Advances in Environmental Biology, 6(11): 2958-2965, 2012
ISSN 1995-0756

This is a refereed journal and all articles are professionally screened and reviewed **ORIGINAL ARTICLE**

Study of utilization in cement of activated drinking water treatment sludge at various temperatures

[1]Yousef Zandi, [2]Nurcan Öztürk, [2]Hasan Tahsin Öztürk, [2]Ahmet Durmuş

[1]Department of Civil Engineering, Tabriz Branch, Islamic Azad University, Tabriz, Iran.
[2]Civil Engineering Department, KTU University, Trabzon, Turkey

Yousef Zandi, Nurcan Öztürk, Hasan Tahsin Öztürk, Ahmet Durmuş; Study of utilization in cement of activated drinking water treatment sludge at various temperatures

ABSTRACT

Increase in population, life standards and industrial activities have caused much more necessity of obtaining drinking water. Processing and eliminating the drinking water treatment sludge, occurring by depending on this obligation and the inevitable secondary product of treatment stages, are becoming very important problems day by day. It is known that this waste negatively affects nature and living being by polluting air, soil and water when it directly discharges environment. Utilization from activated drinking water treatment sludge (ATS), obtained drinking water treatment sludge by burning at different temperatures, and drinking water treatment sludge (TS) in cement was investigated because waste must be recycled. In this study, firstly, physical, chemical and mineralogical characteristics of TS, gaining from Trabzon drinking water treatment plant (in Turkey), was determined. Then, this waste was burnt at different temperatures (500, 600 and 700 ^{o}C) and changing composition and characteristics of it were found out. And then, cement mortar, including drinking water treatment sludge and activated drinking water treatment sludge at different percentages (%5, 10, 15 and 20), was produced and compressive strengths, setting, volume expansion of them were measured 1,2,7,and 28 days later. Obtained findings were compared with both samples, blended cements at various addition levels, and checking samples according to Turkish standards. In conclusion, drinking water treatment sludge and activated drinking water treatment sludge seemed to be suitable to produce blended cements at 5-10 % addition levels.

Key words: Drinking Water Treatment Sludge, Chemical Analysis, Compressive Strength, Portland Cement

Introduction

It is known that environmental problems have been more important in terms of scientific and engineering studies in recent times that these problems increase. Some industrial waste not troubling approximately thirty years ago has been environmental matter for ten years. Increasing world population and people needs have caused growth of production day by day. Thus, increased production also has brought about growing waste and it must be taken precaution for all the waste on time [10].

In drinking water treatment plants row water, obtaining from surface and underground water resources, has been purified for purpose of drinking, treatment sludge (TS), inevitable product in these plants, eliminated hard and expensively.

The inevitable product is increasingly growing problem in respect of processing and eliminating of it. Because these wastes have a large part of water content and only a small portion of solid wastes, they occupy a lot of volume so to be stored in a difficult way. When they aren't stored under suitable conditions, they affect the nature in a negative way by contaminating the air, soil and water.

In the production of the material required by Turkish economy, the researching level is not sufficient to benefit from the use of waste materials (recycling) such as TS. It is known that a plant formed through the partnership of Taiheiyo Cement and Mitsu&Co institutions has began production in 2001 and that it will produce 110,000 tons of cement per year by using 62,000 tons of treatment sludge ash and 28,000 tons of industrial waste in Japan [3].

The construction industry has concentrated on the researches of material options that will reduce costs, improve efficiency, ensure structural integrity and enhance mechanical properties. The performed researching studies have revealed the ideas on the development of alternative materials for the construction industry by eliminating recyclable waste materials [1]. The cement technology is being developed in parallel with the development of current technologies. These developments, in particular, are in the areas of research and development of non-standard new cement mixtures and their standardizations. The focuses are on under standard

Corresponding Author

Yousef Zandi, Member of Academic Staff, Department of Civil Engineering, Tabriz Branch, Islamic Azad University, Tabriz, Iran

cement production intending to use several industrial waste materials polluting the environment, but cheaper than the standard one on one hand, while trying to produce corrosion resistant, chemical resistant, low density cements having high pressure resistance at higher standards [8].

