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Effect of Sewage Sludge as Partial Replacement of Fine Aggregate in Concrete at Elevated Temperature: Compressive Strength and Mass Loss Characteristics

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Abstract: Disposal of sewage sludge resulting from waste water treatment process continues to be a problem especially in developing countries like Ethiopia, where effective and efficient infrastructures for waste disposal system is not sufficiently available. Many researches have been conducted to determine the properties of fresh and hardened concrete made by partially replacing fine aggregate with sewage sludge at room temperature whereas the purpose of the research described in this paper is to evaluate the effect of sewage sludge as partial replacement of fine aggregate in concrete exposed to elevated temperature. The effect of intensity of elevated temperatures (300℃, 600℃, and 900℃), temperature exposure durations (1hr, 4hr, and 8hr) and percentage replacement of sewage sludge (0%, 5%, 10%, and 15%) having constant water/cement ratio are investigated. A total of 120 concrete cube specimens were casted and tested. Compressive strength and weight loss were examined after air cooling. Test results revealed that replacement of 5% sewage sludge as fine aggregate has greater residual compressive strength than the normal concrete followed by 10% and 15% sewage replaced concrete at constant temperature and exposure duration. Test results also showed that as heating duration increases, so does concrete mass loss.

Key words: Concrete, Elevated Temperature, Partial Replacement, Strength, Sewage Sludge (SS)

1. Introduction

Now a day's concrete is the most widely construction material in the world. Even the concrete production needs natural resources (water, coarse and fine aggregates) and cement (Srinivasan et al., 2016). Due to creation of awareness for environmental preservation, considerable weight has been given to methods that promote sustainability, underscoring studies on recycling urban domestic waste such as sewage sludge as a source of alternative raw materials for the construction industry for the production of concrete (de Lima et al.,2015).

Sewage sludge is a by-product left over from the waste water treatment process. Unlike solid materials, sewage sludge contains high moisture content and a great deal of organic matter. The production of sewage sludge from waste water treatment plants are increasing from day to day all over the world. This kind of sludge contains 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 (Foladori et al., 2010).

It is difficult to reuse the Sewage sludge due to the presence of pathogens and heavy metals (Srinivasan et al., 2016). Pathogens should be reduced to levels that they do not cause health hazards to workers handling the sludge, potential health hazards from the spreading of helminth eggs and from horticultural produce contaminated by pathogens (Levlin, 1998). The sewerage treatment plant is connected by mostly residential and commercial areas; hence, the sludge collected is categorized as domestic waste sludge (Bhargava and Bharat, 2016).

On the other hand, Concrete is a multifaceted material and its properties can change in dramatic manner when exposed to high temperature. Because of global warming, temperature increases quickly. This global warming is a result of urbanization, in which due to huge amount of carbon di-oxide (CO2) and carbon monoxide (CO). For this purpose, various civil engineering structures go through temperature changes. The development of high concrete temperatures could cause a number of effects which reflects negative impact to long-term concrete performance.

Even if it is valid for limited period and certain temperature, sustainability of structure is a main concern in the construction industry. One of the most important physical deterioration processes that influence concrete structure is elevated temperature or fire. Fire represents one of the most sever risks to buildings and structures (Foladori, 2010). When concrete is exposed to high temperature the physical and chemical properties also changes (Arioz, 2007).

Concrete is a fire-resistant material due to its properties of being a non-flammable material (Srinivasan et al., 2016). However, the strength and durability properties of concrete highly affected significantly when exposed to high temperature or fire. Structural components still must be able to withstand dead and live loads without collapse even though the rise in temperature causes a decrease in the strength and modulus of elasticity for concrete and steel reinforcement. In addition, fully developed fires cause expansion of structural components and the resulting stresses and strains must be resisted (Bilow, 2008).

