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Sewage sludge ashes: Application in construction materials

S. Naamane[1]*, Z. Rais[1], M. Taleb[1], N.H. Mtarfi[1], M. Sfaira[2]

1 Laboratory of electrochemical engineering, modeling and environmental (LIEME), Faculty of Sciences Dhar El Mehraz, Fez, Morocco.
2 Laboratory of engineering of materials, modeling and environmental (LIMME), Faculty of Sciences Dhar El Mehraz, Fez, Morocco.

*Corresponding Author. E-mail: saranaamane@hotmail.com

Abstract
The objective of the present research is to study the waste material obtained from the incineration of sewage sludge at 700 °C under controlled conditions, i.e. sewage sludge ash (SSA), and their influence on strength and workability of cement based mortars. The SSA was characterized chemically, physically and mineralogically. In addition, the influences of SSA on mortar properties, including workability, time of setting and compressive strength were also investigated. Results show that SSA is composed of a significant amount of oxides and metals, plus an irregular morphology of its grains. The functional behaviour of mortars shows that the mechanical proprieties were moderately affected by SSA. The best mechanical results are obtained for the substitution of 10 % of SSA at 28 days.

Keywords: Sewage sludge ash, Cement, Mortar, Physico-chemical and mechanical characterization.

Introduction

Due to the rapid growth of wastewater production and the reinforcement of the regulations on its treatment, sewage sludge, as an inevitable by-product of the treatment process of wastewater, is increasing very fast. In many countries, large quantities of sewage sludge are difficult to dispose on land [1]. Also, due to the unstable nature of biomass that may contain viable pathogens and parasites as well as a variety of potentially toxic elements and compounds, inadequate sewage sludge disposal may cause environmental impact and health problems [2, 3]. Incineration may be an alternative solution, since it can disinfect the sludge and reduce its volume [4], but substantial amounts of ash are produced, which must be disposed by other means.

Some research work has already been done on the use of this residue of sewage sludge produced from incineration, i.e. the sewage sludge ash (SSA), in construction materials to make bricks [5], tiles [6], lightweight aggregates [7], and cement [8–10]. In a general way, these studies show that SSA reduces the workability of fresh mortars and decrease the compressive strength of mortars and concretes when SSA is used as a cement or sand replacement [8–15]. Most studies also report that the SSA used was incinerated from 800 °C to 1400 °C [9, 16–18].

The use of SSA in cement has been developed not only to solve the landfill sites problem, but also to conserve energy and environment by decreasing energy necessary to the production of cement, reducing CO_2 emission, conserving natural resources and reducing the load to disposal sites.

This paper reports on the characterization of sewage sludge burned at 700 °C and its influence on strength and workability of cement based mortars.

1. Preparation and characteristics of Materials

1.1. Sewage sludge

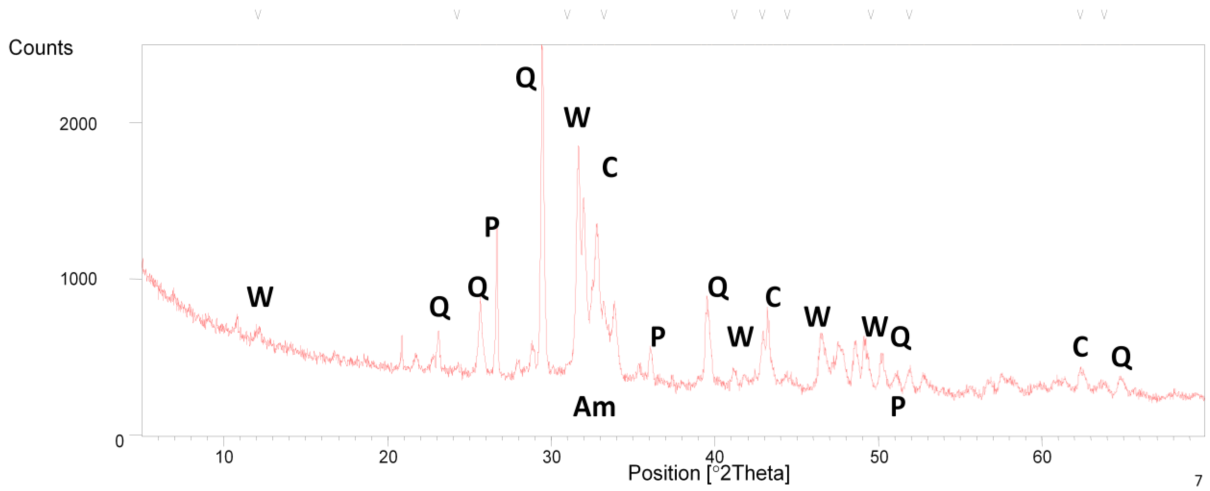
Sewage sludge was collected from an industrial wastewater treatment plant (Fez, Morocco). The sampled dewatered sludge was incinerated at 700 °C during 50 min in an electrical muffle type Nbfertherm GMbH.