Considering the idea of usability of waste materials such as fly ash, wood chips and oven wastes and certain chemicals in the construction works as additives, it is believed that the use of drinking water treatment sludge and activated treatment sludge (ATS) obtained as the result of burning this sludge at different temperatures as construction material would be the solution to the waste problem.

Getting triggered by these basic considerations, it was investigated whether TS resulted through treatment of the water in Trabzon drinking water treatment plant (in Turkey) and ATS obtained as a result of burning TS could be used or not in cement as additives used in construction materials within the scope of this study [9].

Materials and Methods

Used Materials:

Drinking Water Treatment Sludge:

TS used in this study were collected from the treatment plant every day during the months of November and December in 2007 and January in 2008. The collected TS have been thoroughly mixed and accumulated. Before the study, TS were dried by waiting in the laboratory environment for 2 months and then it has been grinded. The grinded materials have been screened through 0.074 mm sieve and were made ready to use. The screened materials have been burnt in the laboratory type ash kiln at 500, 600 and 700^{o}C temperatures for 1 hour and according to the burning temperatures ATS_1, ATS_2 and ATS_3 so-called materials were obtained in different characteristics, respectively. In the studies, TS, ATS_1, ATS_2, ATS_3 materials have been used separately.

Cement:

The cement used in the prepared mortar samples were produced by Aşkale Cement A.S. and it is normal early-strength Portland pozzolana cement (CEMII/A-P 42,5 N) containing 6-20% trass (natural pozzolana) in total mass and having the strength class of 42,5 [11]. Chemical, physical and mechanical properties of used cement are shown in Table 1.

Table 1: Chemical, Physical and Mechanical Properties of Cement (CEMII/A-P 42,5 N).

Chemical Properties	
Components	% by mass
SiO_2	22,6
Al_2O_3	6,0
Fe_2O_3	3,68
CaO	59,09
MgO	1,98
SO_3	2,49
Cl	0,041
Total additive (trass+limestone)	11,64
Insoluble residue	7,73
Loss-on-ignition	3,37
Physical Properties	
Specific gravity, (g/cm^3)	3,06
Specific surface, (cm^2/g. Blaine)	4018
Volume expansion, (mm)	2
Initial set, (h/dk)	2,15
Final set, (h/dk)	3,30
Mechanical Properties	
Compressive strength of 1 day, (N/mm^2)	10,6
Compressive strength of 2 days, (N/mm^2)	24,3
Compressive strength of 7 days, (N/mm^2)	42,0
Compressive strength of 28 days, (N/mm^2)	56,8

First, the physical, chemical and mineralogical properties studies were performed to determine the characteristics of materials. Later, the physical and mechanical properties of cement samples containing these materials were determined. Performed studies are presented respectively.

Physical Properties:

The experiments were conducted using Pycnometer bottle for determining the particle specific density values of TS, ATS_1, ATS_2, ATS_3. As a result of the experiments, the determined particle specific density values are given in the form of a table (Table 2).

Table 2: Particle specific density values of TS, ATS_1, ATS_2, ATS_3

	ρ_s, Particle specific density (Mg/m^3)
TS	2,46
ATS_1	2,59
ATS_2	2,40
ATS_3	2,75

The liquid limit and plastic limit values, known as consistency limits (Atterberg), of TS were determined in the laboratory experimentally. The liquid limit values and the plastic limit values were determined by using Casagrande Method and the standard plastic limit test, respectively.

Table 3: Consistency limits of TS.

Liquid Limit (w_L, %)	39,48
Plastic Limit (w_p, %)	32,96
Plasticity Index (I_p, %)	6,52

For the purpose of sketching the granulometric curves of TS and performing the classification according to this obtained curve, washed sieve analysis was conducted. The hydrometer analysis (wet analysis) was performed since all of the samples passed through No. 200 sieve (0,074mm). The granulometric curve of the sample was obtained by drawing a graph between the amount of sample passed through No. 200 sieve and the grain diameter. It has been identified as a fine-grained material upon the particle size distribution was examined.

