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The Effect of Sewage Sludge Ash On Properties of Cement Composites

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Abstract

The results of research on sewage sludge ash (SSA) and fly ash (FA) and the effect of these ashes on properties of fresh pastes and hardened mortars have been presented. The chemical composition, specific surface area and grading of SSA were determined. By means of XRD analysis, the occurrence of crystalline materials was detected and by means of SEM the morphology of ashes was investigated. By means of Vicat's softening point the initial and final times of setting were defined. The replacement of cement with 10 or 20% SSA resulted in setting times extension. The chemical composition may suggest that setting times extension was caused by the occurrence of phosphorus in SSA. The standard compressive strength of 10% and 20% SSA mortars were lower. The partial replacement of cements with SSA ash makes the kinetics of strength development slow down. However, the long-term increase in compressive strength of mortar was higher compared to OPC mortar. It means that it was partially similar to the influence of the fly ash.

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Keywords: sewage sludge ash; fly ash, setting time; compressive strength; chemical and mineral composition

1. Introduction

The use of waste materials such as blast furnace slag (BFS) and fly ash (FA) has been proved very advantageous economically and ecologically. The advantages include savings on cement and improvement of certain properties of pastes and concrete [1]. The issue of possible applications of ash from sewage sludge combustion (SSAs) has not been explained as yet. The composition of the sewage sludge depends on the sewage type, treatment methods and utilization. Sewage sludge disposal practices include drying and incineration. The SSA is the incineration product, which has not yet been fully accepted as a mineral additive to cement or concrete [2]. The literature vaguely suggests

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that SSA can be used as a cement component in the amount of up to 10% of the cement added to concrete. The important condition for the replacement of a portion of Portland clinker in the cement is pozzolanic activity dependent on the chemical and mineral composition. From the practical standpoint, the effect of the chemical composition is seen first of all in the delayed increase in strength [3,4]. The long-term strength development, which may decide about the suitability of SSA for cement composites, has not been fully understood so far, [5].

2. Objective

2.1 Research objective

The primary objective of this study was to identify chemical and mineral composition of SSA and FA and to evaluate their impact on the properties of fresh pastes and hardened mortars relative to the Portland cement.

2.2 Materials

The study used the ash derived from the incineration of the sewage sludge from the municipal sewage treatment plant. The sludge is dewatered, dried and burnt in a fluidized bed furnace. Siliceous fly ash derived from the combustion of coal was also used in the study. All tests on pastes and mortars were conducted in three series. Sewage sludge ash and Portland cement were used in series 1, siliceous fly ash and Portland cement were used in series 2, whereas series 3, the control series of tests, was performed using CEM I Portland cement.

The initial and final setting time of the cement-ash binder, in which SSA and FA replaced 10% and 20% of the cement, respectively, were measured with a Vicat apparatus. For comparison, cement without the ash addition was also investigated. For this purpose, the paste with the w/s ratio of 0.25 was made. The mortars were prepared with the Portland cement CEM I 42,5R and natural quartz sand with the ratio 1:3:0.6 of cement, sand and water. The strength tests were performed using the mortars in which SSA replacement was 10% and 20% by mass of the cement. The control mortar had the same proportions and contained only the Portland cement. The specimens were stored in water for 90 days. The pozzolanic activity was expressed in percentage as a ratio of the compressive strength of the specimens. The mortars made with 90% cement and 10% SSA and with 80% cement and 20% SSA, were compared to the specimens without SSA and then all specimen's types were subjected to microstructure tests with the use of X-ray diffraction and scanning electron microscopy.