The major and trace chemical compositions of SSA, provided by inductivity coupled plasma-atomic emission spectrometer (ICP-AES), are given in Table 1. SSA is mainly composed of calcium with high amounts of magnesium, sodium, iron, phosphorus, silica and potassium. The overall heavy metals contents were mainly among the lowest found in the literature for SSA, except for copper and lead [9, 16].

Mineral analysis was undertaken by X-ray Diffraction (XRD) where the main components of SSA are identified as anhydrite, calcite, portlandite, quartz and witlokite (Fig. 1). The presence of quartz and calcite is original in sewage sludge [19, 20], but the formation of anhydrite, portlandite and witlokite only took place after calcination. The proportion of crystalline and amorphous phases was not determined.
Figures 2 and 3 present the scanning electron microscopy (SEM) micrographs of SSA and sewage sludge. The organic matters which appear in sewage sludge micrographs disappear after incineration at 700◦C, leaving behind inorganic matters which appear as whitish aggregates. The micrographs of SSA show the irregular morphology of particles and the presence of crystalline aggregates. Shape of particles and granulometric distribution will have a decisive influence on the workability of mortars [9].

Table 1: Trace analysis of SSA

Elements	Ca	Fe	Mg	Mn	Na	P	Si	K
Concentrations (mg/L)	657,245	34,16	69,422	0,33	79,239	55,828	25,985	18,966
Elements	Ba	Co	Cr	Cu	Zn	Pb	V	Cd
Concentrations (mg/L)	0,53	0,02	0,79	1,84	3,82	1,04	0,018	0,04



Am: Amorphous phase; A: Anhydrite; C: Calcite; P: Portlandite; Q: Quartz; W: Witlokite.

Figure 1: X-Ray diffraction diagram of SSA.

