0 % by mass
11	Magnesium oxide (upper limit value)	4,0 % by mass
12	Soluble phosphate (upper limit value)	100 mg/kg
13	Soundness (upper limit value)	10,0 mm
14	Activity index at 28 days (lower limit value) Activity index at 90 days (lower limit value)	75 % 85 %
15	Particle density variation (lower and upper limit values)	± 200 kg/m3 from declared value
16	Initial setting time (upper limit value)	140 min longer than test cement alone
17	Water requirement (upper limit value)	95 % (category S only)

Table 2 - Confirmation and audit testing of samples of certified fly ash taken at dispatching centers [2]

Properties to be tested	Minimum testing frequencies		
	Confirmation auto control by the intermediary		Audit testing by the third party
	Fly ash unloaded and stored at the dispatching centre	Fly ash transshipped at the dispatching centre	
Loss on ignition	1/week	1 per delivered lot byt at least 1 per 1000 tones	3/year
Fineness	1/week		
Activity index at 28 days	1/month		

Moreover, the plant recognized for production of fly ash must check the parameters of fly ash periodically (see Table 2).

Fly ash, used in presented research, originated from thermal power plant "Kolubara". Gravity of fly ash was 2.112 g/cm^3, and bulk density was 0.722 g/cm^3 and 0.783 g/cm^3, in loose and compacted state respectively. Sieve analisys results and chemical composition for this fly ash are shown in Tables 3, 4, 5 and 6. Ignition loss on the intire sample was 1.84%, for the sample above 45μm was 3.49%, and for the sample below 45μm was 1.79%.

Table 3 - Fly ash sieve analysis results

Sieve pass		Sieve pass	
d (mm)	Y (%)	d (mm)	Y (%)
0.00339	6.63	0.63	60.7
0.00538	11.82	0.1	69.1
0.00869	15.32	0.2	92.2
0.01458	27.14	0.315	96.4
0.02412	45.89	0.5	98.6
0.03711	51.3	0.71	99
0.05212	58	1.00	99.6
		200	100

Table 4 - Chemical composition results – oxide 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

Table 5 - Chemical composition results – 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 6 - Chemical composition results – insoluble residue and reactive oxides content

Insoluble residue HCl/Na_2O_3	60.61%
Insoluble residue HCl/KOH	16.85%
Reactive SiO_2	46.05%
Reactive CaO	7.67%

Aggregate and cement

The river aggregate "Moravac" fraction I (0/4) mm was used for making the mortar on the basis of fly ash. Sieve analisys results for this fraction are displayed on Fig 1, along with the limits for this aggregate defined by [5].

