APPLICATION OF SEWAGE DRY SLUDGE IN CONCRETE MIXTURES

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ABSTRACT

In recent decades, disposal of dry sludge have been an important problem of sewage treatment plants due to environmental restrictions. The material is not usually permitted to be buried in soil or used as agricultural fertilizer because of high heavy metal contents. Some investigations performed on application of these materials in construction materials especially concrete mix designs. In this research, application of dry sludge produced in the Alborz (Qazvin) industrial/domestic sewage treatment plant in mass concrete at water to cement (w/c) ratios of 0.55 and 0.45 was investigated. The dry sludge was characterized for chemical composition (XRF analysis), crystalline phases (XRD analysis) and pozzolanic activity (Thermal gravimetery). Thereafter, it was used at 0, 5, 10, 20 and 30% of cement content in concretes. Effect of the dry sludge on compressive strength at different ages of curing 3, 7, 28 and 90 days was investigated. Besides, flexural strength, water absorption and porosity of concretes containing 20% dry sludge were measured after 28 and 90 days of curing. It was found that using dry sludge at 5, 10 and 20% caused decrease in compressive strength about 9, 14.5 and 29% in 28 days cured and 3.5, 8 and 20% in 90 days cured specimens in comparison to control specimens, respectively.

Keywords: Dry sludge; concrete; compressive strength; physical/mechanical properties; sewage

1. INTRODUCTION

Waste is an inevitable consequence of human activity. The most important problem related to waste is pollution of environment [1]. In recent years, waste production increased dramatically in third world countries such as Iran. There were two methods for disposal of solid waste (dry sludge) including; to landfill and to use as fertilizer. Both of these methods have been prohibited by Iran's Environment Organization due to dangers of heavy metals present in sludge. Due to these limitations, high volumes of dry sludge have been produced

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and collected in treatment plants.

In recent decade, disposal of dry sludge by applying in concrete proposed by some researchers [1-7]. The results of these investigations showed that performance of concrete containing dry sludge depends on sludge composition, organic material content and volume of incorporation [1, 5]. It was resulted that using dry sludge decreases considerably concrete strength and slows the curing process [1, 2, 5]. However, due to importance of disposal of this hazardous material, the method seems to be valuable for more considerations.

This study aims to evaluate the effects of adding the dry sludge of Alborz Industrial/domestic sewage treatment plant to mass concrete. Different water to cement ratios (0.55 and 0.45) and sludge contents (0, 5, 10, 20 and 30%) were used to determine effects on compressive strength, flexural strength, water absorption and porosity of samples. The dry sludge chemical composition and crystalline phases was studied by XRF and XRD analysis, respectively. The effects of heating on crystal phases of dry sludge were investigated. Finally, the best w/c ratio and dry sludge content on the basis of economical, technical and environmental issues was selected.

2. MATTERIALS AND METHODS

2.1 Materials

- Dry sludge

The used dry sludge in this investigation was prepared by Alborz industrial city's sewage treatment plant which is 40 kilometers far from Qazvin city. The characteristics of sewage and chemical properties of wet sludge imported to this treatment plant are presented in Tables 1 and 2, respectively.

Table 1: Properties of sewage of Alborz Industrial City’s treatment plant

Property	**unit**	**rate**
Temperature	°C	Variety
Color	-	Dark green
Ec	μ s.cm^{-1}	1800
pH	-	7.6
BOD	mg/lit	1200
COD	mg/lit	2000
TSS	mg/lit	1400
Phosphate	mg/lit	60
Nitrate	mg/lit	10
Sulfate	mg/lit	183
Azotes	mg/lit	44
NH_4	mg/lit	28
Suspended solids (S.S.)	mg/lit	40
Detergent	mg/lit	14.2
No_2+No_3	mg/lit	10
TDS	mg/lit	980

Table 2: Alborz Industrial City's treatment plant chemical wet sludge characteristics (after digestion)

Parameter	Unit	Rate
pH	-	7.2
BOD	mg/lit	130
COD	mg/lit	195

The fineness rate of sludge sample was also measured by 45 micron sieve (mesh 325). Results indicated that 51.5% of sludge remained on the sieve.

- Cement

Portland cement Type II of ABYEK Cement Production Co. was used in this study.

- Aggregate

Applied gravel and sand for making concrete provided from Rahsar Company's mine around Qazvin city. Figure 1 shows particle size distribution of sands, fine and coarse gravels.

