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Mechanical Performance of Concrete With Partial Replacement of Sand by Sewage Sludge Ash From Incineration

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Abstract. The production of sewage sludge from waste water treatment plants is increasing all over the world. Disposal of sewage sludge ash is a serious environmental problem. If we think of the areas needed for sludge ash disposal, we clearly understand the importance of reusing sewage sludge ash in concrete.
This paper presents results related to the replacement of sand by sewage sludge ash. The sludge was characterized for chemical composition (XRF analysis), crystalline phases (XRD analysis) and pozzolanic activity. The effects of incineration on crystal phases of dry sludge were investigated. Two (W/C) ratios (0.55 and 0.45) and three sludge percentages (5%, 10% and 20%) by cement mass were used. The mechanical performance of SSAC at different curing ages (3, 7, 28 and 90 days) was assessed by means of mechanical tests. Results show that sewage sludge ash leads to a reduction in density and mechanical strength. Results also show that concrete with 20% of sewage sludge ash and W/C=0.45 has a 28 day compressive strength of almost 30MPa.

Introduction

The production of sewage sludge ash from waste water treatment plants are increasing all over the world. This kind of sludge includes the solid material left from sewage treatment processes. Specific sludge production in wastewater treatment varies widely from 35 to 85 g dry solids per population equivalent per day [1,2].

The total production of sewage waste for the United States of America and the European Union approaches 17 Mt of dry solids per year (7 Mt in USA + 10 Mt in EU) [3]. Sewage sludge tends to accumulate heavy metals present in waste water and their concentration depends on the sludge origin [4].One of disposal solutions for this waste is trough incineration but this leads to hazardous emissions and even if new technologies are introduced for controlling emissions, still almost 30% of sludge solids remains as ash [5].

The incineration destroys the organic compounds, minimizes odours, greatly reduces sludge volume and has calorific value. Thus, the percentage of incinerated sludge of the sludge produced is increasing all over the world [6].The expected growth of world population and also the increase in the volume of waste water shows that sewage sludge ash will rise at a very fast pace in the next years [4]. According to some authors the best way for the construction industry to become a more sustainable one is by using wastes from other industries as building materials [7-11].

Therefore if we think of the areas needed for sludge ash disposal, we clearly understand the importance of reusing sewage sludge ash in concrete. Since global Portland cement demand will increase almost 200% by 2050 from 2010 levels, this means that concrete structures are expected to increase in a similar trend. Investigations on SSAC has already been reported by several authors. The results show that sewage sludge ash reduces workability [13], decreases mechanical performance [14].

Contradictory the same authors that report a serious decrease in mechanical strength states that SSAC does not show a durability reduction [16]. Recent investigations show that the partial replacement of cement by sewage sludge ash led to substantial retardation of hydration rates [17]. Nevertheless, further investigations are needed about SSAC. For instance since different sewage sludge ashes have different chemical composition different concrete performance are expected.

This study aims to evaluate the mechanical performance and capillarity water absorption when using sewage sludge ash of a water treatment plant in Iran.

Experimental

Materials, mix design and concrete mixing . Sewage sludge ash. The sludge was prepared by Alborz industrial city's sewage treatment plant. The sewage sludge ash is mainly composed by silicon, calcium and aluminum. The sludge was also determined by XRF (Table 1).

Table 1. XRF analysis for dry sludge ash

Elements	LOI	SiO_2	Al_2O_3	CaO	Mg	K_2O	P_2O_3	Fe_2O_3	Br	Na_2O	Zn	Other
%	21.3	54.5	8.9	7.3	2.1	1.8	1.3	0.9	0.5	0.4	0.2	0.8

Chloride peaks observed by others were not detected [15,17]. Due to the high weight loss on ignition (L.O.I) of the sludge and negative effects of oils and fats on concrete performance, heat treatment process was performed for sludge up to 650 ^{o}C. The most important change which was observed visually was the change in sludge color from white-creamy to grey. In order to determine the mineralogical composition the representative samples were analysed by XRD (Table 2).