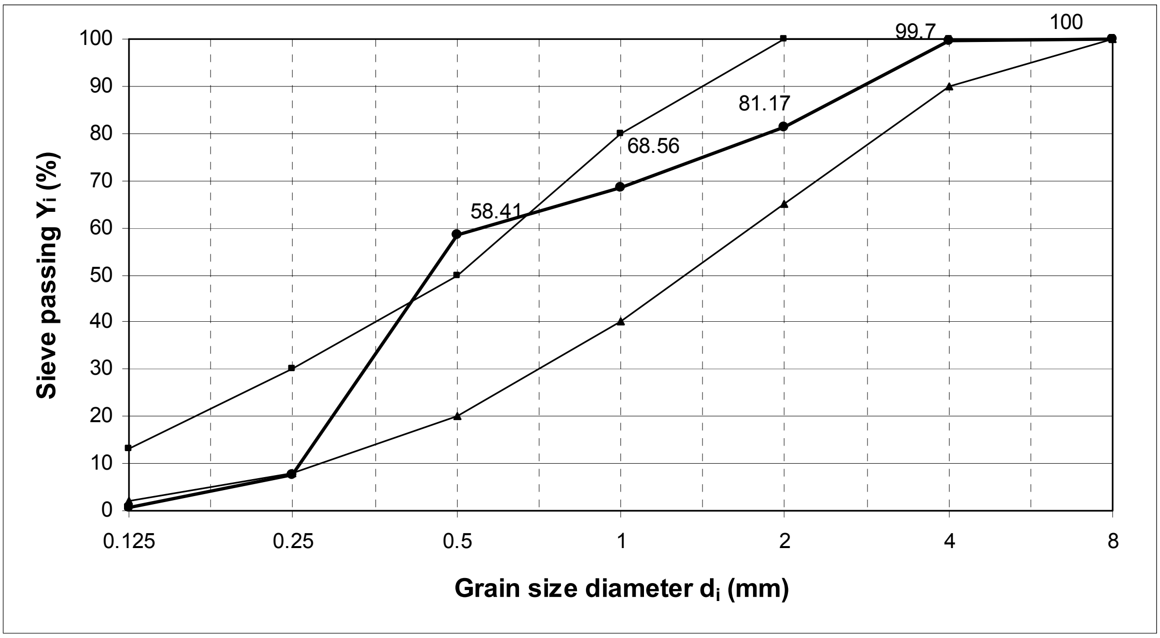

Figure 1 - Passing percentages for the sand used in mortar series

Density of this aggregate grains was 2,632 g/cm^3,while bulk density in loose state was 1.635 g/cm^3. Cement PC 20M (S - L) 42.5 R Lafarge factory "Beočin" was used with the density of 2.945 g/cm^3.

RESULTS

Four series of mortars were made, with different quantities of fly ash (0%-R, 10%-F1, 20%-F2 and 30%-F3) replacing cement. The principle was to keep constant the total quantity of cement+fly ash. Reference mortar was made with the following ratios of components: mass of water : mass of cement : mass of sand= 1 : 2 : 6. Three series, made with fly ash, had 10%, 20% and 30% (by mass) of fly ash replacing cement. Also, in the series with fly ash, water was added in order to obtain the same flow, measured by flow table method [6]. The target flow was 180-185mm, which resulted in following water/cement ratios for F1, F2 and F3 respectively: 0.70, 0.85 and 1.00. Density of mortars is graphically presented on Fig. 2.

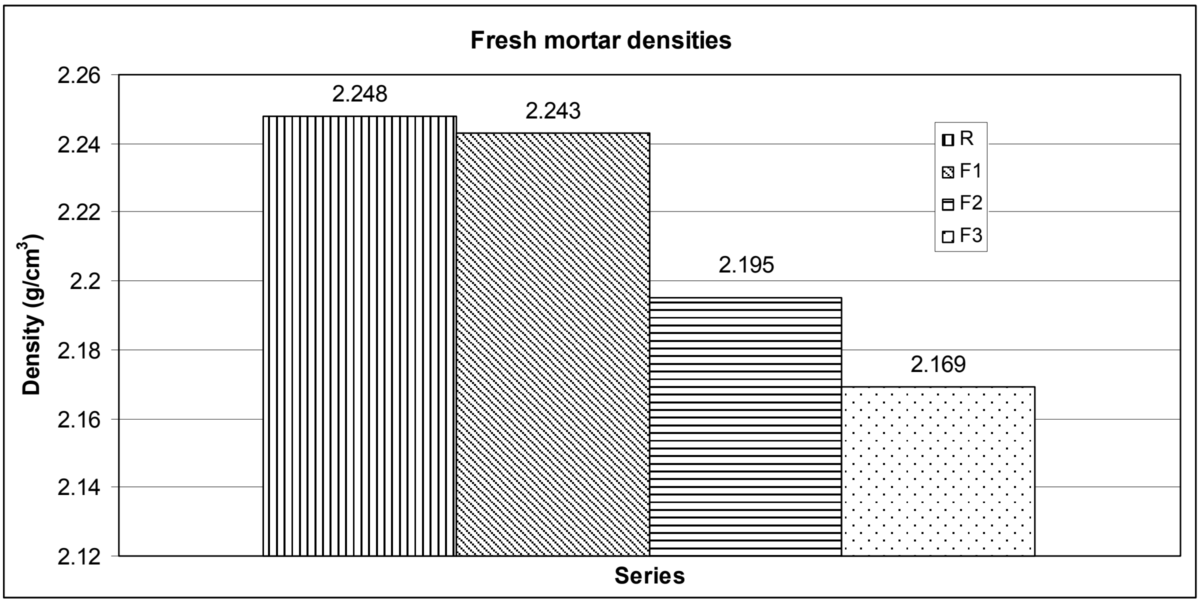

Figure 2 - Densities of fresh mortar series

Hardened mortar density and flexural (f_{fl}) strength were determined at the age of 28 days, while compressive (f_c) strength was measured both at the age of 28 and 90 days. Modulus of elasticity (E), adhesion (f_{at}) and ultrasonic pulse velocity (v) were determined at the age of 28 days only. All the measured hardened mortar properties are shown in Table 7.