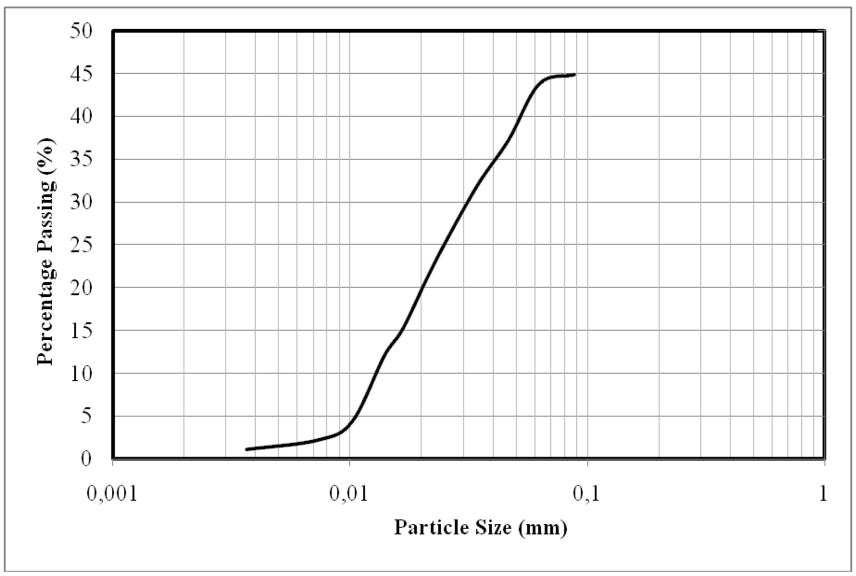


Fig. 1: Granulometric curve of TS.

Results and Discussion

Chemical and Mineralogical Properties:

The obtained values in the analysis conducted with the ICP Atomic Emission Spektroscopy method at ACME Analytical Laboratories Ltd. in Canada by using the samples that were burned in the ash kiln at 500, 600 and 700^oC temperatures are given in the form of a table (Table 4).

As seen from Table 4, SiO_2, Al_2O_3, Fe_2O_3 and CaO are found in the excess amount in the samples. There are the components such as silicon (SiO_2), alumina (Al_2O_3), iron oxide (Fe_2O_3) deemed significant for the hydraulic cement binders within the materials defined as A0 TS, ATS_1, ATS_2 and ATS_3. Each of the materials has assured the condition telling that these three components must be at least 70% in the material for puzzolanic activity of the material according to ASTM C 618. The puzzolanic characteristics of the materials are clear from the total percentage of these components [2].

In order to prevent too rapid hardening of cement, SO_3 ($CaSO_4$ = $CaO.SO_3$) existing in the structure of gypsum ($CaSO_42H_2O$) used in cement production must not exceed a certain value in the cement structure. According to the ASTM standards, the maximum amount of SO_3 in normal Portland cement should be 3,0%. As could be seen in the results of TS, ATS_1, ATS_2 and ATS_3 chemical analysis, there is no SO_3 in their chemical contents.

Table 4: Chemical Properties of CEM II/A-P 42,5 N, TS, ATS_1, ATS_2 and ATS_3

Components (% by mass)	CEMII/A-P 42,5 N	TS	ATS_1	ATS_2	ATS_3
SiO_2	22,56	53,46	50,56	50,72	51,30
Al_2O_3	6,0	16,54	18,58	18,68	18,95
Fe_2O_3	3,68	6,48	6,64	6,65	6,75
CaO	59,09	4,70	7,96	8,00	8,19
MgO	1,98	2,80	2,87	2,87	2,91
SO_3	2,49	-	-	-	-
Na_2O	-	2,04	1,56	1,56	1,58
K_2O	-	1,87	2,25	2,25	2,28
P_2O_5	-	0,186	0,209	0,227	0,220
MnO	-	0,15	0,18	0,18	0,18
Cl^-	0,041	-	-	-	-
Loss on ignition	3,47	2,10	1,45	1,32	1,12

The amount of MgO that can be found in cement is required not more than a certain percentage (5%), as it may cause the reactions to occur leading to expansion in cement paste and the cracking of the cement paste. The MgO contents of TS, ATS_1, ATS_2 and ATS_3 are 2,80%, 2,87, 2,87, 2,91 respectively and they are less than 5%. In addition, MgO value increases as the cooking temperature of the material increased.