The factors that affect post fire concrete's compressive strength are the rate of heating, the duration of heating, whether the specimen was loaded or not, the type and size of aggregate, the water/cement ratio, and the percentage of cement paste. In general, concrete heated by a building fire always loses some compressive strength and continues to lose it on cooling (Nazri et al., 2017).

Aggregates normally occupy 50-75% of the total volume of concrete. Therefore, the behavior at elevated temperature is strongly affected by the type and properties of aggregate used. Aggregate used in concrete can be classified in to three types: carbonate, siliceous and light weight. Carbonate aggregates include lime stone and dolomite. Siliceous aggregate includes materials consisting of silica and include granite and sand stone. Light weight aggregates are usually manufactured by heating shale, slate or clay. Naturally found aggregates are usually stable up to 300-350℃. With regards to high temperature properties of aggregate thermal expansion and conductivity, chemical and thermal stability are known to play an important role. Carbonate and light weight concrete exhibit similar strength characteristics at elevated temperatures and retain approximately 75% of their original strength at 650℃,while siliceous concrete yield a lower strength, particularly above 430℃.it was also found that the original strength of the concrete has little influence on the percentage of residual strength at high temperatures (Bentz,2007) and(Abrams,1973).

1.1 Objective of the Study

The overall objective of this work to investigate the feasibility of incorporating sewage sludge in concrete by partially replacing fine aggregate at elevated temperature. To achieve the main objective, the specific objectives are listed as follows:

- To identify the effects of sewage sludge in the compressive strength of concrete under an elevated temperature.
- To investigate the local optimum amount of sewage sludge that can replace fine aggregate at an elevated temperature.

2. Materials and Methods

2.1 Materials

The type of construction materials used to this experimental work for the production of concrete specimens is as follows.

Cement: Ordinary Portland cement (OPC) of 43 grades available in local market satisfying ASTM standard is used in the investigation. This ordinary Portland cement (OPC) produced in DANOGOTE Cement Factory was used in this study.

Water: the water used for mixing of concrete specimens is a tap water which is available in the laboratory.

Coarse Aggregate: Crushed angular granite aggregate passing through 25 mm sieve and retained on 4.75mm sieve was used. Well graded crushed aggregate collected from quarry sites located around Bahir Dar area was used for this study. Material Property tests of the coarse aggregates are carried out according to ASTM Standards and (Abebe,2005).

Fine Aggregate: The fine aggregate in this experiment is brought from Lalibela river quarry site. Sand has been used as fine aggregate in concrete was with specific gravity 2.71 and fineness modulus (F.M.) of 2.81. Material Property tests of the fine aggregates are carried out according to ASTM Standards and (Abebe, 2005).

Sewage Sludge: The dry sludge used in this study was brought (free of cost) from Debre Markos University waste water treatment pond. The sludge collected is categorized as domestic waste sludge. This waste sludge has been collected in plastic bags and brings it to the laboratory, where it is spread on land for making it in the direct contact to sun and air. It is light and water absorbent.

2.2 Methods

Concrete mix design: The proportioning of the raw materials of the C-30 concrete has been done as per the mix design ratio after preparation of all the required raw material and conduct the required material property test on it. In this research the above raw materials were proportioned by the mass batching method at the ratio of 1:2:3.1(cement, sand and gravel) with water cement ratio of 0.435 according to ACI was adopted for this study. In the present study it is intended to prepare concrete strength of grade C-30. The levels of percentage replacement of fine aggregate with SS were at; 0%, 5%, 10% and 15%. Table 1 shows the mix proportions for 1m^3 concrete.

