The Influence of the Ash Addition from Thermal Power Plant on the Mechanical, Thermal and Dielectric Characteristics of Mortars

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The influence of fly ash adittion (90 % fraction < 100 μm) on the cement mortar characteristics was studied. The XRD, XRF, SEM and FTIR determinations indicated that fly ash used has a hollow microstructure of microsphere and cenosphere whose total content in SiO_2, Al_2O_3 and Fe_2O_3 is 88.63 % and that of CaO and MgO of 8.55 %. The mechanical, thermal and dielectric determinations made on mortar samples with content of fly ash in the 0-40 % range have highlighted fact that the mechanical strength of cement mortars is maximal at 20 %, the increase in fly ash content leads to a decrease in relative density and thermal conductivity as well as and to increased dielectric losses tgδ.

Keywords: mortar, fly ash, mechanical resistance, thermal conductivity

With a view to sustainable development, with the objective to ensuring long-term of working and living conditions in a clean and healthy environment, both energy saving and the capitalization of industrial waste are priority issues.

The thermal comfort of buildings is determined to a large extent by the thermal conductivity of the materials / composites used to make them. On the other hand, as a result of the continuous increase in electricity production and the increase in the share of generators of electromagnetic fields consumers, the electromagnetic pollution of the environment in the built habitats is increasingly pronounced [1] - with all the consequences on human health [2 - 6] and on living matter [7-11].

The level attenuation of electromagnetic pollution of inhabited habitats is largely determined by electrical characteristics of building materials [12]. On the other hand, large quantities of fly ash, a collateral product with a negative impact on the environment and the neutralization/ treatment of which impose substantial costs [13], are produced as a result of coal combustion in thermal power plants.

The ash resulting from the combustion of coal in the thermal power plants is made up of oxides such as SiO_2, Al_2O_3, Fe_2O_3, which in water presence combines with the calcium hydroxide (lime, cement, etc.) to form hydrocompounds [14,15]. Since the density of the microspheres in the ash of thermal power plants can be with a third less than that of the cement, their presence imparts to the mortars a lower thermal conductivity [15-18] and a better thermal insulation than conventional mortars (without the addition of fly ash). It is remarked that the durability of mortars and concretes, including those with fly ash is determined by their degradation under stress factors action [18] as: DC stray currents generated by urban electric transport [19-30], AC stray currents [20, 26, 28, 31-34], microbiological factors [34-36], etc.

In this context, the scientific work purpose is to study the possibility of using fly ash in construction - as addition in mortars.

Experimental part

In order to assess the influence of fly ash addition in mortars, mortar samples were prepared with the compositions shown in table 1.

The Portland cement used was CEM I type according to SR EN 197-1: 2011. The sand river sand used was of river with a SiO_2 content of approx. 93%. The ash of thermal power plant used with a grain size of less than 1 mm (90 %, fraction with diameter < 100μm) was harvested from the Govora, Romania thermal power plant. The ash used was analyzed structurally and compositionally by FTIR analysis (FT-IR Tensor 27, Bruker Optik GmbH), SEM (equipment FESEM-FIB Auriga Workstation), XRF (WDXRF-S8 Tiger) and XRD (Bruker- AXS type D8 ADVANCE).

The matured and hardened samples after drying, 30 days at ambient temperature with RH <75% were characterized microstructural by SEM and from electrically point of view by dielectric spectroscopy (AMTEK - 1296 Dielectric interface, produced by Solartron Analytical). Thermal conductivity according to SR EN 12664-2002 and compression strength with a specialized equipment (Mohr & Federhaff AG) and apparent density by immersion in water, were also determined.