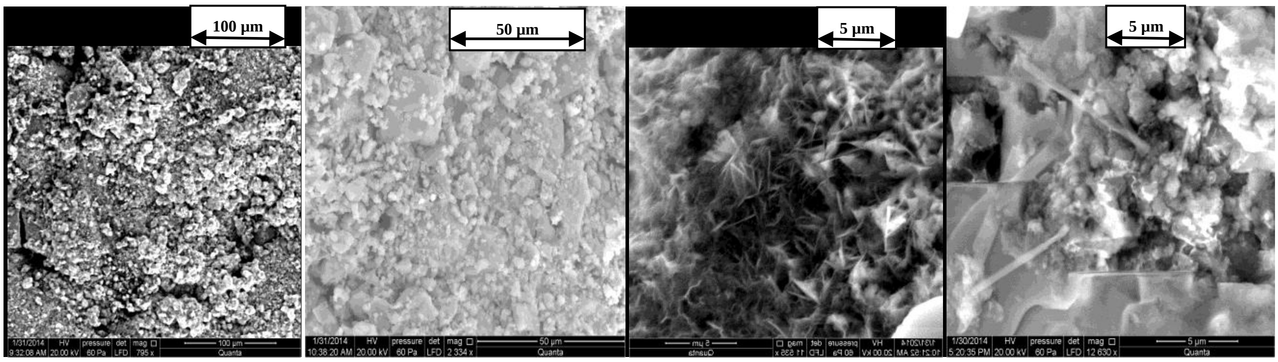


Figure 2: SEM images of SSA**.**

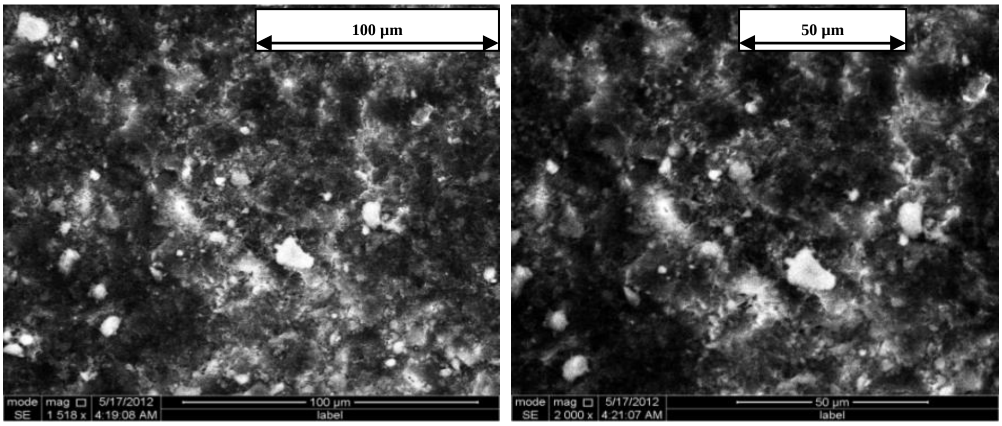


Figure 3: SEM images of sewage sludge.

1.2. Cements composing

The cement used was CPJ_{45} Portland cement according to EN 197-1[21]. The chemical compositions provided by X-ray fluorescence of clinker, limestone and gypsum are given in Table 2. The sand was from quartz with particle sizes between 0 and 2 mm in accordance with standard EN 196-1[22].

Table 2: Chemical compositions of clinker and lime

%	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	P_2O_5	LOI *
Clinker	21.47	5.29	3.27	66.05	0.91	0.88	0.06	0.95	0.02	0.64
Limestone	2.50	0.68	0.26	52.89	0.47	0.03	0.00	0.31	0.03	42.40
gypsum	-	-	-	-	-	36.60	-	-	-	22,46

**LOI: loss on ignition*

3.1. Cements- SSA mixurtures

The mortar mixtures were prepared according to French standard NF EN 196-1 [22] and contained three parts of sand to one part of binder by mass, with a W/C ratio of 0.50. The binders were composed of cement and SSA. The mixtures were prepared by replacing (5, 10, 15 and 20 %) of clinker by SSA. To study the influence of SSA, one batch of control mortar without adding any SSA was also prepared. The mixtures were cast in 4×4×16 cm molds for the first 24 h. Then the mortar prisms intended for compressive strength measurements were stored in a temperature-controlled room at 20 ◦C. Strength tests were performed in accordance to European Standard NF EN 196-1[22].

The chemical compositions, Blaine fineness, free lime, water requirement and the Setting time of SSA–cement mixtures were also determined.

The chemical compositions of the cements made with different amounts of SSA are listed in Table 3. In comparison with ordinary portland cement, the cements made from sludge contain lower percentages of SiO_2, CaO, $A1_2O_3$, Na_2O and K_2O, but higher contents of Fe_2O_3, MgO, SO_3, P_2O_5 and LOI. Most of the chemical compounds of the cements made from sludge are within the limiting values. Cement having a low CaO content generally has slow and low strength development properties. SiO_2 and Al_2O_3 compose the reactive part of pozzolanic materials [17]. Excessive levels of SO_3 in cement may lead to higher sitting time of mortars and thus loss of durability. Increasing the P_2O_5 content lowers strength due to the decomposition of C_3S, obtaining a-C_2S rich in P_2O_5 [23]. The raise of LOI is possibly due to incomplete incineration and adsorbed water.

Figure 4 presents results showing the decrease of free lime in cements with SSA. This diminish may lead to an improvement in the durability of cements as long as the percentage of free lime is superior to 1.