The amount of alkali (Na_2O and K_2O) found in the cement structure is required not more than a certain value, as it will cause cracking and fracture in the concrete as results of the occurrence of major expansions in the hardened concrete. For example, according to ASTM standards, " $Na_2O + 0,66K_2O$ " amount is recommended no more than 0,6% [7]. In TS, ATS_1, ATS_2 and ATS_3 this amount is more than 0,6%.

The loss on ignition indicates that the cement has not been stored in appropriate conditions or a very long time ripe. The loss on ignition of Portland cement is required not more than certain value. For example, according to ASTM standards, the loss on ignition should not exceed 3,0% in normal Portland cement [7]. Loss on ignition of TS, ATS_1, ATS_2 and ATS_3 are 2,10% , 1,45 , 1,32 , 1,12 respectively.

The data obtained through the examinations of TS's mineralogical structure using XRD method with Rigaku D/MAX-3C model device are shown in Figure 2. According to these data, it was assumed that the sample contained intense kaolinite, quartz, muscovite and calcite minerals, as it indicated typical peaks belonging to kaolinite, quartz, muscovite and calcite minerals.

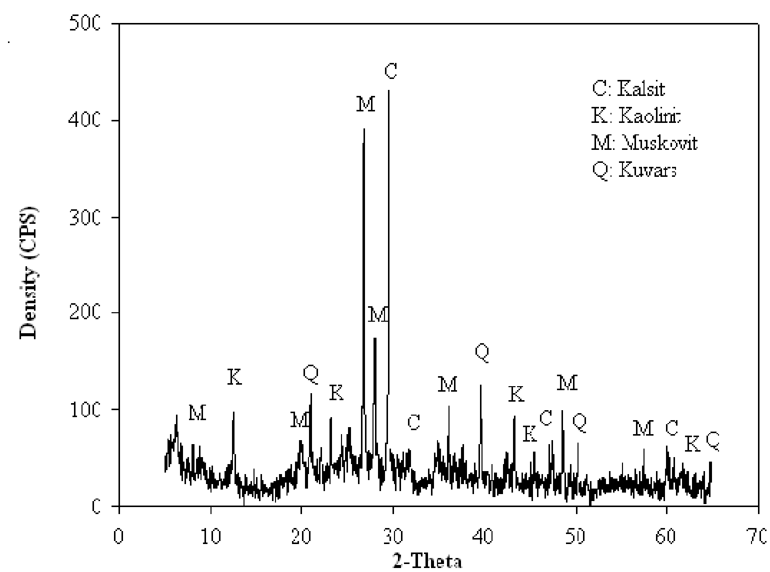


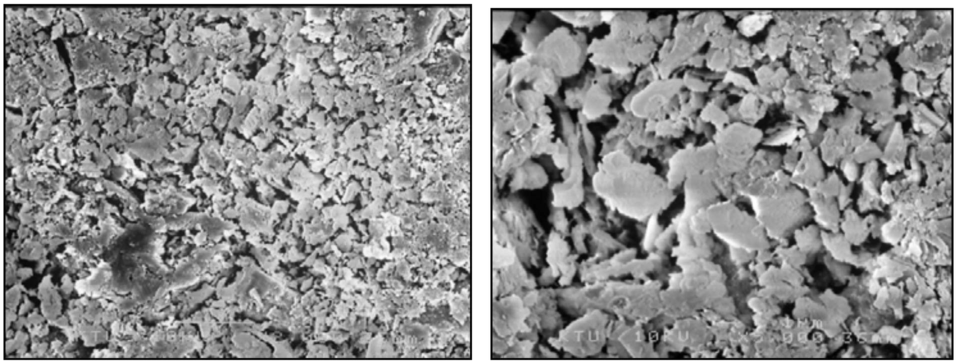
Fig. 2: XRD of TS.

The Scanning electron microscopy (SEM) analysis method has been used to determine the grain size and surface morphology of the mineral phases in TS and ATS_3 samples, 2000 and 5000 times enlarged photos of each sample were taken with Jeol brand device and those are given in Figure 3 and 4.