2.3. Method

The tests followed the methods specified in the binding standards and used the state-of-the-art laboratory equipment:

- the chemical composition was determined by WDXRF spectroscopy
- the grading was identified with the use of modular laser diffraction sensors Helos and Rodos
- crystalline phases were identified using the XRD analysis
- the ash grain microstructure was analysed with the use of environmental SEM/EDS
- the specific area was determined using laser diffraction sensors Helos and Rodos
- a Vicat Consistency Apparatus was used to determine the initial and final times of setting to EN 196-3:2005+A1
- the standard and long-term compressive strength of mortars was measured on 4x4x16 cm specimens to EN 450-1:2009

3. Research results

3.1 Table 1 compiles the chemical composition results.

In addition to basic component such as CaO, SiO_2 and Al_2O_3, excessively high contents of phosphorus compounds and low contents of metals, insufficient to pose a threat to the safety of mortars and concrete are observed.

Tab.1a. Chemical composition of SSA.

SiO_2	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**SO_3**	**Cl-**	**P_2O_5**	**Na_20**	**K_20**
[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]
16.60	5.10	9.10	12.90	3.80	2.10	0.01	15.00	3.50	2.80

Tab.1b. Chemical composition of SSA.

Cr	**Mn**	**Cu**	**Ni**	**Zn**	**Ba**	**Pb**	**Sn**
[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]
0.02	0.07	0.06	0.01	0.30	0.09	0.01	0.01

Tab.2. Chemical composition of siliceous fly ash.

SiO_2	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**SO_3**	**Cl-**	**Na_2O_{eq}**
[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]
50.50	26.10	7.40	4.50	2.90	0.50	0.01	-

Tab.3 Chemical composition and phase composition of Portland cement CEM I.

Skład chemiczny	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**CaO**	**$CaO_{(wolne)}$**	**MgO**	**SO_3**	**Cl-**	**Na_2O_{eq}**
	19.50	6.00	3.10	62.10	1.75	1.70	2.60	0.03	0.80
Skład fazowy	**C_3S**	**C_2S**	**C_3A**	**C_4AF**					
	54.00	17.00	11.50	10.10					

3.1 As evident from Fig. 1a, the SSA ash contains such crystalline phases as quartz, hematite, anhydrite and those with phosphorus.

Figure 1b shows the main crystalline phases identified in the siliceous fly ash: quartz, hematite, mullite and anhydrite. The remaining phases include amorphous phases and crystalline phases undetected by XRD.

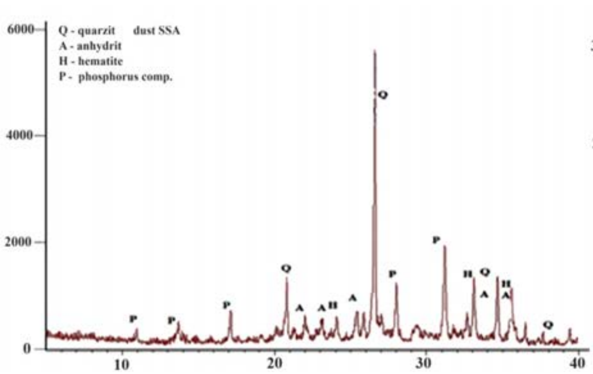

Fig.1a) Phase composition of SSA.

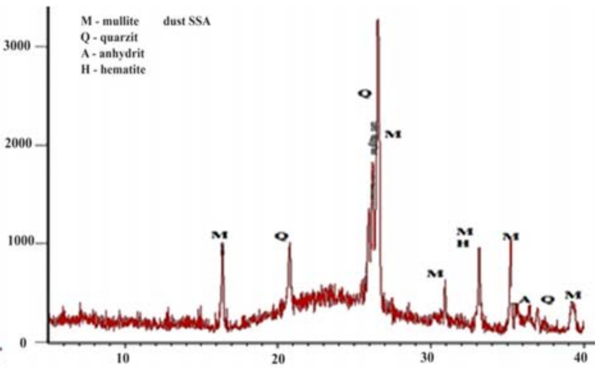

Fig.1 b) Phase composition of FA Fig.

Quartz, hematite and anhydrite are the phases present in both ash types. Mullite does not occur in SSA but the phosphorus compounds, undetected in FA, were observed.