The test results of Blaine fineness of cement-SSA admixtures are indicated in Figure 5. The fineness of cements increased with the increase of the SSA percentage in cement. Once the fineness of SSA cements increases, the workability of SSA mortar also increases due to morphology improvement. On the other hand, the compressive strength of SSA mortar rises with the augment of SSA fineness, mainly due to the improvement of pozzolanic activity and the augment of the outer surface of SSA particles [24].

Table 3: Chemical compositions of cements

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	P_2O_5	LOI
Reference	18,96	4,10	2,43	59,25	1,07	3,06	0,17	0,82	0,07	10,27
5% SSA	18,73	4,03	2,48	59,01	1,23	3,23	0,13	0,78	0,35	10,82
10% SSA	18,21	3,90	2,51	57,70	1,36	3,36	0,10	0,75	0,67	11,54
15% SSA	18,18	3,87	2,60	57,06	1,55	3,43	0,09	0,77	0,92	12,07
20% SSA	18,12	3,82	2,74	55,98	1,72	3,51	0,09	0,79	1,40	12,96

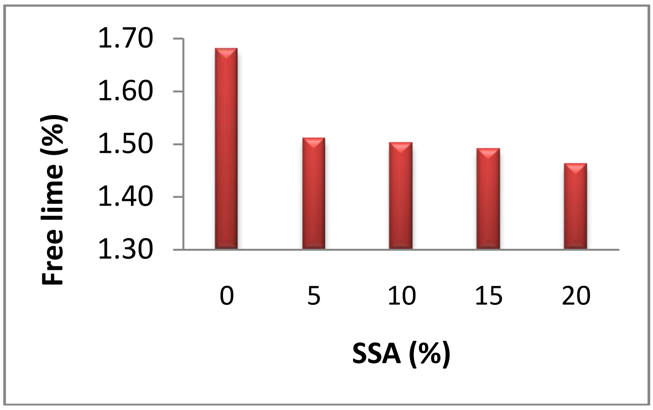


Figure 4: Free lime of cements-SSA mixtures

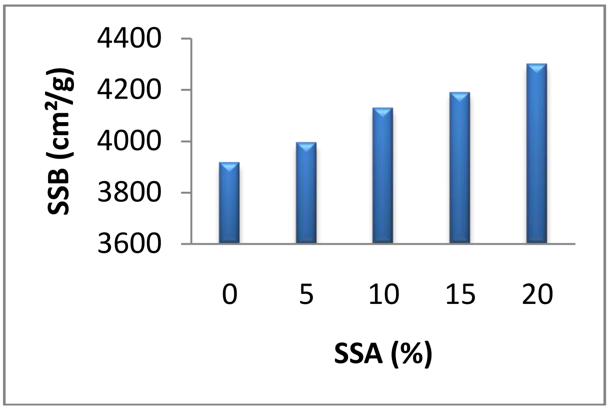


Figure 5: SSB of cements-SSA mixtures

Figure 6 presents results giving the increase of water demand of mortars containing SSA as a cement replacement. The water demand of SSA is related to the high specific surface area of the grains, which are mostly composed of small sintered particles. These particles are irregular in shape, their surfaces present irregularities and porosity witch increase the water demand for a given paste consistency. This water requirement can lead to a decrease in the mechanical performance of mortars [9].
Vicat needle (French Standard NF EN 196-3) [25] was used to determine the setting time of mortars. Initial setting was obtained after 3 h. increasing fractions of SSA induced higher setting delays compared to the control mortar (delays of 10 min, 25 min, 38 min and 51 min for 5, 10, 15 and 20% of SSA, respectively). Figure 7 gives the setting times. It can be seen that the results for all cements are in an average range.