Table 1
RECIPE OF PREPARED MORTAR SAMPLES

Sample	Composition [%]			
	Cement	Fly ash	Sand	Water
Mref	19	–	66	15
Mfa1	19	10	56	15
Mfa2	19	20	46	15
Mfa3	19	30	36	15
Mfa4	19	40	26	15

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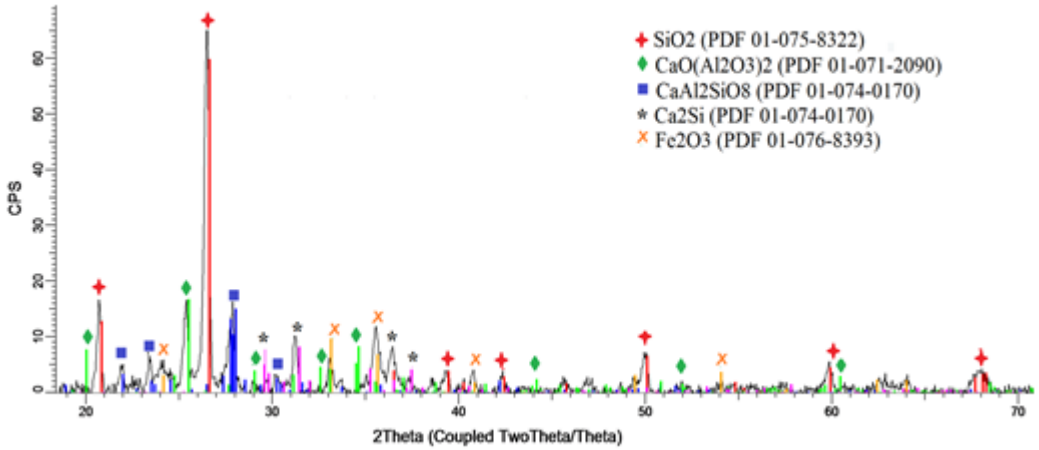

Fig. 1. XRD spectrum of used fly ash

Sample	Oxide Composition (in wt %)								
fly ash	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	TiO_2	P_2O_5	MnO
	52.22	22.58	13,83	6.45	2.10	1.0 7	0.98	0.57	0.16

Table 2
THE FLY ASH OXIDE COMPOSITION USED

Results and discussions

The fly ash characterization

The results of the, X-ray diffraction (XRD) determinations obtained on the ash from thermal power plant are shown in figure 1.

The analyze of figure 1 shows that in fly ash the crystalline phases are present as: SiO_2 - quartz (most significant), calcium aluminosilicates, calcium silicate and hematite - Fe_2O_3, these data are in good agreement with the results reported in [37].

The results of X-ray fluorescence spectrometry (XRF) assays on the fly ash oxide composition used are summarized in table 2.

Table 2 shows that the main constituents of used fly ash are SiO_2, Al_2O_3, Fe_2O_3, in a weight percentage total of 88.63 %. Also, is noticed a relatively high content of Fe_2O_3 (13.83 % - higher than in cements and sands commonly used in construction), as well as remarkable content in CaO (6.45 %) and MgO (2.1 %) and K_2O (1.07 %) which in case of use in mortars and concrete contributes to alkalinity, thus their stability is diminished. It is noted that the fly ash oxide composition resulting from the thermal power plant is largely determined by the quality and origin of the coal used for combustion.

The Fourier transformation infrared spectroscopy (FTIR) was also applied and the FTIR spectrum obtained on fly ash used is shown in figure 2.

From analysis of figure 2, the presence of bands widened to 3448 cm^{-1} and 1638 cm^{-1} could be observed which could correspond to vibrations of the water molecules bonded as -OH and HOH on the fly ash surface. The intense band at 1080 cm^{-1} corresponds to Si-O-Si and Al-O-Si vibrations. The bands located at 797cm^{-1} and 466 cm^{-1} are attributed to the vibrations of the Si-O-Si and O-Si-O bonds, which is explained by the presence of the quartz in the ash composition. These results confirm the results obtained by XRD (fig. 1) and are in good correlation with data reported in [37-39].