Table 2. XRD analysis

Before calcination	After calcination
Quartz (SiO_2)	Quartz (SiO_2)
Muscovite ($KAl_2(Si_3Al)_{10}(OH,F)_2$)	Muscovite ($KAl_2(Si_3Al)_{10}(OH,F)_2$)
Calcite ($CaCO_3$)	Ilite ($KAl_2(Si_3Al)O_{10}(OH)_2$)
Dolomite ($CaMg(CO_3)_2$)	

Result showed that two crystalline phases calcite and dolomite have been removed from the sludge. This is attributed to the remove of CO_2 content from the sludge due to the calcination. Probably calcite and dolomite crystals changed to calcium and magnesium oxides in dry sludge. Also, an additional crystalline phase appeared in sludge composition (i.e. Illite) its chemical structure is close to muscovite. It is clear that calcination not only eliminates the organic matter but also changed the crystalline phases.

Mix design and concrete mixing. For the production of concrete specimens, Portland cement, Portland cement Type II of ABYEK Cement Production Co was used along with both gravel and sand from Rahsar Company's. To improve concrete workability a Melcrete super-plasticizer was used. A reference mixture (Control) and three more mixtures according to the sludge ash content (5%, 10% and 20%) were designed. Two water/cement ratios were evaluated (0.45 and 0.55). Table 3 presents the concrete mix proportions per cubic meter of concrete.

Table 3. Concrete mix proportions per cubic meter of concrete

Mixtures	Cement (Kg)	Gravel (Kg)	Sand (Kg)	Sludge (Kg)	Super plasticizer (Kg)	Water (l)	
						w/c=0.55	w/c=0.45
Control	360	861	852	0	3.6	198	162
SSAC - 5	360	861	852	18	3.6	198	162
SSAC-10	360	861	834	36	3.6	198	162
SSAC-20	360	861	798	72	3.6	198	162

The specimens were left for one day in the mold at the laboratory conditions (23±2 ^oC). Then they were removed and immersed in water until tested in compression.

Compressive strength. The compressive strength was determined following the ASTM C39/C39M [18]. The test was performed on 15×15×15 cm^3. Compressive strength for each mixture was obtained from an average of 3 cubic specimens determined at the age of 3, 7, 28 and 90 days.

Flexural strength. The compressive strength was determined following the ASTM C78 [19]. Compressive strength for each mixture was obtained from an average of 3 cubic specimens determined at the age of 28 days.

Capillarity water absorption coefficient. Capillarity water absorption coefficient was carried out according the C1585 ASTM [20] and using 10×10×10 cm^3 specimens with a 28 days curing age. Preparation of test specimens is done as follows: after drying in an oven at 105 ºC for 48 h, the specimens are waterproof along the lateral surface with a fine layer of silicon in order to reduce water evaporation and guarantee capillary water absorption. The test specimens are then placed on desiccators, for some hours, to allow the hardening of the silicon. Capillary water absorption was obtained from an average of 3 specimens. Capillarity water absorption coefficient corresponds to the slope of the curves representing water absorbed per unit area versus square root of time.

Results and Discussions

Compressive strength. Fig. 6 shows the results of compressive strength of concrete mixtures with a W/C=0.55.