Table 1: Proportions of the mix design

Materials (Kg)	Percent replacement of sewage sludge (%)			
	0	5	10	15
Cement	357.41	357.41	357.41	357.41
Fine aggregate	717.6	681.72	645.84	610.05
Coarse aggregate	1111.99	1111.99	1111.99	1111.99
Water	186.97	186.97	186.97	186.97
Sewage sludge	0	35.88	71.76	107.55

Sample Preparation: standard cubical molds of 100mmx100mm made of cast iron was used to cast the specimen. Then cement, fine aggregate and coarse aggregate are thoroughly mix at dry state for about 3min. and then add the weighted water and mix it again in wet stage for about 4min. the total mixing time was kept at 7 minutes approximately for all the trials until a homogenous mixture was obtained. Once a concrete mix was done, the slump of concrete is measured by compaction of concrete in three layers with 25 stokes of 16 mm rod was carried out for each layer. The required volumes of mix ingredients were measured and mixing was done thoroughly to ensure that homogenous mix is obtained. The concrete mixtures were produced in a pan – type mixer which has a capacity of 0.02 m^3. The interior surface of the metal mold was cleaned and oiled to avoid striking of the mix. The concrete was placed in to the mold and set for

24 hours. After staying for one day the specimens were removed from the molds and immersed in a curing tank for 28 days.

Firing program: All the specimens were cured in water for 28 days and then air dried and record the mass to know the weight loss before being subjected to fire in a furnace maintained at a fixed temperature of 300°C, 600°C and 900°C. The specimens were subjected to fire for different time duration's, 1hr 4hr and 8hr. For each time of exposure, three specimens were tested to calculate mean test results with reasonable accuracy. The test specimens were removed from the furnace after the specified duration of heating and then allowed cooling on the air (intending to simulate the natural extinction of the fire) at room temperature before being tested in the compression testing machine.

Testing of concrete samples

Compressive strength testing: Compressive strength was carried out according to [ASTM C 39-03] by using a hydraulic compression machine of 2000 KN.

3. Results and Discussions

3.1 Effect of Elevated Temperature on Compressive Strength of Concrete with Sewage Sludge as Fine Aggregate Replacement

The results of the experiments on the residual compressive strength of concrete with the percentage increase of sewage sludge content from 0% to 15% with an interval of 5 and varying temperature intensities and exposure durations are shown on table 2. It is clear that 5% replaced concrete shows an increase in the compressive strength when the exposure duration increases. in addition to this the residual compressive strength decreases when exposed to 300℃ at 1hr duration. At 900℃ the residual compressive strength for the case 5% replaced concert is greater than all other concrete types.

Table 2: Residual compressive strength of concrete subjected to various temperature intensities and durations

Group	Compressive Strength (Mpa)									
	RT	300℃/ 1hr.	300℃/ 4hr.	300℃/ 8hr.	600℃/ 1hr.	600℃/ 4hr.	600℃/ 8hr.	900℃/ 1hr.	900℃/ 4hr.	900℃/ 8hr.
0	38.04	33.23	40.48	40.03	34.47	31.21	31.08	29.93	8.39	7.03
5	39.29	33.72	40.82	47.57	32.74	34.81	33.37	32.09	8.7	8.51
10	38.13	32.07	31.37	31.19	31.8	21.44	18.84	23.53	9.22	4.56
15	21.62	19.69	18.62	17.83	17.85	14.41	13.12	17.57	3.84	3.16

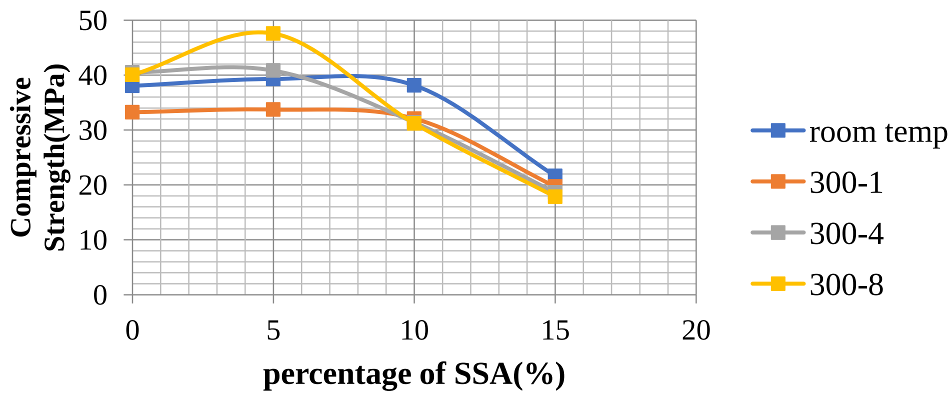

Figure 1: Effect of percentage replacement of sewage sludge on compressive strength of concrete at 300℃