Table 7 – Hardened mortar properties

	R	F1	F2	F3
Density, 28d (g/cm^3)	2.215	2.195	2.179	2.151
$f_{fl,28}$ (MPa)	7.17	7.29	6.13	6.54
$f_{c,28}$ (MPa)	38.54	36.15	30.73	27.29
$f_{c,90}$ (MPa)	41.23	39.37	39.06	34.79
$f_{at,28}$ (MPa)	2.79	2.85	2.58	2.39
E (GPa)	25.6	23.4	22.8	20.7
v (m/s)	3673	3587	3542	3385

Determination of modulus of elasticity was conducted on prism shaped (4x4x16cm) specimens, after five cycles of loading and unloading in the stress interval between 0.5MPa and $f_c/3$; where f_c is compressive strength measured on the same shaped specimens, at the age of 28 days. The value of the modulus of elasticity (E) was calculated on the basis of strain difference measured during the last cycle of loading. The apparatus for this investigation is shown on Fig. 3.

Figure 3 - Determination of modulus of elasticity (E)

In order to investigate the property of adhesion of mortars to concrete, a substrate layer in the form of finished (precast) concrete slabs, measuring 40x40x5cm, was chosen. After preparing, fresh mortar mixtures were applied manually to the surface of the slabs, in a 3cm thick layer. Concrete slabs were pre-cleaned using a steel brush and water saturated before applying the mortar. The curing of the mortar layer was done over the next 28 days using a wet cloth. The adhesion was tested using a "Pull-off" tester produced by

"Controls", with the tension force increment of 0.5kN/s±0.1kN/s. The disposition of this test is shown on Fig. 4.

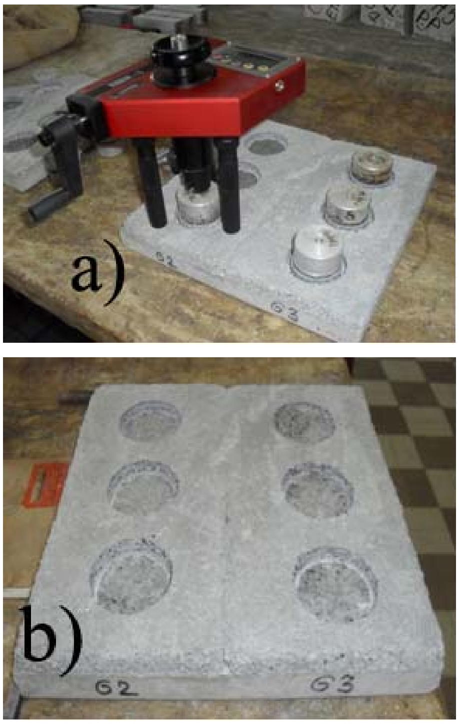

Figure 4 - Pull-off investigation of mortar layer adhesion to concrete substrate – a) apparatus and disks, and b) appearance after the investigation

CONCLUSION

Over the decades, the practice of using fly ash as cementing material became common, not only in developed countries, but all over the world, especially in Europe. In the most developed countries of the world the utilization rate of fly ash almost matches its production. The replacement of cement as a binder with fly ash has several benefits, most of all, in terms of utilization of this industrial by-product [7]. There is a constant update in legislation and technical regulations, which have the effect of increasing confidence in fly ash, providing also the strict control of fly ash composition and its properties.

This paper presents laboratory research, where four mortar series were made, with different quantities of fly ash, which originated from thermal power plant "Kolubara", Veliki Crljeni. The intention of this research was to replace a part of cement as a binder. The replacement percents were 0%, 10%, 20% and 30%, while the summarized quantity of cement + fly ash was held constant. The consistency of all the mortars was also held constant, by changing the water needed to achieve the same targeted flow of 180-185mm, measured by the flow table method.