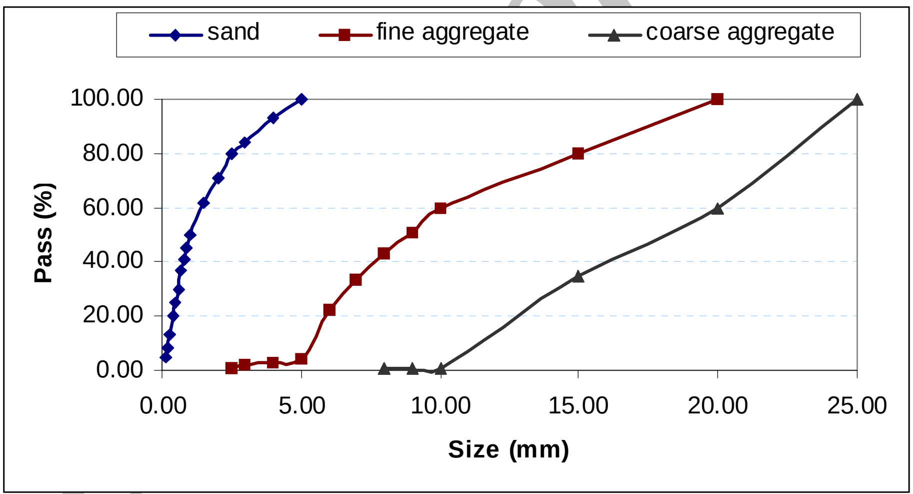

Figure 1. Particle size distribution of used aggregates

- Super plasticizer

To improve concrete workability Melcrete super plasticizer was used.

2.2 Methods

- Concrete mix design

To determine effects of treated dry sludge on concrete, mix designs with water to cement ratios of 0.45 and 0.55 was considered. The dry sludge was added to concrete mixture at different contents of 5, 10, 20 and 30%. Table 5 shows mix designs used in this investigation.

Tabel 3: Concrete mix designs

Mixtures	**Cement (kg)**	**Gravel (kg)**	**Sand (kg)**	**Sludge (kg)**	**Super plastilizer (kg)**	**Water (lit)**	
						w/c=0.55	**w/c=0.45**
S0*	360	861	852	0	3.6	198	162
S5	360	861	852	18	3.6	198	162
S10	360	861	834	36	3.6	198	162
S20	360	861	798	72	3.6	198	162
S30	360	861	762	108	3.6	198	162

*** Control specimens were prepared by S0 mix design.**

- *Curing of specimens*

Casted specimens left for a day in mold in humid condition at laboratory condition (23±2^{o}C). Then they removed and immersed in water for 27 days.

- *Density of samples*

The density of concrete mix designs (samples) were determined which results are shown in Figure 2.

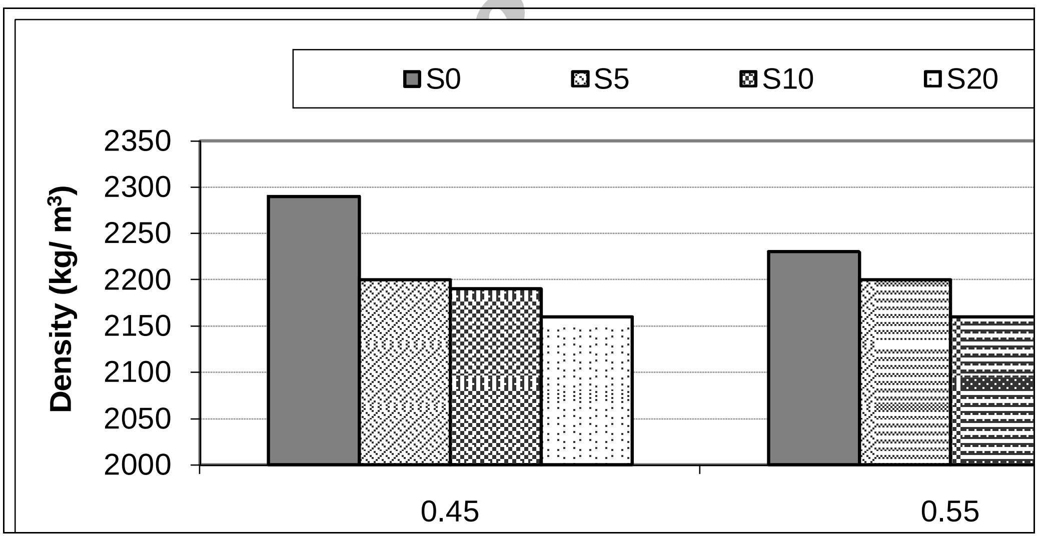

Figure 2. Density of concrete mix designs

- *Thermal analysis*

Thermal analysis was performed by STA-499C instrument. The sludge was analyzed up to 650^{o}C by temperature rate of 10^{o}C per minute.