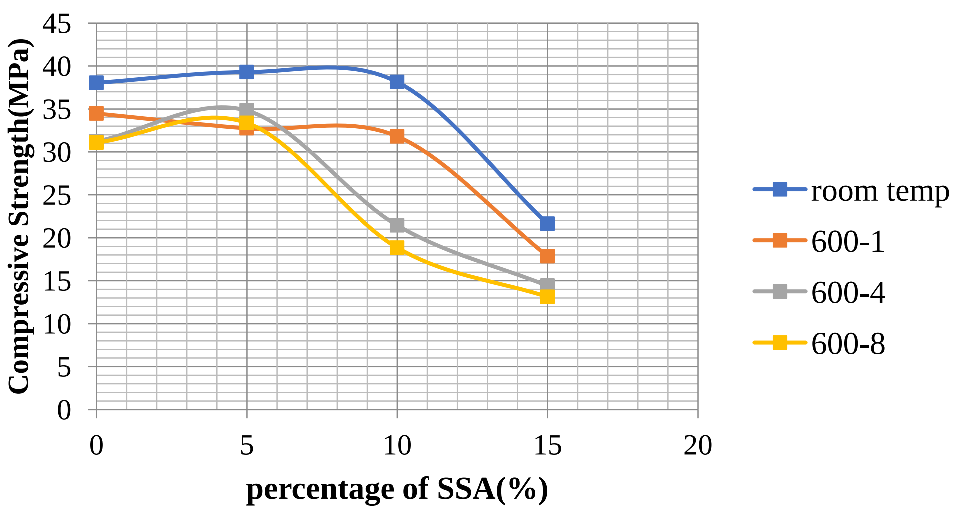

Figure 2: Effect of percentage replacement of sewage sludge on compressive strength of concrete at 600℃

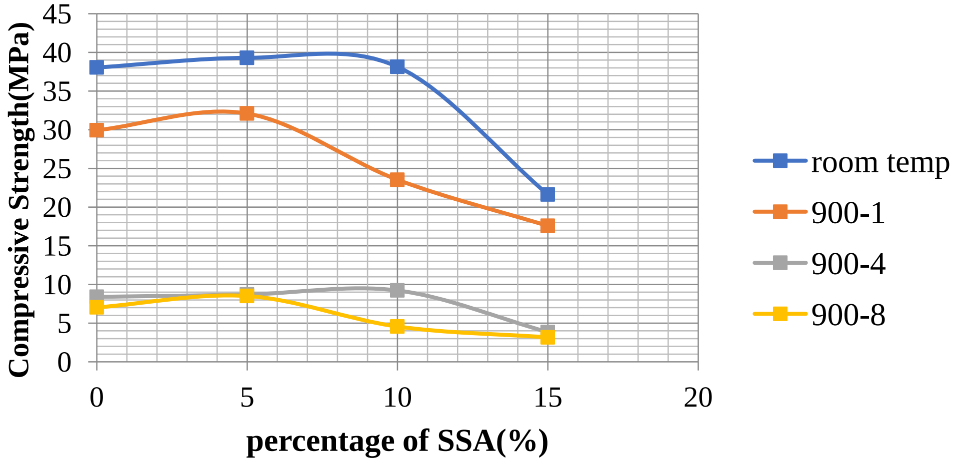

Figure 3: Effect of percentage replacement of sewage sludge on compressive strength of concrete at 900℃