3.2 Microstructure of SSA

The predominant grains in the sewage sludge ash are those with irregular surface, with much smaller quantities of regular spherical particles. The grains in the siliceous ash have regular spherical shapes and smooth surface.

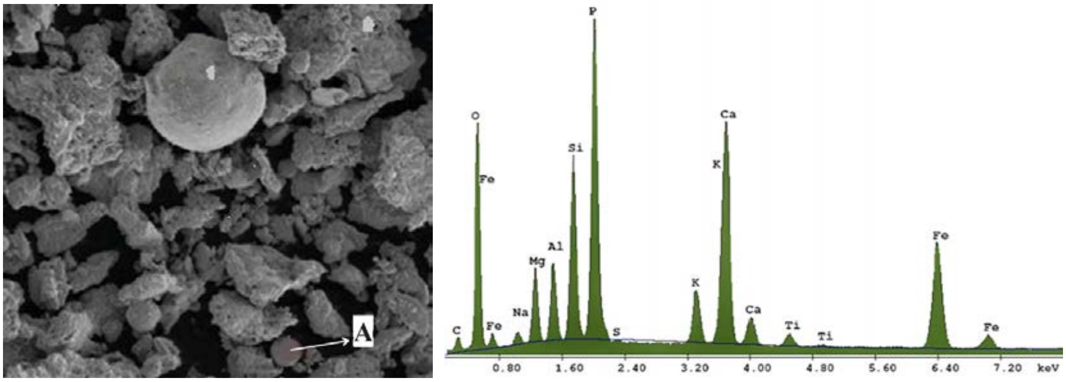

Fig. 2. SEM image of SSA grains with EDS analysis at point A.

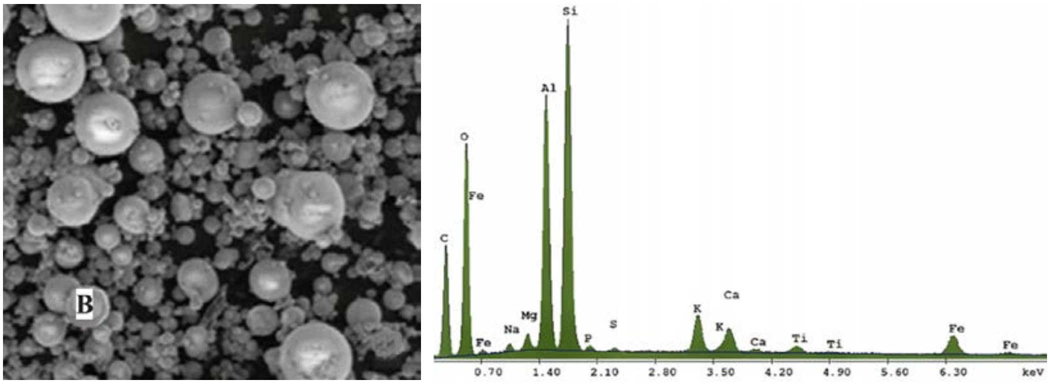

Fig. 3. SEM image of siliceous ash with EDS analysis at point B.

3.3 Grading of SSA

The grain size composition analysis results are shown in Fig. 4.

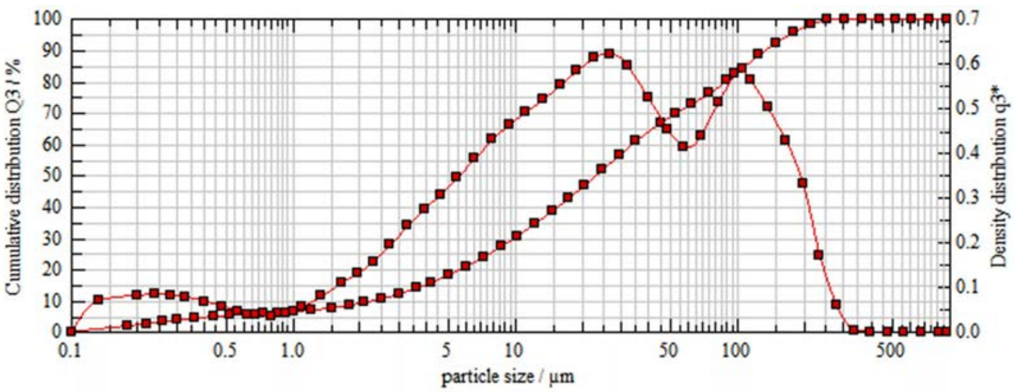

Fig. 4. Grain size composition of SSA and FA.