3. RESULTS AND DISCUSSIONS

3.1 Analysis of dry sludge

The used dry sludge was characterized using XRF and XRD analysis to determine crystalline phases. Table 4 shows results of XRF analysis. It is evident that more than 20 % of the dry sludge composed of organic materials (especially oils and fats). Furthermore, there are more than 50% (weight percent) of SiO_2 in the sludge. This was very interesting because lower SiO_2 contents were reported in previous researches [1].

Table 4: Results of XRF analysis for dry sludge

Elements	Percentage
L.O.I*	21.3
Na_2O	0.436
MgO	2.194
Al_2O_3	8.962
SiO_2	54.545
P_2O_3	1.303
SO_3	0.171
K_2O	1.79
CaO	7.337
TiO_2	0.2
Fe_2O_3	0.927
Zn	0.149
Br	0.541
Sr	0.031
Zr	0.114

*** Loss on ignition**

Figure 3 and Table 5 show XRD analysis diagram and crystal phases. Four types of crystals were detected in the dry sludge. The dominant phase was related to quartz crystals.

Table 5: Determined crystals in dry sludge (XRD analysis)

Chemical formula	Crystals
SiO_2	Quartz
$KAl_2(Si_3Al)_{10}(OH,F)_2$	Muscovite
$CaCO_3$	Calcite
$CaMg(CO_3)_2$	Dolomite

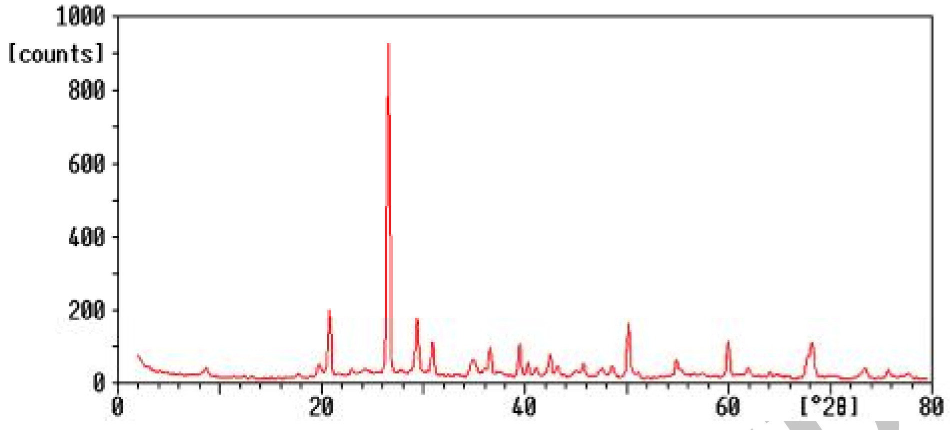

Figure 3. XRD diagram of dry sludge

3.2 Effect of heat treatment of dry sludge

Due to the high weight loss on ignition (L.O.I) of dry sludge and negative effects of oils and fats on concrete performance, heat treatment process was performed for dry 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. To determine crystalline changes in the dry sludge, it was analyzed by XRD again. Results are shown in Figure 4 and Table 6.