Representative scanning electron microscope (SEM) images obtained on fly ash are shown in figure 3.

From figure 3 it is noted that the investigated fly ash has a cavernous structure in the form of microspheres with regular and irregular cavities which have even submicronic dimensions (cenospheres); a detail is shown in figure 4.

These observations are in line with those reported in [40-42] and are correlated with results obtained by XRF, XRD, and SEM which indicate that the investigated fly ash can be used for light weight concretes and mortars [39-45].

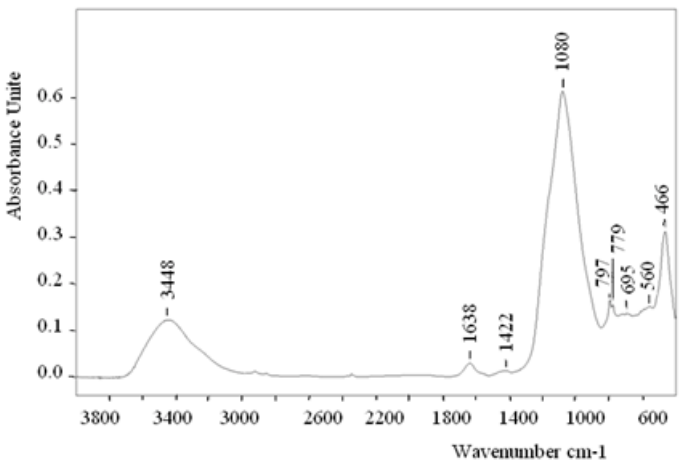

Fig. 2. The used fly ash FTIR spectrum

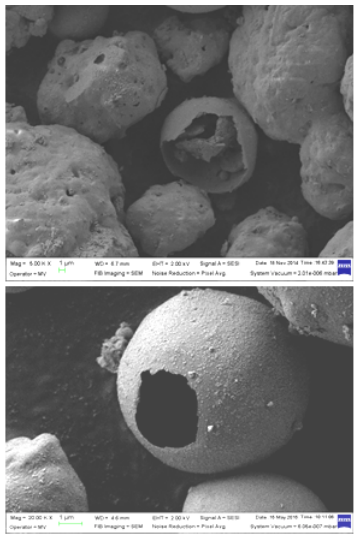

Fig. 3. SEM images on fly ash used

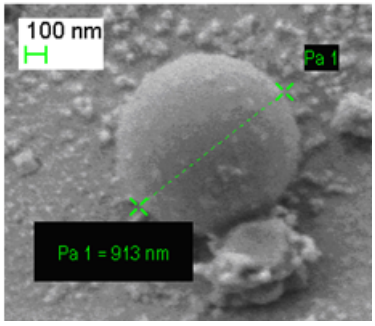

Fig. 4. SEM detail - cenosphere with 0.913 µm diameter

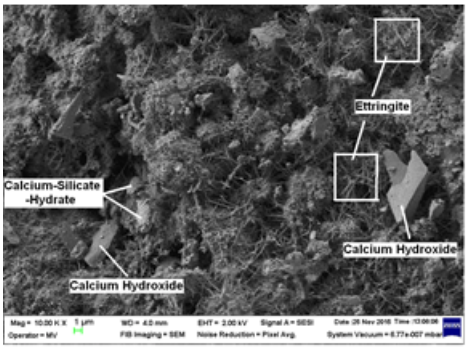

Fig. 5. The SEM image of the Mref sample

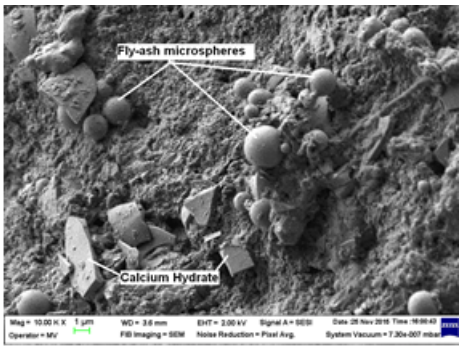

Fig. 6. The SEM image of the Mfa2 sample

Characterization of obtained mortar samples

An SEM representative image recorded on the reference mortar Mref is shown in figure 5, and figure 6 shows the SEM image of the Mfa2 mortar (with 20 % fly ash).