As a result of microstructure analysis of TS and ATS_3, it was observed that it contained square quartz particles at the changing sizes. In the TS and ATS_3 photographs obtained by SEM analysis methods too much difference was not observed in terms of in porosity. This is an evidence of TS's very low

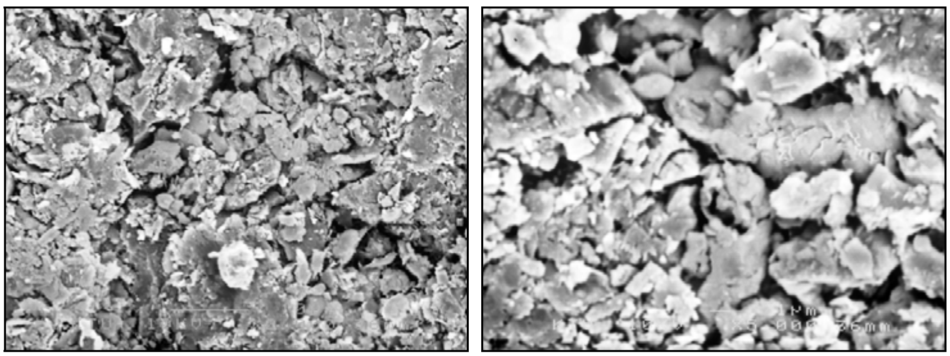
Adv. Environ. Biol., 6(11): 2958-2965, 2012

organic content. If TS had a high organic content, the Treatment Sludge activated at 700^{o}C (ATS_3) would have much more porous structure in comparison to the non-heat treated Treatment Sludge (TS).



(a) (b)

Fig. 3: SEM photographs of TS: (a): 2000X, (b): 5000X.



(a) (b)

Fig. 4: SEM photographs of ATS_3: (a):2000X, (b): 5000X.

Determine of Physical and Mechanical Properties of Cement Samples Containing TS, ATS_1, ATS_2 and ATS_3:

EN 196-1 and EN 196-3 numbered [5,6] standards were used for the standard strength tests of cement samples containing TS, ATS_1, ATS_2 and ATS_3 and in determining their hardening times and volume expansion values. In order to determine the standard strengths of materials, the cement mortars were prepared based on the defined method in the cement standards as firstly with no additives included (control sample) and with TS, ATS_1, ATS_2 and ATS_3 included at rates 5, 10, 15 and 20% by weight. The prepared mortars have been poured into 4x4x16cm sized molds and 3 samples from each were prepared for different additive percentages. The compressive strengths of prepared samples were measured at the end of 1, 2, 7 and 28 days curing times [5,6].

For compressive strengths, as shown in the graphics in Figure 5, 6, 7 and 8, we have observed that the 1, 2, 7 and 28 days compressive strengths decreased as TS, ATS_1, ATS_2 and ATS_3 rates increased in the mixtures. It is also a fact that these values were lower than the values of control samples produced with CEM 42.5 N. However, here it must be specified that 1-day compressive strengths of mortar samples obtained by including 5% TS, ATS_1, ATS_2 and ATS_3 were higher than the one in control samples. In addition, 2-days compressive strength of mortar sample obtained by including 5% ATS_1 and 1-day compressive strength of mortar sample obtained by including 10% ATS_1 were higher than the one in control sample.

As seen from Table 5, the set times of mortar samples in which TS, ATS_1, ATS_2 and ATS_3 were used have increased compared to control samples. This shows the decrease in hydration heat.

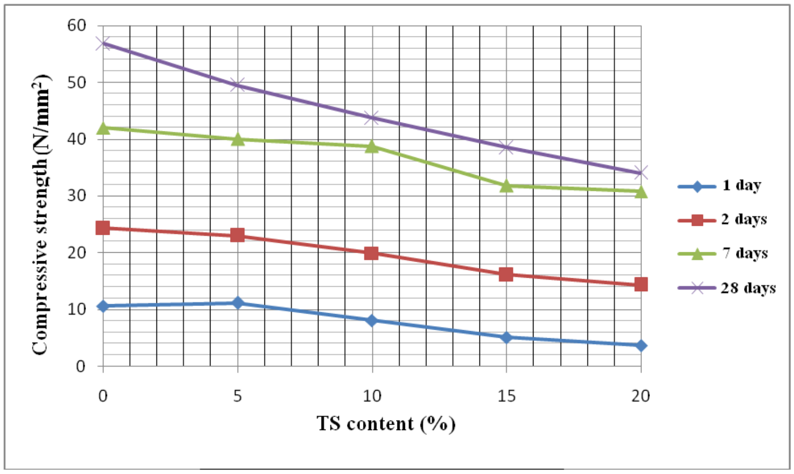


Fig. 5: Variation in compressive strengths of mortar samples for different additive (TS) rates.