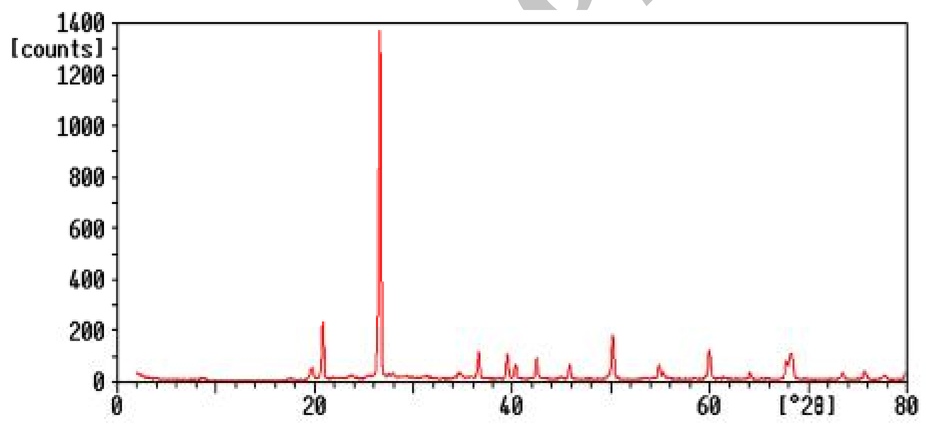

Figure 4. XRD diagram of dry sludge after heat treatment

Table 6: Detected crystals in heat treated dry sludge (XRD)

Chemical formula	**Crystals**
SiO_2	Quartz
$KAl_2(Si_3Al)O_{10}(OH,F)_2$	Muscovite
$KAl_2(Si_3Al)O_{10}(OH)_2$	llite

Result showed that two crystalline phases of Calcite and Dolomite have been removed from dry sludge. It was attributed to remove of CO_2 content from the dry sludge due to heating. It was assumed that Calcite and Dolomite crystals changed to Calcium and Magnesium oxides in dry sludge. Also, an additional crystalline phase appeared in dry sludge composition (i.e. Lllite) which its chemical structure is so much close to Muscovite.

It is clear that heating action besides eliminate organic matter causes change in crystalline phases. To investigate generation of pozzolanic activity in dry sludge (i.e. reaction to water like to Portland cement and natural pozzalans) after heat treatment, thermal analysis (TGA) was performed by STA-499C apparatus. Results are shown in Figure 5.

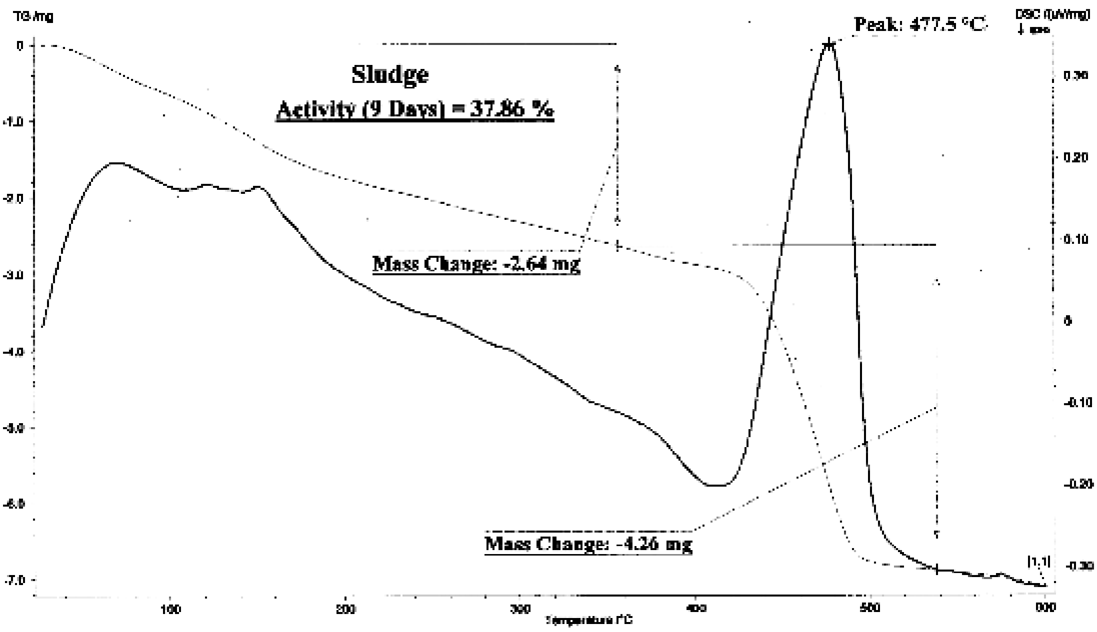

Figure 5. Thermal analysis of the used dry sludge

According to the analysis results, the activity of sludge sample was 37.86% which is too much lower than natural pozzolans activities (i.e. 70%). On the basis of this finding, it was concluded that dry sludge has not considerable chemical activity and it can only act as filler or aggregate in concrete depending on particle size.