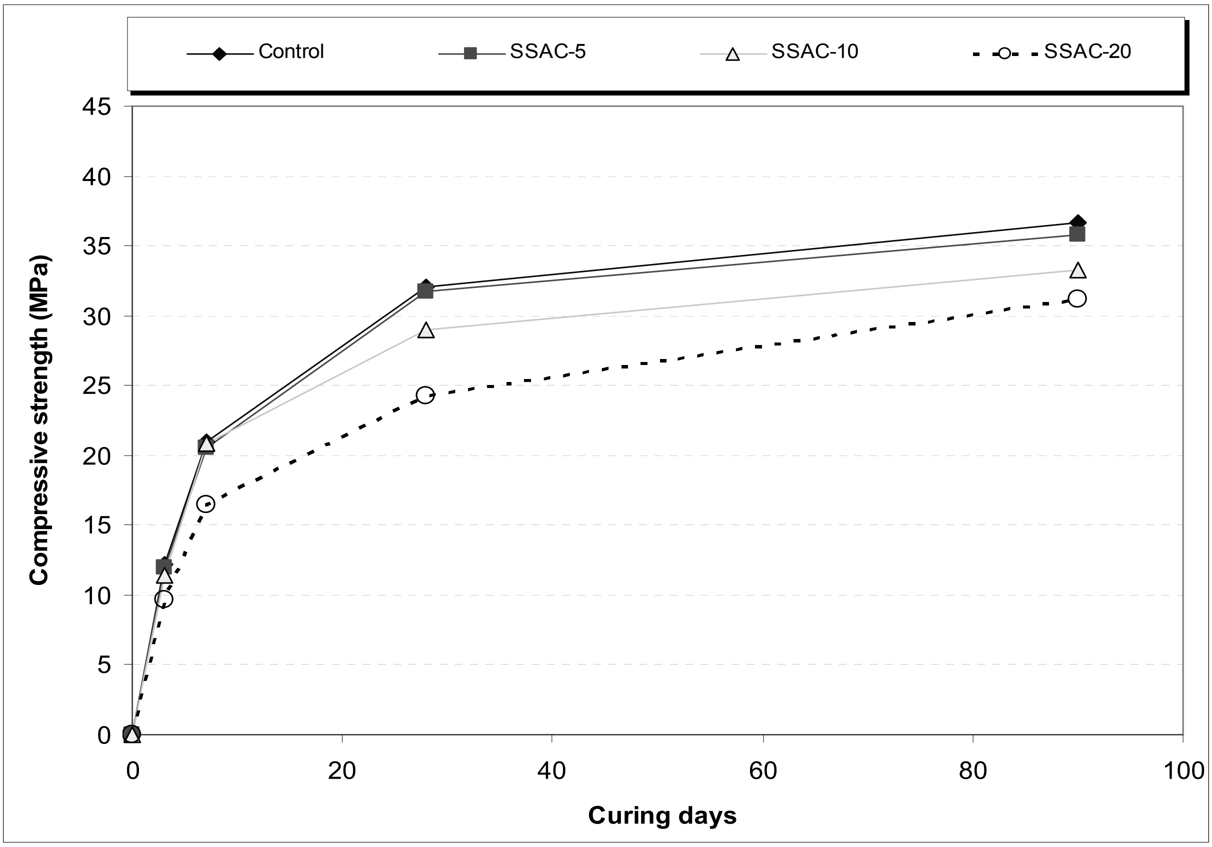

Fig.1. Compressive strength of concrete mixtures with W/C=0.55.

For a hydration period of 3 days no significant differences are noticed. Beyond 7 days curing until 28 days the concrete mixture with a 5% content of sludge ash shows almost no compressive strength loss. Mixtures with 10% sludge ash have a 10% compressive strength loss and similar performance happens to the concrete mixture for a 20% sludge ash content, meaning that strength loss is proportional to the sludge ash content.

The mixture with 20% sludge ash content shows increase compressive strength with curing time, and for 90 days almost reaches the same compressive strength of the mixture with just 10% sludge ash. This could be attributed to a minor pozzolanic effect as reported by other authors [21] or to the fact that sludge ash particles could behave like extra sites for the nucleation and growth of hydration products enhancing the overall hydration process [22, 23].

Results show that concrete mixtures with 5% or even 10% sludge ash shows minor compressive strength loss. Even the use of a 20% sludge ash content leads to a compressive strength above 25MPa for 28 days curing.

Fig. 7 shows the results of compressive strength of concrete mixtures with a W/C=0.45. The results show that the reduction in the water leads to an overall increase in compressive strength associated with a denser microstructure.