The cumulative curve plot indicates that the grains with sizes from 0.1 to 1.0 µm comprise 8%, and from 1.0 to 5 µm comprise 20% with no grains observed larger than 400 µm in diameter. The specific area of SSA is 1930 cm²/g.

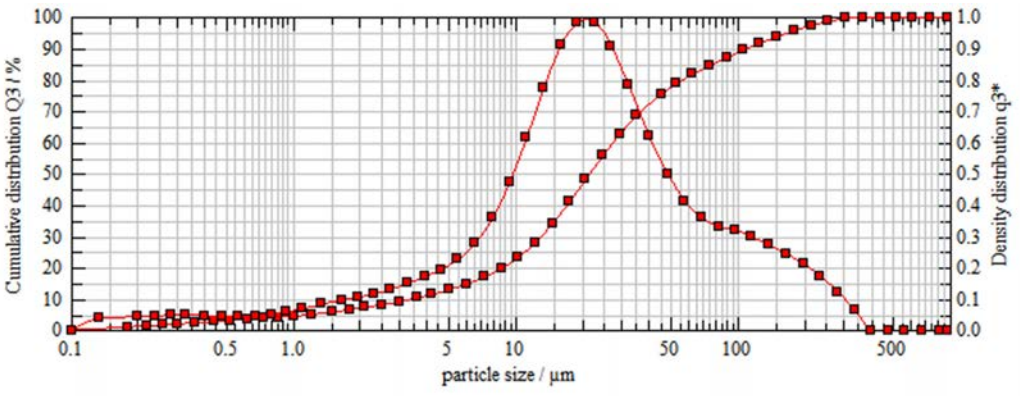

Fig. 5. Grain size composition of SSA and FA.

Figure 5 shows the curve representing the size of siliceous ash particles. It indicates that the particle with diameters between 0.1 to 1.0 µm comprise 5%, from 1.0 to 5.0 µm comprise about 20%, and the particles larger than 500 µm are not seen.

3.4 Vicat setting time measurement

The measurements were made with the use of a Vicat apparatus. The 10% and 20% addition of SSA to the binder resulted in the longer setting time compared with the binder containing Portland cement CEM I. The delay in setting onset and end were observed to increase with the amount of the ash used. The 10% and 20% by mass of cement addition of FA delayed the setting time relative to that of CEM I without the addition.

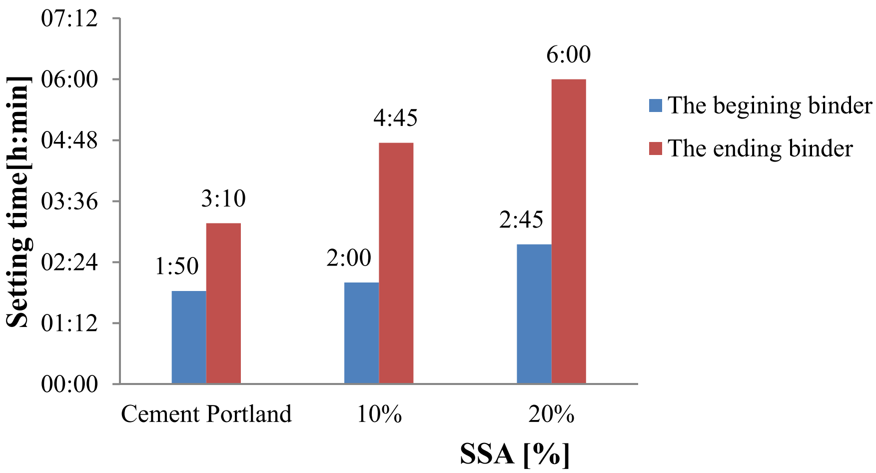

Fig. 6. The impact of SSA and FA contents on the initial and final time of paste setting.