3.3 Compressive strength test

Figure 6 shows the results of compressive strength of concretes at w/c ratio of 0.55. Decreases about 25, 10 and 1% in compressive strength was obtained for the concretes containing 30, 20 and 5% dry sludge (in 28 days cured specimens), respectively. These were changed to 15, 10 and 2.5% in 90 days cured specimens. It is evident that concretes containing higher sludge contents showed better performance at longer curing times.

It was found that by adding 5 percent of dry sludge to concrete, negligible decrease in compressive strength (less than 3%) is achieved. There were not considerable differences between compressive strength of specimens containing 10 and 20% dry sludge.

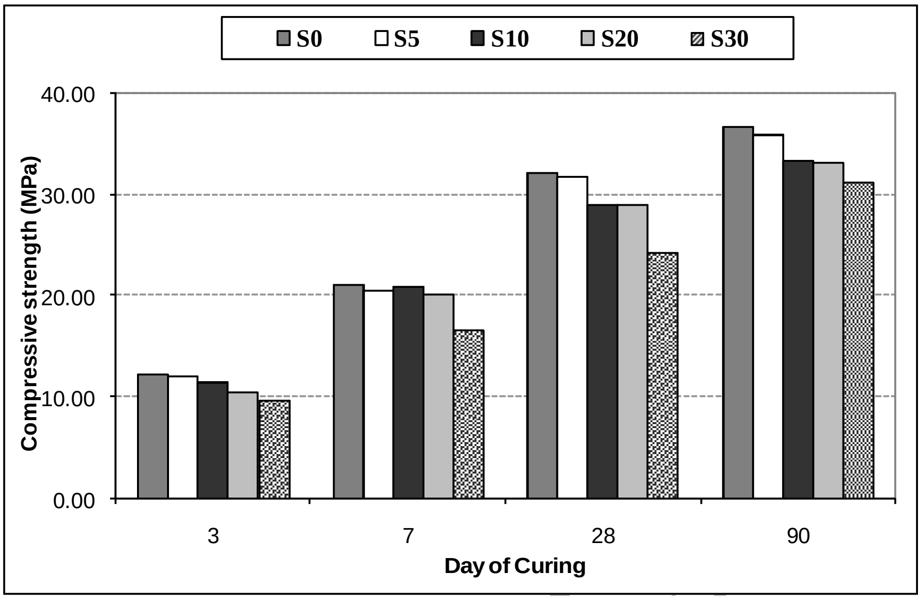

Figure 6. Compressive strength of specimens prepared at water to cement ratio of 0.55

Figure 7 shows the results of compressive strength of concretes at w/c ratio of 0.45. At this water to cement ratio, the production of concrete with 30% dry sludge was not possible due to high water consumption of sludge. The figure shows that by increasing the dry sludge content up to 5, 10 and 20%, the compressive strength decreases to 6, 10 and 22% for 28 days cured specimens and 2.6, 6.2 and 16% for 90 days cured specimens.

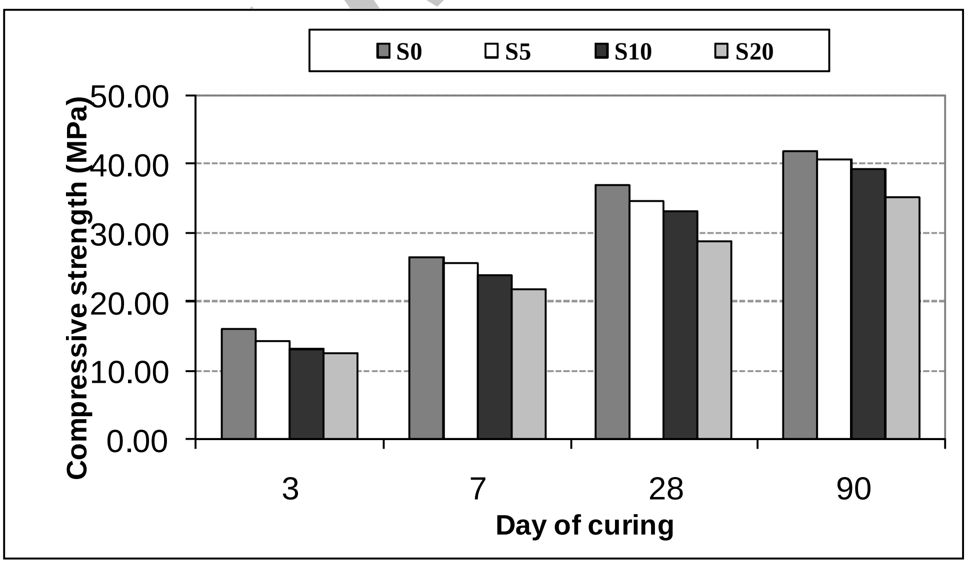

Figure 7. Compressive strength of concrete specimens prepared at water to cement ratio of 0.45