By analyzing figure 5 it is noted that the standard mortar sample has a structure specific to a biphasic material formed from fine sand particles dispersed in the binder matrix consisting in hydrated cement paste. In figure 6 the presence of fly ash distributed relatively uniformly in the mortar mass is highlighted. Both SEM images in figure 5 and figure 6 highlight the presence of hydrated phases of calcium hydro silicate, which are slightly structured with irregular shapes, respectively. From both figures it is observed that besides the calcium-silicate-hydrate (CSH) formation there are also hexagonal Portlandite plates (calcium hydroxide - CH), $Ca(OH)_2$ denoted as CH, as well as needle like crystals of ettringite (hexacalcium aluminate trisulfate hydrate) as an AFt phase (meaning Al_2O_3-Fe_2O_3).

The results of the and compressive strength determination of the mortar samples are presented in figure 7. Therefore the compactness of mortar, was modified and voids between solid particlas are filled with hydrates leading to degradation of mechanical strength.

From analyzing figure 7 it is noted that increasing the fly ash content to 20 % an increase of compressive strength of the mortar from 15.1 to 18.8 N/mm^2 was recorded.

At an over 20 % ash content, the fly ash decreases the compressive strength of the mortar which drops to 15.9 N/mm^2 at 40 % ash content.

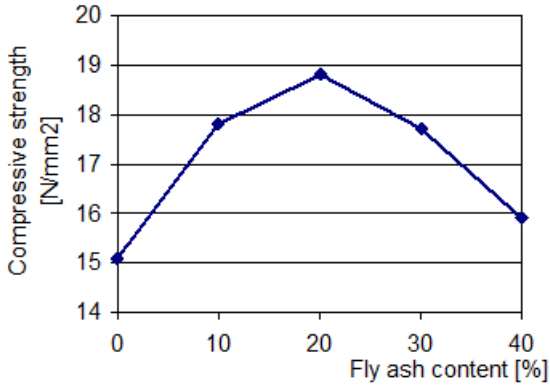

Fig. 7. Evolution of compressive strength in function of fly ash content of the mortar

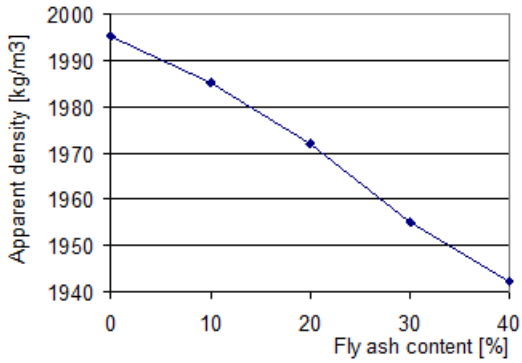

Fig. 8. Evolution of apparent mortar density according to fly ash content

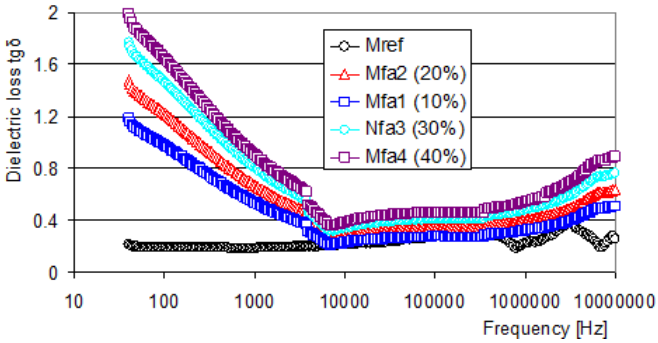

Fig. 9. Evolution tgδ of frequency function on investigated mortar samples

Evolution of apparent density of mortar samples in function of fly ash content is represented in figure 8, which shows that the increase in fly ash content leads to an approximately linear decrease of the apparent density. This dependence may be explained by the cavernous structure of fly ash as figure 3 and figure 4 have shown.

