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Scientific paper
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The incorporation of fly ash as suplementary cementing material in concrete

Fly ash is a residue derived from the combustion of coal in furnaces of thermal power plant. The characteristics of fly ashes vary according to the combustion operation system as well as the coal composition. When fly ashes are used as partial replacement of Portland cement they alter the properties of the mortar or concrete.

In this study, under scanning microscopic examination (SEM) as well as X-ray powder diffraction and other analyses, are investigated the characteristics of two fly ashes (imported by Fushe Kruja Cement Factory from Germany and Macedonia), such as the particles size and shape, the chemical and mineralogical composition and their content of glass and crystalline phase. In addition are investigated the effects of each fly ashes on fresh and hardened mortars properties, using Portland cement produced in Fushë-Kruja Cement Factory, in Albania.

The investigated characteristics of ashes are confronted with tested properties of concretes produced with them and it is concluded that the better quality of the concrete produced by adding the ash from Germany is due to the composition and the content of glassy phase as well as the spherical form of particles in that fly ash.

***Keywords**: fly ash, Portland cement, microscopic examination, glass and crystalline phase, etc.*

INTRODUCTION

The production of every tonne of Portland cement contributes about one tonne of CO_2 into atmosphere. In order to reduce CO_2 emissions, it is imperative that supplementary cementing materials be used to substitute the Portland cement. The use of these materials not only helps to reduce this greenhouse gas emission but results in concrete that has excellent long term strength and is often more economical than normal Portland cement concrete. Fly ash is one of these materials. Being a finely divided powder consisting of silica-alumina glass of various forms, fly ash in concrete and mortar acts as filler between cement grains and aggregate and as an effective binder providing pozzolanic and cementitious properties.

When fly ash is used as a partial replacement of Portland cement in concrete, the calcium hydroxide liberated during hydration of Portland cement reacts slowly with the amorphous alumosilicates, that are pozzolanic compounds present in fly ash.

The products of these reactions, termed as pozzolanic reaction products, are time depending but are basically of the same type as the products of cement hydration. Thus, these additional products become available which impart additional strength to concrete. The effectiveness of fly ashes used in concrete depends on the physico-chemical properties of them which in turn depend on the source of the coal and its combustion conditions. Fineness and particle morphology of fly ash are the primary characteristics that are related to its pozzolanic activity [2], [3].

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EXPERIMENTAL PART

Materials: The Portland cement used in the experiments is CEM I (95 % clinker and 5 % of gypsum), produced in Fushë-Kruja Cement Factory, Albania. The laboratory analyzes revealed that this cement has the following composition: SiO_2 20.73%, Al_2O_3 6.07%, Fe_2O_3 2.99%, CaO 63.37%, MgO 1.82%, SO_3 2.69%, loss in ignition 1.28%, CaO_{free} 0.73 %, insoluble residue 0.97%.

The fly ashes used in experiments as additive in Portland cement are two Class F fly ashes, one imported from Macedonia and the other from Germany. These fly ashes are marked as FA_1 and FA_2.

Standard sand conform ISO 679:1989 is used for preparing of mortar bars.

The fineness of the CEM I and of the fly ashes is determined. The fly ashes are analysed under microscopic examination and X-ray powder diffraction.

Mixture proportions: A total of nine different mixtures are proportioned; eight mixtures with fly ashes as replacement of cement and one, without any fly ash addition, as a control mixture, for comparison

purposes. For each fly ash, the percentage of fly ash replacement is 20, 25, 30 and 35%.

With each recipe are prepared mortar test prisms 4 x 4 x 16 cm. The physico-mechanical characteristics, such as setting time as well as compressive and flexure strengths at the ages 2 and 28 days, are determined respectively for each recipe [1].

RESULTS AND DISCUSSION

The fineness for CEM I and two fly ashes are shown in the Table 1 [1].

Table 1 - Residue on 45 μ sieve for Portland cement and two fly ashes

	CEM I	Fly ash FA_1	Fly ash FA_2
Residue (wet), in %	4.20	29.66	23.3
Residue (dry), in %	4.50	30.18	23.1

It resulted that the residue measured according to wet and dry methods are approximately the same. The two fly ashes belong to the type N (residue on 0.045 mm sieve is under 40 %).