Comparing results of Figures 6 and 7 shows that due to denser microstructure, specimens prepared at w/c ratio of 0.45 performed better than 0.55 in compressive strength. It is a normal effect in concrete materials. However, by decrease in w/c ratio, workability decreased considerably even in presence of super plasticizer due to huge water demand of due to cementing behavior and water demand of dry sludge for wetting. In fact, it seems that preparation of concrete samples containing more than 20% dry sludge is impossible at w/c ratios less than 0.45 even by using more super plasticizers.

3.4 Flexural strength

On the basis of results of compressive strength test, the concretes containing 5, 10 and 20% dry sludge at w/c ratios of 0.45 and 0.55 was assumed as producible samples. Therefore, flexural strength was measured for both samples prepared with w/c ratio of 0.45 and 0.55.

Flexural strength test was performed on 50 cm×10 cm× 10 cm specimens cured for 28 days in dry condition. Figure 8 shows the flexural strength test results.

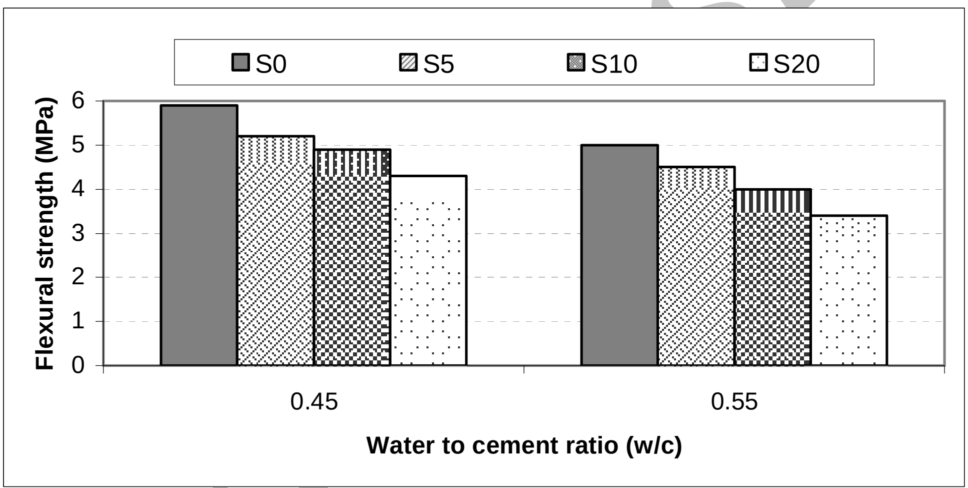

Figure 8. Flexural strength of specimens prepared at different water to cement ratios

It is evident that using dry sludge caused decrease in the flexural strength in comparison to control specimens in both w/c ratios. Albeit, the flexural strength of these specimens are in normal range for mass concrete and so they are acceptable. It can be seen that like to compressive strength results, flexural strength of samples with w/c ratio of 0.45 are higher than those with w/c ratios of 0.55.

It was resulted that concretes containing 5, 10 and 20% dry sludge showed 11, 17 and 27% (at w/c ratio of 0.45) and 10, 20 and 32% (at w/c ratio of 0.55) decreases in flexural strength.

3.5 Water absorption

To determine capillary water absorption of the concretes containing 5, 10 and 20% dry sludge at w/c ratio of 0.45, 10 cm×10 cm× 10 cm specimens were made and cured for 28 days. They were exposed to capillary absorption and weighted after 0.5, 1, 24 and 72 hours.

Results are shown in Figure 9.