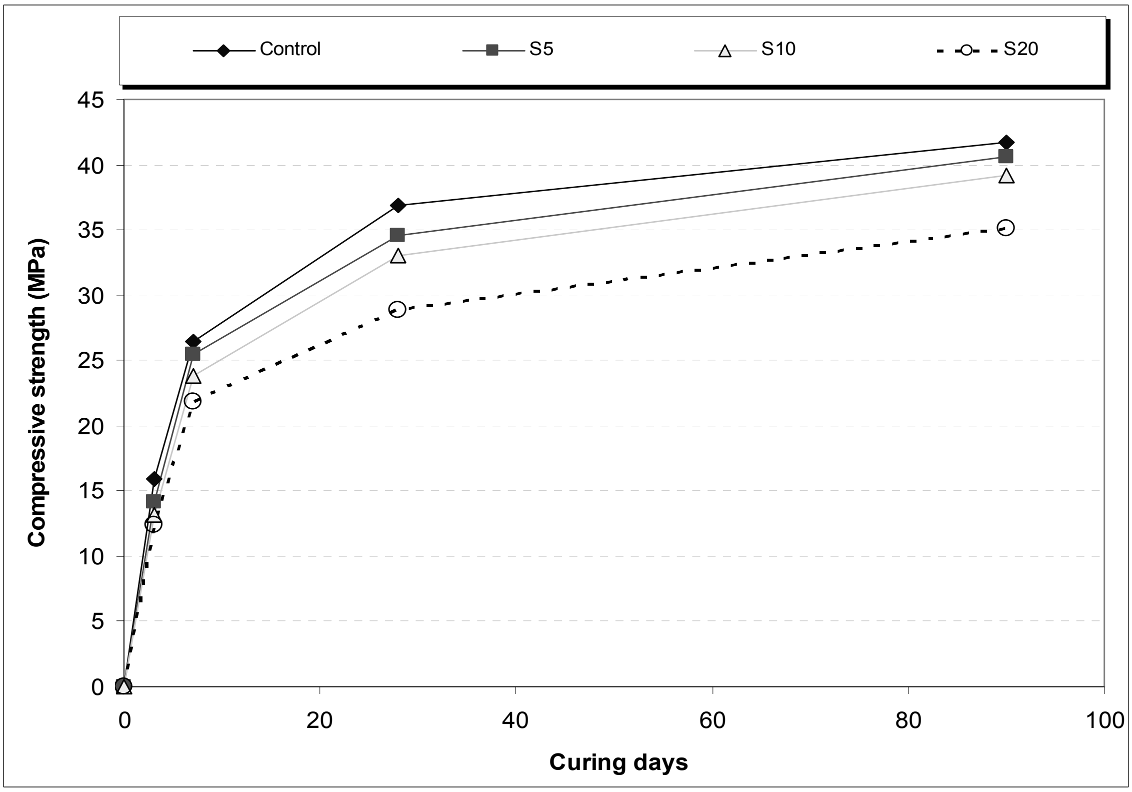

Fig.2. Compressive strength of concrete mixtures with W/C=0.45.

The mixture with a 20% sludge ash content has almost 30MPa for 28 days curing. For this hydration period the sludge content influences the compressive strength in a proportional way. This compressive strength level is very promising when compared to the feeble performance obtained by other authors [14, 16].

Flexural strength. Fig. 3 shows the flexural strength of the several concrete mixtures. Results show that an increase in the sludge content leads to a decrease in the flexural strength. The reduction in the W/C ration leads to denser mixtures and higher flexural strength.

Capillarity water absorption coefficient. Capillarity water absorption coefficients are shown in figure 4. Results show that using a sludge ash content of 5% or even 10% does not changes the concrete capillary network. But when a 20% sludge ash content is used the capillarity water absorption coefficient almost doubles. Having said that on must bear in mind that other authors [22] obtain capillarity water absorption coefficients between 0.85 and 2.6 $kg/m^2.h^{0.5}$, for a plain C20/25 strength class concrete (the most used strength class in Europe), this means that the capillarity water absorption coefficient associated to 20% sludge ash mixture has a good capillarity water absorption performance.