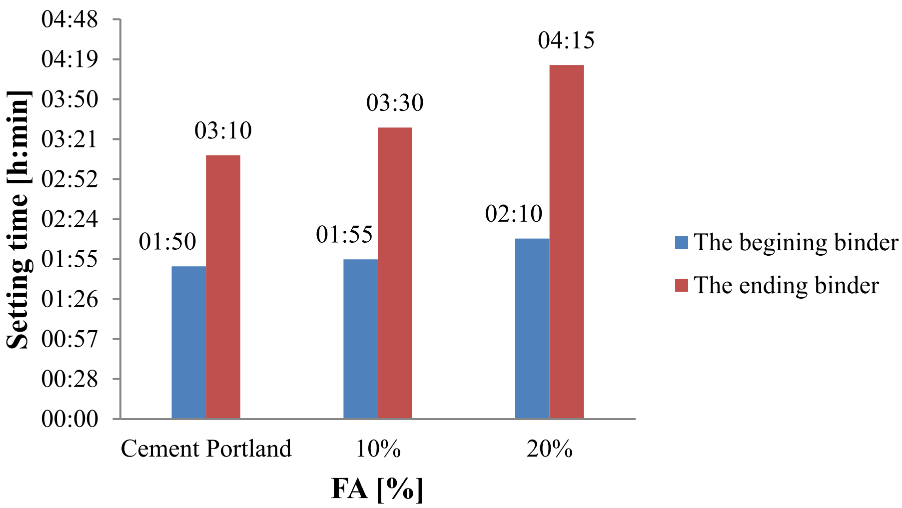

Fig. 7. The impact of SSA and FA contents on the initial and final time of paste setting.

3.5 Compressive strength of mortars

The mortars with the SSA addition demonstrated a slower strength increase, which is attributed to the lower cement content in the binder and the slower pozzolanic reaction at the initial stage of hydration. At both 10% and 20% addition of ash, a considerable strength gain was observed at 28 to 90 days.

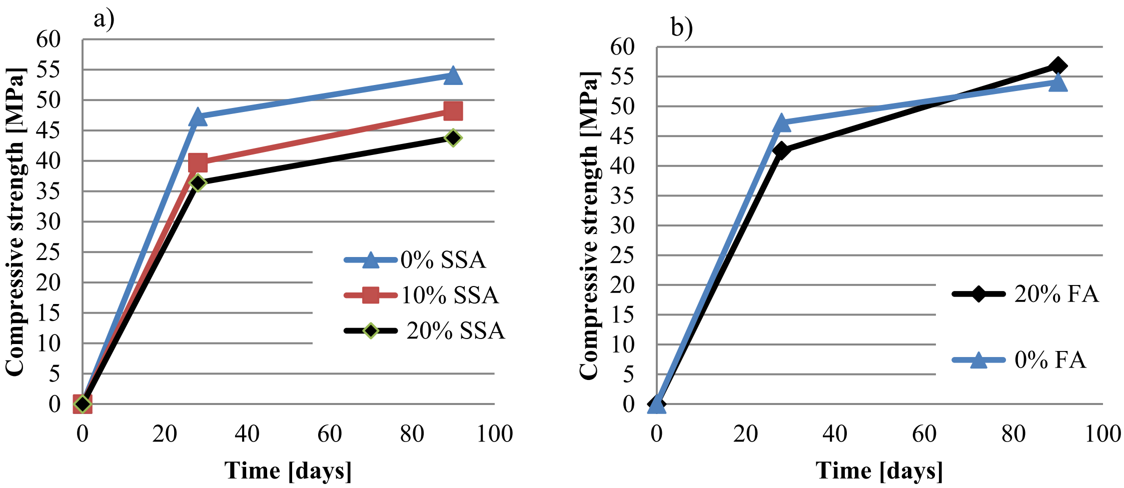

Fig. 8 (a) and (b) average compressive strength of mortars after 28 and 90 days of curing.