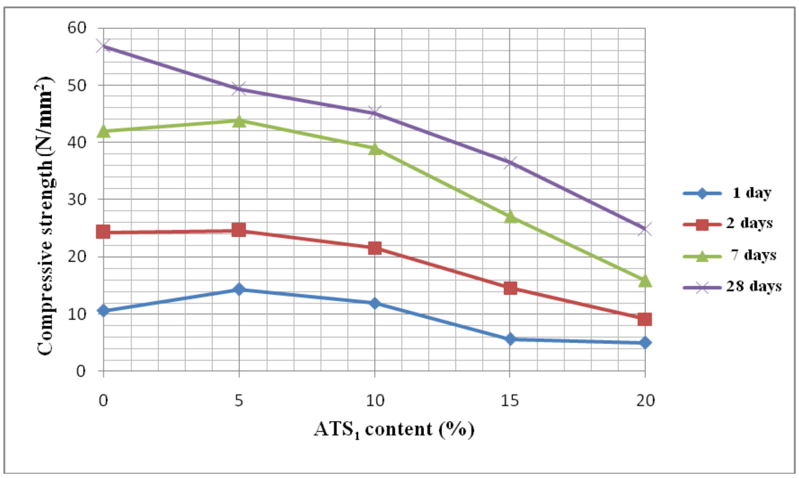


Fig. 6: Variation in compressive strengths of mortar samples for different additive (ATS_1) rates.

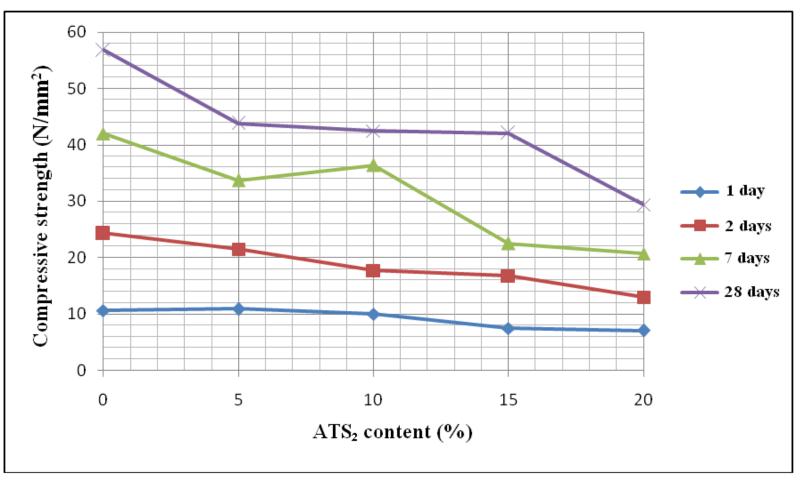


Fig. 7: Variation in compressive strengths of mortar samples for different additive (ATS_2) rates.

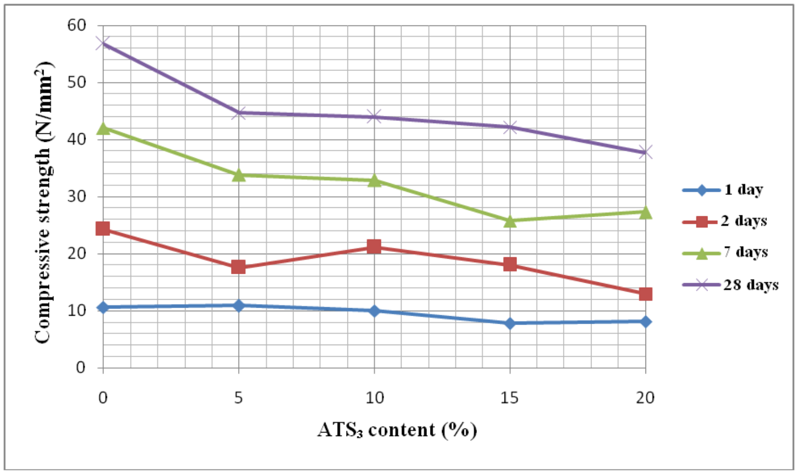


Fig. 8: Variation in compressive strengths of mortar samples for different additive (ATS_3) rates.