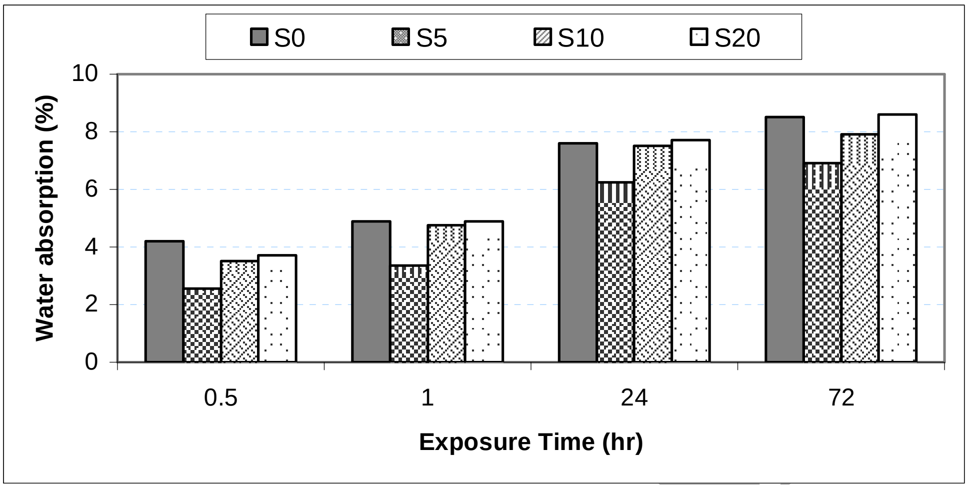

Figure 9.Water absorption of the specimens prepared at different water to cement ratios

Results show that by increasing immersion time, water absorption increased. The most important finding in this test was nearly equal water absorption of samples containing 10 and 20% dry sludge to control specimens. Despite of negative effect of the dry sludge on mechanical properties of concrete, it seems that dry sludge has not important effect on water absorption of concrete.

4. CONCLUSION

Application of dry sludge of a domestic/industrial 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:

- Heat treatment is required to remove organic materials from the dry sludge and obtaining better results. Depending to heating temperature and process some changes can be obtained in dry sludge crystalline phases.
- By increasing in dry sludge content to 20% in concrete samples, a decease about 20% in compressive and flexural strengths was obtained. Concretes containing 20% dry sludge showed acceptable results at w/c ratio of 0.45, considering economical and technical reasons and environmental issues.
- By increasing the dry sludge content in concrete, workability decrease considerably even in presence of super plasticizer. This fall in workability prevents mixing and formulation of samples containing 20% dry sludge at w/c ratios lower than 0.45.
- Dry sludge postponed hydration process in concrete specimens. This delay increases by increase in sludge content. It is proposed to use supplementary cementing materials (SCM's) to improve hydration rate and mechanical properties.
- It was found that dry sludge act as filler in concrete, so sizing and milling of this

materials can improve concrete mechanical performance and water absorption.

- Considering previous investigations in Spain, it was found that dry sludge's with higher SiO_2 contents, can be used at higher contents in concrete mix designs.

On the basis of the results, authors proposed that the selected dry sludge after heat treatment and milling can be used as cheap (in fact costless) filler in general purpose concretes such as pavement and mass concretes. Yearly in Iran, about 40 million tons of cement is generally used in concrete production. Therefore, there is a potential of using up to 8 million tons of costless and harmful dry sludge in concrete production which highlights importance of more considerations on this subject area.

REFERENCES

1. Yague A, Valls S, Vazquez E, Albareda F. Durability of concrete with addition of dry sludge from waste water treatment plants, *Cement and Concrete Research*, **35**(2005) 1064-73.
2. Valls S, Yague A, Vazquez E, Mariscal C. Physical and mechanical properties of concrete with dry sludge from sewage treatment plant, *Cement Concrete Research*, **34**(2004) 2203-8.
3. Mun KJ. Development and test of lightweight aggregate using sewage sludge for nonstructural concrete, *Construction & Building Materials*, **21**(2007) 1583-8.
4. Muller U, Rubner K. The microstructure of concrete made with municipal waste incinerator bottom ash as an aggregate component, *Cement and Concrete Research*, **36**(2006) 1434-43.
5. Valls S, Vazquez E. Stabilization and solidification of sewage sludges with cement, *Cement and Concrete Research*, **30**(2000) 1671-8.
6. Valls S, Vazquez E. Accelerated carbonation of sewage sludge-cement-sand mortars and its environment impact, *Cement and Concrete Research*, **31** (2001) 1271-6.
7. Monzo J, Paya J, Borrachero MV, Girbes I. Reuse of sewage sludge ashes (SSA) in mixture: the effect of SSA on the workability of cement mortars, *Waste Management*, **23**(2003) 373-81.