Figure 1 shows the electronic scanning micrographs of the two different fly ashes samples.

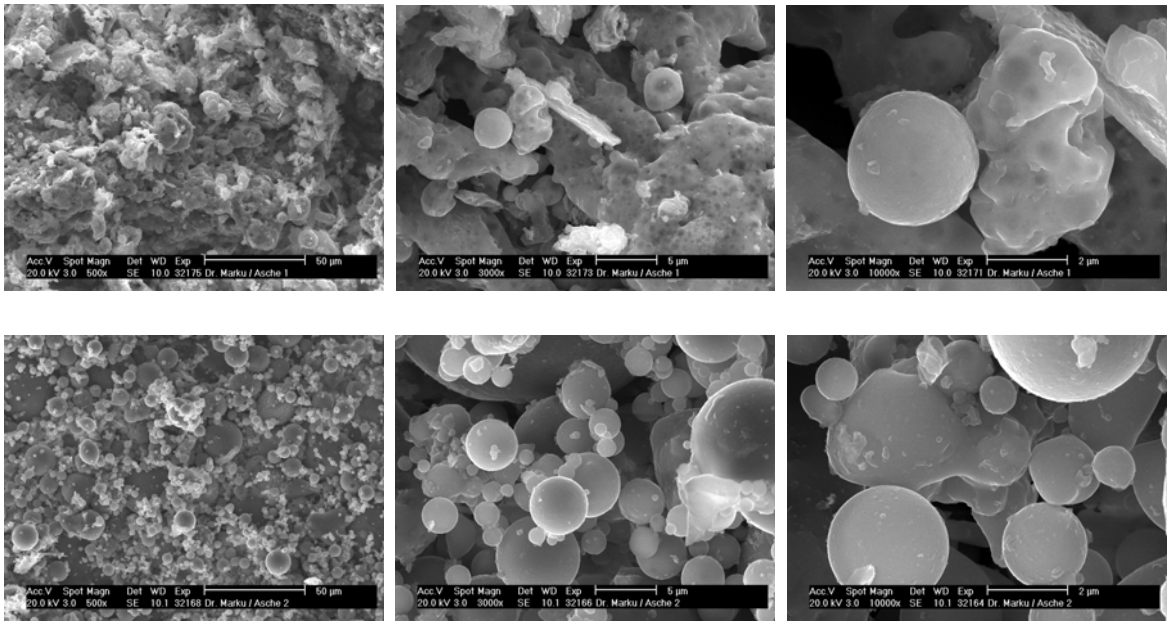
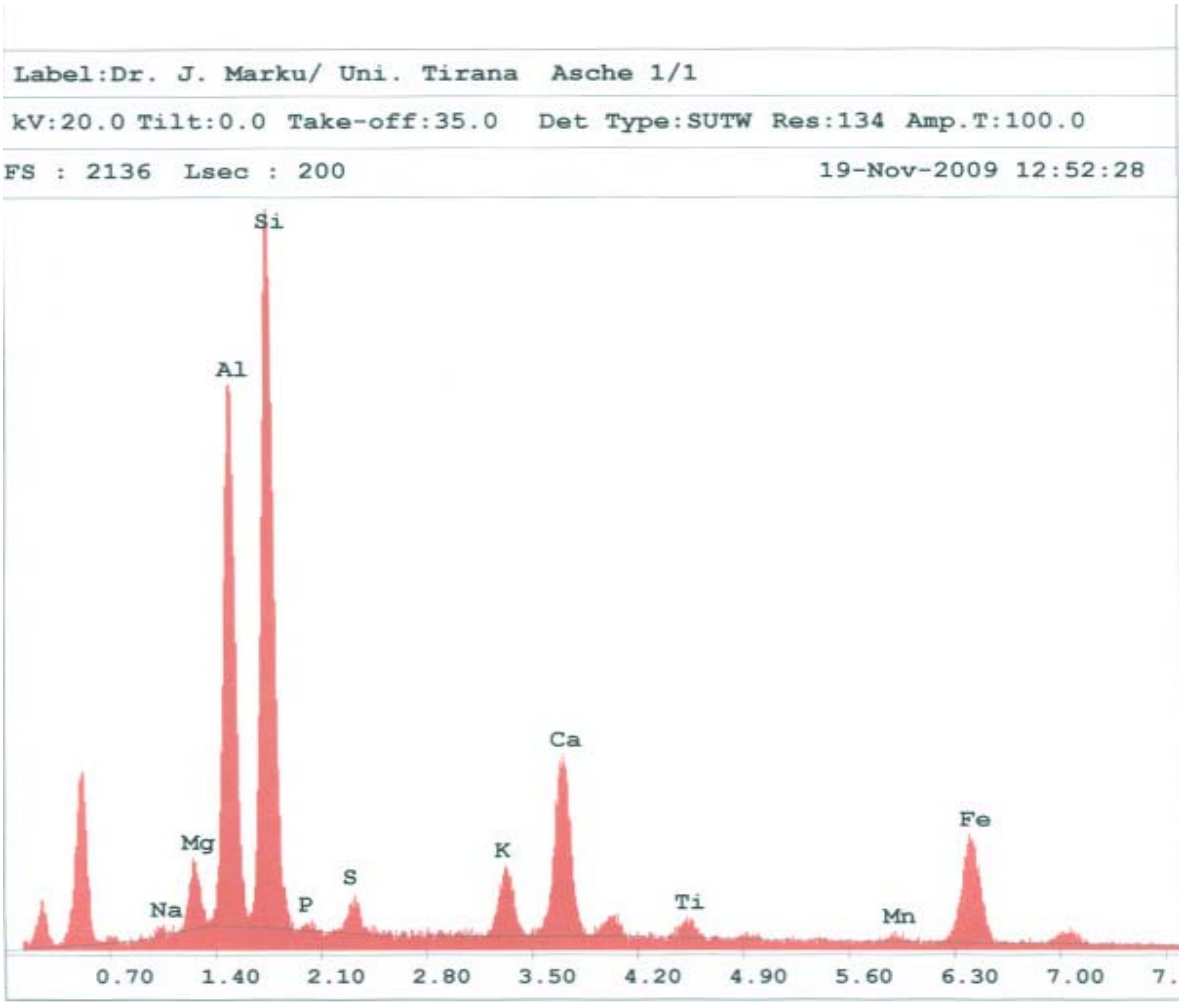