Table 5: Set time and volume expansion values of TS, ATS_1, ATS_2 and ATS_3 in different additive rates.

Additive (%)		Set time (h)		Volume expansion (mm)
		Initial	Final	
TS	0	2,15	3,30	2
	5	3.00	4.15	1
	10	2.55	4.10	1
	15	2.40	3.55	1
	20	2.35	3.50	1
ATS_1	0	2.15	3.30	2
	5	3.00	4.10	1
	10	3.00	4.05	1
	15	2.50	3.45	1
	20	3.00	4.05	1
ATS_2	0	2.15	3.30	2
	5	2.55	3.55	1
	10	2.50	3.50	1
	15	2.55	3.50	1
	20	3.05	4.10	1
ATS_3	0	2.15	3.30	2
	5	2.50	3.55	1
	10	3.00	4.05	1
	15	2.55	4.00	1
	20	2.55	3.55	1

Conclusion:

Having all findings examined, it is also a fact that the compressive strength values of mortar samples in which ATS1 was used at the rates of 5% and 10% have reached the nearest value of the control sample. In such a case, it must be specified that the samples in which ATS_1 was used at the rates of 5% and 10% when the rate of 10% to 5% created the optimal ratio range in use of the aforementioned material.

It was observed that the samples in which TS, ATS_1, ATS_2 and ATS_3 were used at the rates of 5% and 10% assured the early (2 days) and standard (28 days) strength conditions of class 42.5 N cement expressed in EN 197-1 numbered standard. Here, it is required to mention that all the samples in question also provide the set time condition specified in the said standard (EN 197-1, 2002).

Acknowledgments

The authors would like to thank Trabzon Dirinking Water Treatment Plant and Aşkale Cement Co. for supplying Portland cement and treatment sludge used in this study.

References

1. Aslan, M., 2007. Use of Drinking Water Sludge in Wood Cement Particleboard Production, Master Thesis, Karadeniz Technical University Graduate School of Natural & Applied Sciences, Trabzon. (in Turkish).
2. ASTM, C., 618, 2005. Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland cement Concrete, Annual Book of ASTM Standards, Ankara.

3. Çelik, İ.B. and M. Öner, 2003. Use of Waste water treatment filters cake in cement. Journal of Mining, 12: 11-18 (in Turkish).
4. EN 196-1, 2002. Methods of Testing Cement - Part 1: Determination of Strength, The European Committee for Standardization (CEN).
5. EN 196-3, 2002. Methods of Testing Cement- Part 3: Determination of Setting Time and Soundness, The European Committee for Standardization (CEN).
6. EN 197-1, 2002. Cement- Part 1: Compositions and conformity criteria for common cements, The European Committee for Standardization (CEN).
7. Erdoğan, T.Y., 2007. Concrete", Middle East Technical University development foundation publications, Ankara. (In Turkish).
8. Ergi, E., G.S. Bilgin, M.S. Zeybek and A. Asan, 2007. Effect of Industrial waste blended cement on concrete strength and Corrosion of reinforcement, 2nd Symposium on mineral additives in structures, Proceeding Book, pp: 311-317, Ankara. (in Turkish).
9. Hacısalihoğlu, N., 2008. Investigation on the Utilization of Activated Drinking Water Treatment Sludge at Various Temperatures in Cement, Master Thesis, Karadeniz Technical University Graduate School of Natural & Applied Sciences, Trabzon. (in Turkish).
10. Uçar, G., 1997. Investigation of Ways of Evaluation of Waste Sludge in City Drinking Water Treatment Facility, Master Thesis, Ankara University Graduate School of Natural & Applied Sciences, Ankara. (in Turkish).
11. Yeğinobalı, A. and T. Ertün, 2007. New standards in cement and mineral additives, Institute of Ar-Ge, Turkish Cement Manufacturers Association, Ankara.