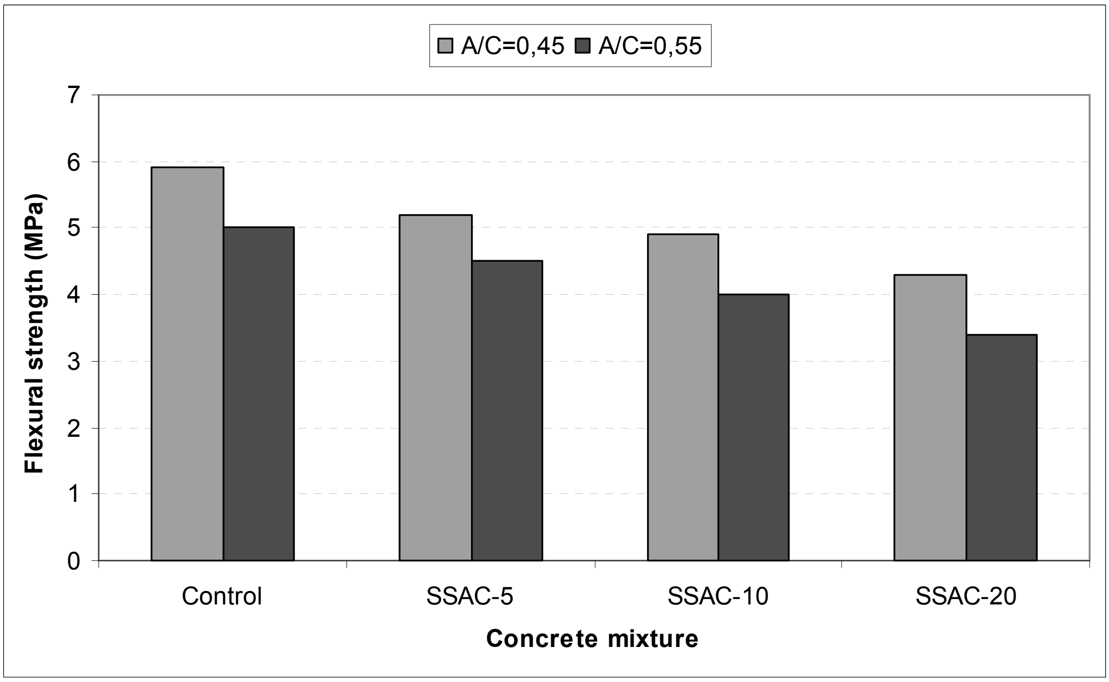

Fig. 3. Flexural strength

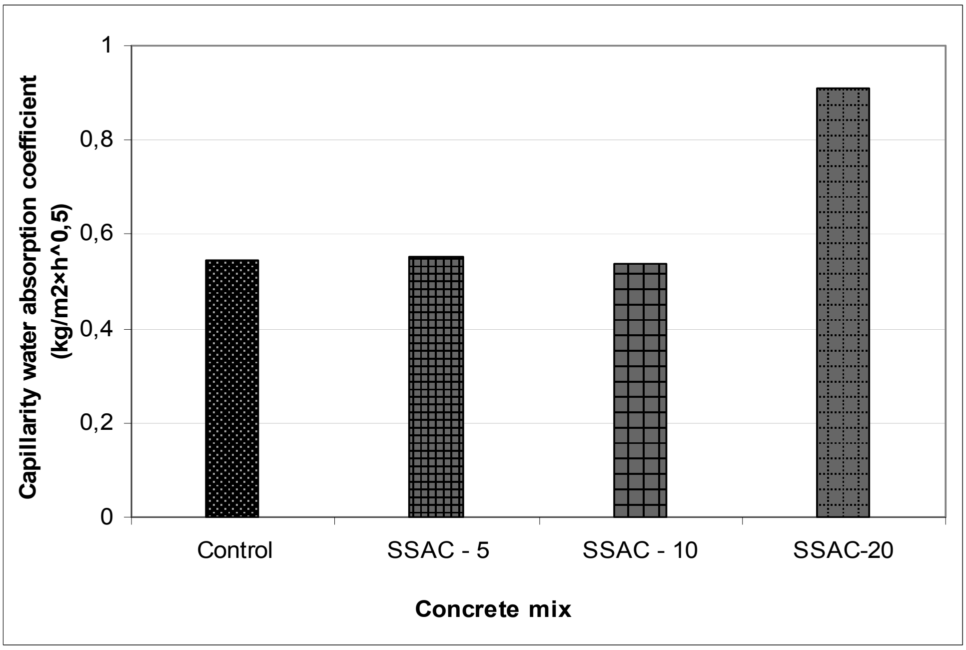

Fig. 4. Capillarity water absorption coefficients of concrete mixtures with W/C=0.45

Conclusions

Application of sludge ash of a water treatment plant in concrete was investigated at water to cement ratios of 0.45 and 0.55. The following conclusions were obtained on the basis of results. Concrete mixtures with 5% and 10% sludge ash content show minor reductions in the mechanical performance. By increasing the sludge ash content to 20%, a decrease of about 20% in compressive and flexural strengths was obtained. Still concretes containing 20% sludge ash showed acceptable mechanical performance at W/C=0.45. This sludge ash content leads to an increase of the capillarity water absorption coefficient, however, it compares favourably with the performance of a C20/25 strength class concrete. SSAC can contribute to reduce sludge disposal areas and also to reduce the exploration of sand. Further investigations on leaching tests and ecotoxic performance are needed to insure the environmental performance of SSAC.

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