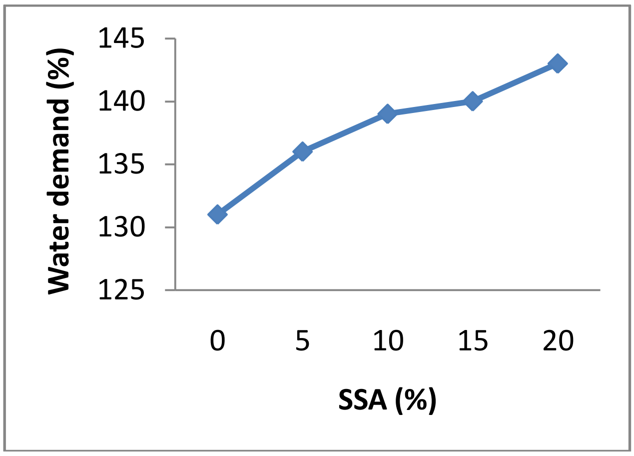


Figure 6: Water demand of cements-SSA mixtures

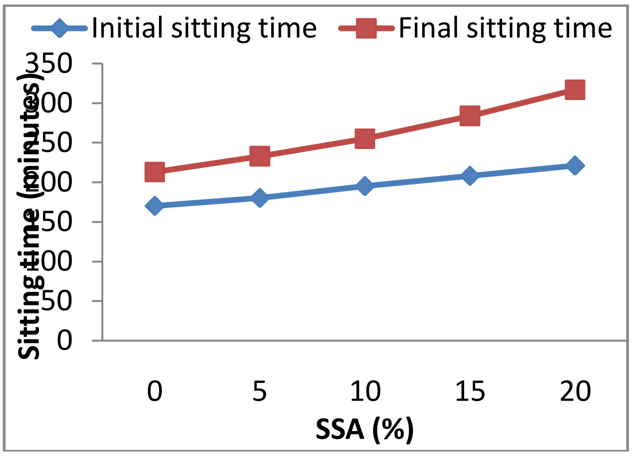


Figure 7: Sitting time of cements-SSA mixtures

Figure 8 gives the compressive strengths at 2, 7 and 28 days for mortars containing 0, 5, 10, 15 and 20% of SSA in cement. From this figure, it can be seen that the compressive strengths of cements with 5 % and 10 % of SSA are similar to the control mortar after 28 days. However, cements with 15 % and 20 % of SSA have known a decrease in the compressive strength.

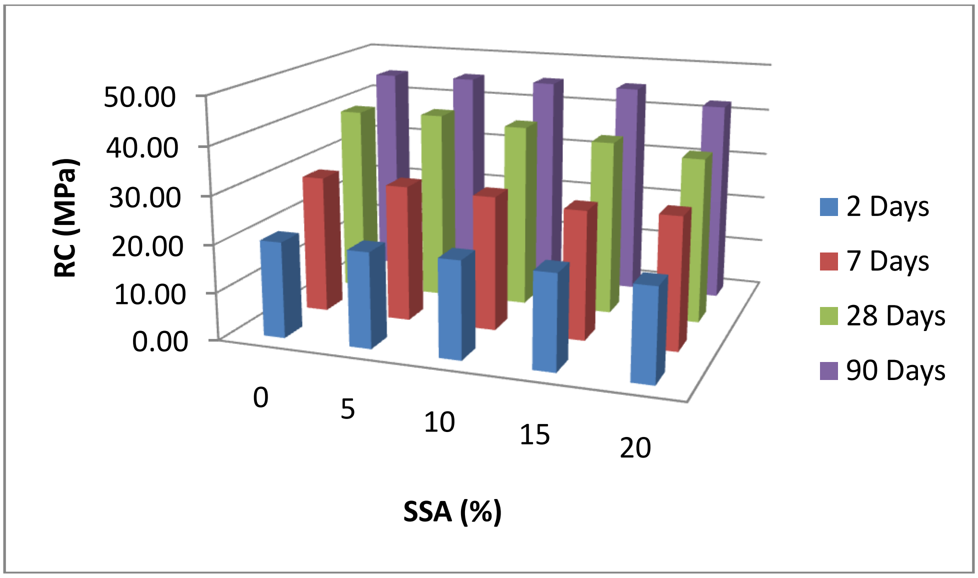


Figure 8: Compressive strengths of cements-SSA mixtures

Conclusion

This paper aimed to investigate the characteristics of sewage sludge, incinerated at 700 °C for 50 minutes, and its effect on the properties of cement based materials. This analysis highlighted the principal characteristics that must be taken into account in order to use SSA correctly in cement-based materials. The following conclusions can be made from the studies carried out:

- SSA contains anhydrite, calcite, portlandite, quartz and witlokite minerals; high amounts of calcium, magnesium, sodium, iron, potassium, phosphorus and irregular morphology of its particles.
- The partial substitution of Portland cement by SSA produces an increase of Blaine fineness, water requirement and setting time.
- The compressive strengths, after 28 days, of cements with 5 % and 10 % of SSA are comparable to the control mortar.
- The best results are obtained for the substitution of cement CPJ_{45} by 10 % of SSA.