4. Discussion

The chemical composition of the ash under investigation varies in terms of the contents of individual elements. The silicon oxide content in SSA is 16.6% with 50.5% in FA; aluminium oxide content in SSA is 5.1%, with 16% in FA; and calcium oxide in SSA amounts to 12.9%, with 4.5% in FA. Phosphorus was detected in SSA but not in FA. SSA contains heavy metals in very low concentrations. Phase composition of both ash types (Fig. 1a and 1b) reveals the presence of quartz, hematite and anhydrite. The setting time for the binder with 20% SSA by mass of cement was two times longer than that of cement. The longer setting time of the binder with 10% and 20% SSA is probably the result of a considerable content of phosphorus in SSA. Phosphates entering the solution in the paste join with the calcium ions on the cement grain surfaces and form non-soluble tricalcium phosphate, hindering access of water to the cement particles, which delays its hydration [6]. The initial and final setting times of the binder containing 10% and 20% FA were longer compared with Portland cement. But the initial setting time of binders containing FA or SSA were comparable. The mortars with 10% and 20% ash demonstrated lower compressive strength than the Portland cement-based mortar. The average strength value at 90 days of curing and the contents of 10% SSA was comparable to that of the CEM I mortar. The strength variability is caused by inhibition of the pozzolanic reaction due to, among other factors, the contents of phosphorus compounds in SSA. The mortar with 20% FA had higher strength at 28 days of curing but at 90 days, these values were comparable.

5. Conclusions

1. The setting times of binders with SSA or FA are extended compared with the Portland cement. The initial setting times of binders containing SSA or FA are comparable, but the final setting time for the binder with SSA is markedly longer than that for FA. This may be attributed to the presence of phosphorus compounds in SSA.

2. The strength gain in mortars containing cement with 10% and 20% SSA was slower than that of the mortars with Portland cement. Pozzolanic activity of SSA was less intense than that of FA. The strength gains of the mortar with FA between 28 and 90 days was higher than that for the mortar with SSA. The cement binder containing 10% SSA can be used as a safe addition to cement composites.

3. The contents of each of the metals: Cr, Pb, Ni, Cu, Mn, Zn, Ba in SSA is less than 0.1% and should not have any impact on the properties of the cement containing this ash. The low content of metals in SSA makes it a suitable addition to mortars and concrete. Phosphorus compounds were detected in SSA but not in FA.

References

[1] Antoni., Chandra L., Hardjito D., 2015, The impact of using fly ash, silica fume and calcium carbonate on the workability and compressive strength of mortar, Procedia Engineering 125, 773-779

[2] Smol M., Kulczycka J., Henclik A., Gorazda K.,Wzorek Z., 2015, The possible use of sewage sludge ash (SSA) in the construction industry as a way towards a circular economy, Journal of Cleaner Production, 95,45-54

[3] Lynn C.J, Dhir R. K., Ghataora G.S., West R. P., 2015, Sewage sludge ash characteristics and potential for use in concrete, Construction and Building Material, 98, 767-779

[4] Maozhe Ch., Denise B., Mathieu G., Jacques M., Remy G., 2013, Environmental and technical assessments of the potential utilization of sewage sludge ashes SSAs as secondary raw materials in construction, Waste Management, 1268-1275

[5] Kazberuk-Kosior M.,Karwowska J.,2011, Wybrane problemy zagospodarowania popiołów pochodzących ze spalania osadów ściekowych w technologii materiałów cementowych, Selected problems of ash from the combustion of sewage sludge in cement materials technology Inżynieria Ekologiczna nr 25

[6] Kurdowski W., Chemia cementu, Warszawa 1991