The results of the dielectric spectroscopic determination and the dielectric losses (tgä) according to the frequency of AC voltage on the investigated mortar samples are presented in figure 9. The dielectric loss quantifies the inherent dissipation of dielectric materials of electromagnetic energy (in heat, for example) and it is expressed in tems of dielectric loss tangent (tgδ).

Figure 9 shows that the dielectric losses in the investigated mortars increase as the fly ash content increases. This increases is more pronounced in the range of 40 -1000 Hz. This behavior suggests that, in the 50 Hz industrial frequency range of AC voltage and its up to the harmonics of 21-st order, the attenuation of the disturbing signals increases significantly as the fly ash content increases. The phenomenon can be explained by the increase in the overall Fe_2O_3 content in the mortar.

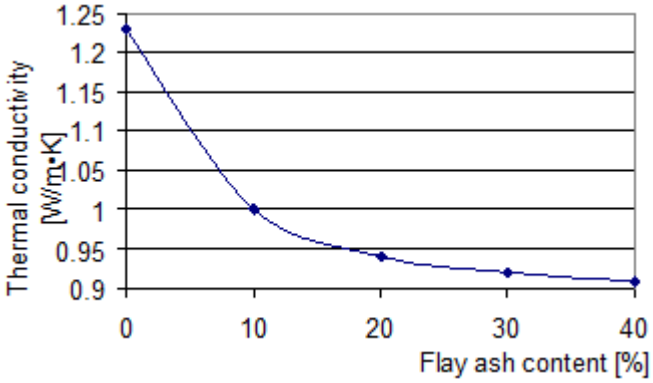

Fig. 10. Evolution of thermal conductivity of mortars versus fly ash content

The results of the thermal conductivity determinations are summarized in figure 10.

It can be obseved from figure 10 that the thermal conductivity of mortars decreases as the fly ash content increases, a fact which is explained by the cavernous microstructure and is correlated with the apparent density of the samples.

Conclusions

By the XRD, XRF, SEM and FTIR techniques was characterized a fly ash with particles smaller than 1 mm (90%, fraction < 100 μm) harvested from a thermal power plant. From the experiments it was resultad that the investigated fly ash has a cavernous microstructure of microspheres and cenospheres whose total weight content in SiO_2, Al_2O_3 and Fe_2O_3 is 88.63 % and that of CaO and MgO of 8.55 %.

In order to characterize the influence of fly ash, samples of Portland cement mortar containing up to 40 % fly ash were prepared. Following the microstructural, physical and dielectric characterization of the obtained mortar samples, it was found that:

-the fly ash particles are evenly distributed in the mortar mass and form hydrolysis bonds, with its constituents (cement and sand); the hexagonal portlandite plates and acicular crystals of ettringite in the AFt phase were evidenced;

-the compressive strength of the mortar is maximum at 20 % flay ash and minimum at the reference sample mortar (without fly ash);

-the increase in fly ash content from 0 to 40% leads to an approximately linear decrease of the apparent density, from 1995 kg/m^3 to 1942 kg/m^3;

-the dielectric losses tgä in the investigated mortars increase as the fly ash content increases and the increases are more pronounced in the range 40-1000 Hz;

-the thermal conductivity of mortars decreases as the fly ash content increases.

It follows from these findings that the addition of fly ash investigated in mortars results in the improvement of their characteristics decrease of apparent density, increase in the mechanical resistance, decrease of the thermal conductivity and significant decrease of disturbing electromagnetic fields, especially those signals with industrial frequency of 50 Hz.

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