References

1. S´anchez-Monedero M.A., Mondini C., Nobili M.D., Leita L., Roig A., *Waste Manage.* 24 (2004) 325–332.
2. Ødegaard H., Paulsrud B., Karlsson I., *Wat. Scien. Tech.* 46 (10) (2002) 295–303.
3. Young S.J., Patrick R., *Res. Conserv. Rec.* 35 (2002) 191–200.
4. Naamane S., Rais Z., Lachquar M., Taleb M., *J. Mater. Environ. Sci.* 5 (S1) (2014) 2212-2216.
5. Anderson M., Skerratt R.G., *British Ceramic Transactions* 102 (3) (2003) 109–113.
6. Lin D.F., Luo H.L., Sheen Y.N., *Journal of the Air and Waste Management Association* 55 (2) (2005) 163–172.
7. Cheeseman C.R., Virdi G.S., *Res. Conserv. Rec.* 45 (1) (2005) 18–30.
8. Lin K.L., Lin C.Y., *Cem. Concr. Res.* 35 (10) (2005)1999–2007.
9. Monzo J., Paya J., Borrachero M.V., Girbes I., *Waste Manage.* 23 (4) (2003) 373–381.

10. Naamane S., Rais Z., Mtarfi N.H., El Haji M., Taleb M., *Phys. Chem. News* 74 (2014) 44-50.
11. Monzo J., Paya J., Borrachero M.V., Corcoles A., *Cem. Concr. Res.* 26 (9) (1996) 1389–1398.
12. Monzo J., Paya J., Borrachero M.V., Bellver A., Peris-Mora E., *WASCON '97*, ISBN: 0-444-82771-4 Elsevier Science Publishers (1997) 349.
13. Monzo J., Paya J., Borrachero M.V., *Exploiting Wastes in Concrete, Proc. Int. Seminar* (1999) 47–56.
14. Monzo J., Paya J., Borrachero M.V., Peris-Mora E., *Cem. Concr. Res.* 29 (1) (1999) 87–94.
15. Paya J., Monzo J., Borrachero M.V., Amahjour F., Girbes I., Velazquez S., Ordonez L.M., *Journal of Chemical Technology and Biotechnology* 77 (3) (2002) 331–335.
16. Garcés P., Pérez Carrión M., García-Alcocel E., Payá J., Monzó J., Borrachero M.V., *Waste Manage.* 28 (2008) 2495–2502.
17. Cyr M., Coutand M., Clastres P., *Cem. Concr. Res.* 37 (2007) 1278–1289.
18. Lin K.L., Lin C.Y., *Cem. Concr. Res.* 35 (10) (2005) 1999–2007.
19. Naamane S., Rais Z., Chaouch M., *J. Mater. Environ. Sci*. 5 (S2) (2014) 2515-2521.
20. Naamane S., Rais Z., Taleb M., *Matér. & Tech.* 101 (2014) 703.
21. EN 197-1: Ciment – Composition - Spécifications et critère de conformité - Partie 1: Composition, spécifications et critères de conformité des ciment courants.
22. EN 196-1: Méthodes d'essais des ciments - Détermination des résistances mécaniques.
23. Jefferson C., Jorge A.S., *Resour. Conserv. Recycl.* 29 (2000) 169– 179.
24. Pana S.C., Tsenga D.H., Leea C.C., Lee C., *Cem. Concr. Res.* 33 (2003) 1749–1754.
25. NF EN 196-3: Méthodes d'essais des ciments - Partie 3: détermination du temps de prise et de la stabilité.

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