From figure 1 indicates the effect percentage replacement of sewage sludge in concrete at 300℃. It can be seen clearly that replacement of 5% sewage sludge in concrete as fine aggregate shows an increment even greater than the compressive strength at room temperature when exposed to 8hr. the compressive strength of concrete made with 15% sewage sludge replacement shows approximately the same result for all exposure durations. Figure 2 shows the effect of percentage replacement of sewage sludge on the compressive strength of concrete at 600℃. Still the compressive strength increases due to replacement of 5% sewage sludge at room temperature, 4hr and 8hr exposure duration but shows a slight reduction at 1hr duration compared to the normal concrete. 10% replacement shows increment at room temperature but decreases in the compressive strength at 1, 4 and 8hr duration. 15% sewage replaced concrete losses more than half of the compressive strength of the normal concrete for 4hr and 8hr duration. Figure 3 indicates the effect of percentage replacement of sewage sludge in concrete at 900℃. Normal concrete shows significant reduction on compressive strength when exposed to 4hr and 8hr. Replacement of 5% sewage sludge indicates better performance than normal concrete for all exposure durations. At 900℃ 5% sewage sludge blended fine aggregate concrete shows 21% increment on the residual compressive strength when exposed to 8hr duration compared to normal concrete. 15% sewage sludge blende fine aggregate concrete shows reduction of about 55% of the normal strength concrete when subjected to 8hr duration.

3.2 Effect of Heating on The Weight Loss of SS Blended Fine Aggregate Concrete

Table 3: Summary of percentage mass reduction of different concrete types

Temp.	Normal			5% Sludge			10% Sludge			15% Sludge		
	1hr.	4hr.	8hr.	1hr.	4hr.	8hr.	1hr.	4hr.	8hr.	1hr.	4hr.	8hr.
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
300	2.8	7.9	8.8	6.9	7.9	8.4	4.9	8.9	9.6	4.8	9.1	10.1
600	7.9	10.2	10.2	9.4	9.9	10.1	7.7	11.7	11.8	11.1	13.3	13.9
900	12.2	12.4	12.4	11.2	11.3	11.5	11.0	12.4	14.1	11.6	15.0	15.2

Table 4 displays that the longer the heating period, the mass loss of the concrete had the tendency to increase. At the temperature between 600℃ and 900℃cause the hardened paste to lost its cementing property and thus significantly reducing the weight of the hardened concrete. When concrete was heated for 4hr, its weight reduced about 7.9% for normal concrete and 5% sewage replaced concrete and about 9% for 10% and 15% sewage replaced concrete at a temperature of 300℃. The highest lost was recorded when 15% sewage replaced concrete was heated for 8hr duration at a temperature of 900℃ which is 15.2%.

4. Conclusions

- Normal control concrete and 5% sewage replaced concrete shows an increase in compression strength whereas 10% and 15% replaced concrete shows reduction when exposed to 4hr and 8hr at 300℃. At 1hr duration the compressive strength decreases for normal concrete and sewage replaced concrete.

- At 600°C, 5% sewage replaced concrete has better performance than all other concrete specimens and 15% sewage replaced fine aggregate concrete has less than half of the compressive strength of the normal concrete.
- At 900°C, 5% sewage replaced concrete has 21% greater compressive strength than normal concrete and 15% sewage replaced concrete has 55% lesser compressive strength than normal concrete when exposed to 8hr duration.
- For 1hr duration all concrete types show reduction in compressive strength at 300, 600, and 900°C and the reduction was significant at 900°C compared to 600°C and 300°C.
- During the experiments, the longer the heating period, the mass loss of the concrete had the tendency to increase.
- A 5% replacement of fine aggregate with sewage sludge ash for the production of concrete is a step forward in using waste materials as construction input ingredients can save the natural sand and promoting clean environment and green construction.

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