Figure 1 - SEM micrographs of two different fly ashes (above for fly ash FA1 and below for fly ash FA2)

Under high temperature created by the ignition of the burnable matter, the inorganic compounds in coal melt and from that liquid various forms of fly ash particles are shaped, such as spherical shape, some of which are hollow (cenosphere), irregular shaped particles, etc.

Comparing the SEM micrographs of the same magnification, it is seen that in the fly ash FA_2, there are mainly particles with spherical shape, whereas in the fly ash FA_1 predominate the irregular shapes of particles. But the spherical shape of fly ash particle is related with the workability of fresh mortars, permitting greater workability for the same water-cement ratios. In other words, the water-ratio can be reduced for equal workability in a concrete mixture by including fly ashes, especially those with high amount of spherical shape particles.

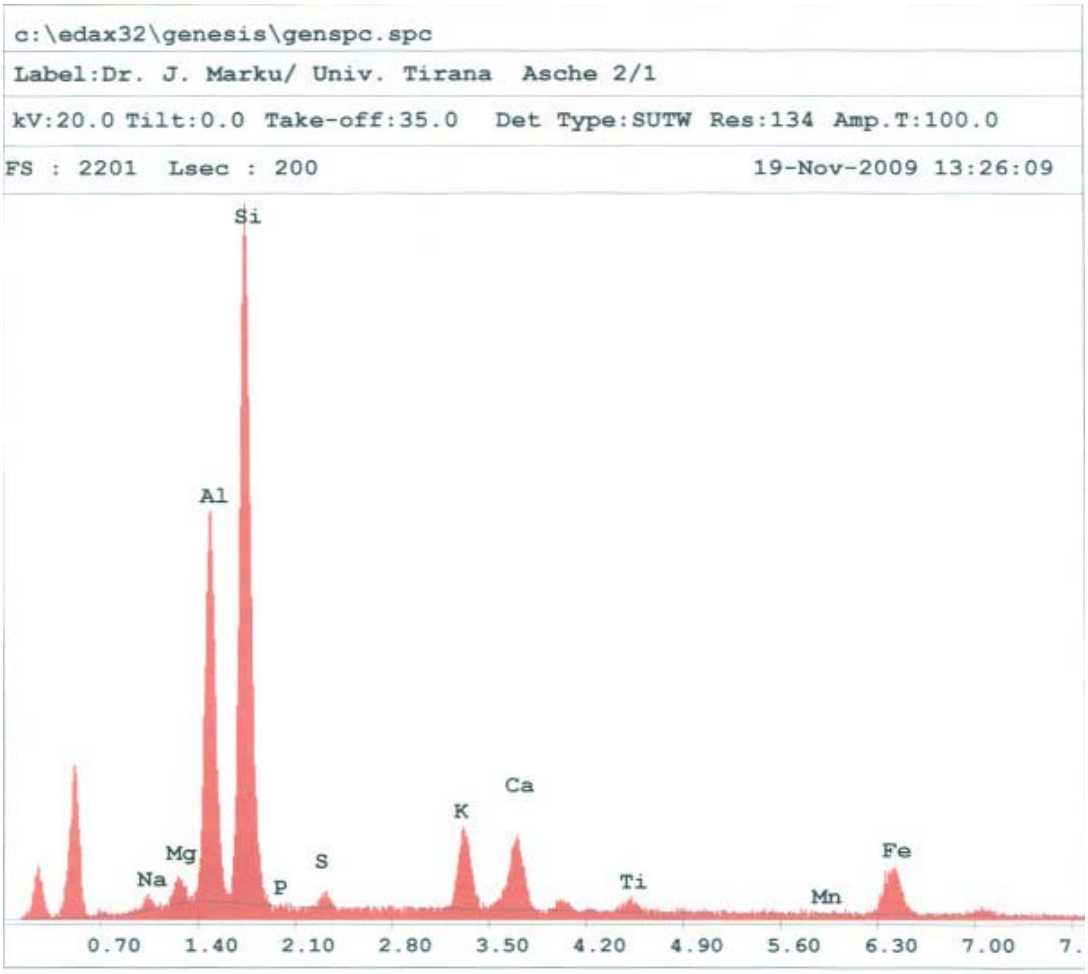
The examination of representative samples from the two ashes under the EDAX analyses is shown in Figure 2 and Figure 3.



EDAX ZAF Quantification (Standardless)
Oxides
SEC Table : Default

Element	Wt %	Mol %	K-Ratio	Z	A	F
Na2O	0.49	0.60	0.0012	0.9742	0.3325	1.0035
MgO	3.35	6.21	0.0096	0.9986	0.4743	1.0066
Al2O3	26.69	19.58	0.0829	0.9693	0.6020	1.0063
SiO2	38.55	48.00	0.1091	0.9975	0.6060	1.0016
P2O5	0.52	0.27	0.0013	0.9621	0.5913	1.0025
SO3	2.69	2.51	0.0074	0.9840	0.6967	1.0036
K2O	2.79	2.21	0.0199	0.9470	0.8949	1.0131
CaO	9.09	12.12	0.0583	0.9693	0.9204	1.0059
TiO2	1.44	1.35	0.0073	0.8852	0.9469	1.0115
MnO	0.67	0.71	0.0045	0.8652	0.9858	1.0000
Fe2O3	13.72	6.43	0.0839	0.8810	0.9926	1.0000
Total	100.00	100.00				