The research results, presented in the paper, showed that replacement of cement with fly ash leads to modification in mortar properties, both in the fresh and hardened state. The water addition of up to 22.8% (for 30% replacement of cement with fly ash) was necessary to achieve the targeted consistency of 180-185mm, leading to decrease of density both in fresh (3.5%) and hardened state (2.9%).

When it comes to hardened state mechanical properties of mortars, the overall conclusion can be drown that they are all affected by the replacement of cement with fly ash. Compressive and flexural strength decrease reaches 29.2% and 8.8%, respectively, for the replacement of 30% of mass of cement with fly ash. Pull off test results also show a decrease of 14.3% for the mortar series with the largest content of fly ash, when compared to reference. Decrease in modulus of elasticity, in same terms, reached 19.1%.

There was also a substantial increase in 90-days compressive strength, compared to 28-days, from 7% for the reference mortar (without fly ash) and 8.9% for the mortar with 10% mass replacement of cement with fly ash, up to 27.7% and 27.5% for mortars with 20% and 30% of fly ash. Compressive strength of all the mortars increased over time, showing pozzolanic properties of fly ash. It is to be expected for the properties dependent on fly ash influence to improve further in time. Also, it should be stressed out that all the mortars achieved adequate mechanical properties, namely compressive strength of over 30MPa; even with the replacement of cement by 30%. Finally, when discussing adhesion, investigated by means of Pull off apparatus, values ranged from 2.79 MPa (reference) to 2.39 MPa (30% replacement) for all the mortars; the conclusion can be drown that all the values can be considered satisfactory, and all of them above common limit of 1.5 MPa. Ultrasonic pulse velocity didn't decrease drasticaly, only 7.8%, indicating high level of compaction for all series. All of these results show the great potential of utilization of fly ash in mortar composites, for a wide scale of application.

Acknowledgement

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REFERENCES

[1] SRPS EN 450-1:2010 Fly ash for concrete - Part 1: Definition, specifications and conformity criteria

[2] SRPS EN 450-2:2010 Fly ash for concrete - Part 2: Conformity evaluation

[3] Fly Ash in Concrete Properties and Performance, Rilem report 7, K. Wesche (Ed), First edition, E&FN Spoon, London, 1991

[4] Miletic, S., Ilic, M., (2007) Iskorišćenje otpada u građevinarstvu, Konferencija savremena građevinska praksa,

[5] SRPS B.B3.100:1983 Crushed aggregates for concrete and asphalt

[6] ASTM C230 / C230M - 08 "Standard Specification for Flow Table for Use in Tests of Hydraulic Cement".

[7] Siddique, R.: Waste Materials and by-products in concrete, Department of Civil Engineering,Thapar University, 2008., ISBN: 978-3-540-74293-7

[8] Jevtić D., Zakić D., Savić A., Radević A.: The influence of fly ash on basic properties of mortar and concrete, Scientific conference Planing, design, construction and building renewal, Novi Sad, 28-30. November 2012. pp.614-620, ISBN 978-86-7892-453-8,

ИЗВОД

МОДЕЛОВАЊЕ СВОЈСТАВА МАЛТЕРА ПРИМЕНОМ ЕЛЕКТРО-ФИЛТЕРСКОГ ПЕПЕЛА

Постоји низ предности употребе електрофилтерског пепела у цементним композитима. Електрофилтерски пепео је познат деценијама по својим пуцоланским својствима и из тог разлога се у највећој мери употребљава као минерални додатак у процесу производње цемента. На тај начин се остварују предности у уштеди енергије и у смањењу емисије CO_2. У раду су приказани резултати испитивања спроведених на цементним композитима са електрофилтерским пепелом из Србије, у циљу делимичне замене стандардног цемента. Својства свежих и очврслих цементних композита проучавана су са заменом различитим количинама стандардног цемента. Истраживања су показала да се уз умерену замену количине цемента електрофилтерским пепелом (до 30%) могу постићи задовољавајућа физичко-механичка својства цементних малтера, како у свежем тако и у очврслом стању.

Кључне речи: *електрофилтерски пепео, малтери, цемент, физичко-механичке карактеристике.*

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