Figure 2 - EDAX spectrum for representative sample of fly ash FA_1



EDAX ZAF Quantification (Standardless)
Oxides
SEC Table : Default

Element	Wt %	Mol %	K-Ratio	Z	A	F
Na2O	1.16	1.36	0.0030	0.9700	0.3566	1.0039
MgO	1.74	3.14	0.0053	0.9943	0.4996	1.0076
Al2O3	25.35	18.06	0.0831	0.9651	0.6368	1.0083
SiO2	49.82	60.25	0.1471	0.9932	0.6352	1.0012
P2O5	0.00	0.00	0.0000	0.9575	0.5773	1.0020
SO3	1.58	1.43	0.0042	0.9789	0.6851	1.0031
K2O	4.61	3.55	0.0323	0.9425	0.8902	1.0076
CaO	5.09	6.60	0.0321	0.9647	0.9099	1.0040
TiO2	1.39	1.26	0.0070	0.8810	0.9497	1.0076
MnO	0.24	0.24	0.0016	0.8610	0.9874	1.0000
Fe2O3	9.04	4.11	0.0551	0.8766	0.9939	1.0000
Total	100.00	100.00				

Figure 3 - EDAX spectrum for representative sample of fly ash FA_2

The figure 2 results show that the MgO content of F_2 is within the limits of corresponding standard for the fly ashes used in substituting of Portland cements in concretes, while in F_1 the MgO content is above these limits.

The results of X-ray powder diffraction identified that the fly ash FA_2 contains around 50% amorphous phase whereas F_1 only 30%. Apart of other characteristics, the high amount of glassy phase is very important for the pozzolanic activity of fly ashes incorporated in concrete.

The results taken for fresh and harden mortars produced with nine different mixtures using various amount of fly ashes are represented in the Table 2 [1].

Table 2 - The characteristics of fresh and harden mortars with various amount of fly ashes

The measured parameters			CEM I (without fly ash)	Fly ash FA_1 (%)				Fly ash FA_2 (%)			
				20	25	30	35	20	25	30	35
The setting times of fresh mortars (min)	Initial		125	190	200	210	225	155	165	175	195
	Final		160	250	265	275	295	245	255	265	285
The mechanical strength of hardened mortars (MPa)	Compressive	2 days	27.30	20.05	17.10	15.63	14.89	18.40	16.70	15.50	13.90
		28 days	60.38	51.70	46.50	40.00	39.20	49.50	44.90	43.70	39.90
	Flexure	2 days	6.30	4.67	3.96	3.55	3.49	4.53	4.22	4.45	4.02
		28 days	9.81	8.63	8.42	7.78	7.46	9.25	9.06	9.90	9.50

The setting times of the all fresh mortars (with and without fly ash) resulted to be in accordance with the standard. The increase of initial and final setting times is normal when fly ashes are used as Portland cement replacement. The influence of fly ash FA_1 in the increase of initial and final setting times is bigger then of the FA_2 for the same CEM I - fly ash ratio.

Even after 28 days, the mortar samples made with all the cementing materials with both fly ashes have compressive and flexure strengths lower than the reference sample (CEM I + 0 % fly ash). This influence of fly ash addition in the development of early compressive and flexure strengths for the hardened mortars is expected due to the type of fly ashes used in these experiments. The two fly ashes are of the same Class F, with siliceous and aluminous content, with only pozzolanic characteristics and without any self cementitious property.

But after 28 days of hardening, the rates of gaining the compressive and flexure strengths of the mortar samples incorporating fly ashes are higher than those of the reference sample made without fly ashes. This happens because of the pozzolanic contribution of the fly ashes, which is not the same.

Higher compressive and flexure strengths resulted for the hardened mortars with German fly ash FA_2 for the same amount of fly ash substituting Portland cement. Also, in all mixtures with fly ash FA_2, are verified higher rates of gaining the compressive and flexure strengths after 28 days compared with the mixtures with fly ash FA_1.

CONCLUSION

From the above results and their discussion, it is clear that there is a strong correlation between the physical and chemical properties of fly ashes and their performance in fresh and hardened mortars.

The fly ash taken from Germany has better properties compared with Macedonian fly ash, because of:

- lower residue on 0.045 mm sieve (wet and dry)
- a predominant amount of spherical shape particles
- the content of MgO closer to the requirements of the standard
- higher amount of glassy amorphous phase

These indicators are confirmed by experimental behaviour of the mortars made using the same amount of each fly ash, where the German fly ash performed better in the fresh and hardened phases. Since the German fly ash results with predominant amount of glassy spherical shape particles it is possible to substitute more than 35% of Portland cement with this fly ash.

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