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Tensile Strength Characteristics of Sewage Sludge as Partial Replacement of Fine Aggregate in Concrete at Elevated Temperature

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Abstract: The production of sewage sludge from waste water treatment plants are increasing all over the world due to increase in human needs however disposal of sewage sludge is yet a persistent question. This research work explores potential use of sewage sludge as a construction input material. Many studies have been conducted to determine the properties of both fresh and hardened concrete partially replaced fine aggregate with sewage sludge at normal temperature whereas there is research gap on mechanical properties of concrete produced with fine aggregate being partially replaced with sewage sludge (SS) at elevated temperatures. The effect of intensity of elevated temperatures (300℃, 600℃ and 900℃), temperature exposure durations (1hr, 4hr, and 8hr), and various sewage sludge (SS) fine aggregate blending percentages (0%, 5%, 10%, and 15%) are investigated. A total 120 concrete cylinders were casted and tested to investigate behavior of concrete with fine aggregate replaced with sewage sludge at elevated temperature in the blast furnace. Physical and mechanical properties including cracking and spalling and residual splitting tensile strength were determined after air cooling. The results revealed that replacement of 5% sewage sludge as fine aggregate has greater residual split tensile strength than normal control concrete and up to 10% replacement reduction in split tensile strength is not that much significant and however beyond 10% sharp decrement is observed. Test results also indicated that visible micro cracks on specimens appeared at 600℃ and 900℃ temperatures intensities.

Key words: Concrete, Elevated temperature, Partial replacement, Strength, Sewage sludge (SS)

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1. Introduction

The production of sewage sludge from waste water treatment plants are increasing all over the world due to increase in human needs however disposal of sewage sludge is yet a persistent question. Sewage sludge originated from the process of waste water treatment has become an environmental issue. This is due to the sludge contains pathogens, heavy metals and organic compounds that are harmful to the environmental and human health; high volumes of sewage sludge are daily generated; and there is shortage of landfill sites for proper disposal (Fontes et al., 2016).

The characteristic of sludge differs upon the region and the method of treatment. Sludge are formed after undergoing various steps such as stabilization, composting, anaerobic digestion, thickening, dewatering and drying. This sludge contains maximum amount of nitrogen content and so it is majorly used for agricultural purpose. This practice is considered unsatisfactory because of the presence of pathogens in the sludge in high numbers (Srinivasan et al., 2016). Using sludge as a fertilizer is not allowed if harmful microorganisms are present. Final disposal in landfill sites is not the solution due to space constraint and environmental pollution (Subramani and Anbuchezian, 2017). The usage of improved construction materials in construction industry has been on increase daily which has led to the investigation of its environmental impact and meeting required standards when waste are used in developing sustainable construction material (Johnson et al., 2014).

On the other hand, when structures are exposed to elevated temperature (fire) the internal part of the building possesses several physical transformations accomplished with chemical reaction and as a result leading total destruction of the material (Drzymała et al., 2017). Concrete due to high temperature event has a complex behavior due to the difference in coefficient of thermal expansion of each concert ingredient (Yehia and Kashwani, 2013).

The change in concrete properties depends on the type of aggregate used when exposed to high temperature. The Aggregate used in concrete can be classified into three types: carbonate, siliceous and lightweight. Carbonate aggregates include limestone and dolomite. Siliceous aggregate includes materials consisting of silica and include granite and sandstone. Lightweight aggregates are usually manufactured by heating shale, slate, or clay. The strength of concrete containing siliceous aggregate begins to drop off at about 800°F and is reduced to about 55% at about 1200°F. Concrete containing lightweight and carbonate aggregate retain most of their compressive strength up to about 1200°F. Lightweight concrete has insulating properties, and transmits heat at a slower rate than normal weight concrete with the same thickness, and therefore generally provides increased fire resistance (Bilow et al, 2008).

Concrete with lightweight aggregate are well known for their importance of being light weight and fire resistant and their strength is high. They are applicable at high rise building chimneys, high temperature furnaces, tunnel fire proof layers and large span bridges. Lightweight aggregates like pumice are produced by burning and scoria produced by quarrying is excellent in resisting high temperature. Even if lightweight aggregate concrete has high resistant to high temperature, due to the poor property of eater absorption they have worse spalling resistance than ordinary concrete. Structural lightweight concrete can be produced from light weight aggregates but the workability of the fresh concrete decreases when the concrete is produced from pumice and perlite (Karakurt and Özen, 2017).

Concrete structures are frequently exposed to elevated temperature or fire. The nature of the fire varies not only from application to another, but also from fire to fire depending up on the fire load, the geometric configuration and the availability of oxygen. At a temperature of up to 100℃ concrete structure starts to lose the free water.at this stage, the permeability increases. at temperatures of 350℃ the calcium hydroxide becomes to dissociate in the concrete structure. At this stage gravels start to break up. When concrete structures are exposed to temperatures of 650℃ calcium carbonate dissociates and total loss of water hydration occurs. Concrete structure starts to melt when exposed to temperatures above 1200℃ (Maged et al., 2014).

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 ash on the split tensile 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 cylindrical molds of 100mm diameter and 200mm height cast iron was used to cast the specimen. All ingredients are measured according to their proportion. Thorough mixing of the materials is essential for the production of concrete which is uniform in colour, homogeneous, and consistency. 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 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

Tensile Strength Test*:* the tensile strength of the concrete is determined by indirect test methods like split cylinder test. Split tensile test is an indirect method of determining the tensile strength of concrete by loaded a cylindrical specimen diametrically across the circular cross section. The split tensile strength of the concrete was determined using the indirect split tensile strength test in accordance with ASTM C496.

3. Results and Discussions

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

The specimen which is used in this test was concrete cylinders of 200mm height with 100mm diameter. The study focuses on the results of effect of sewage sludge on selected mechanical properties of concrete. Below shows the split tensile strength of concrete with different sewage sludge content at 300℃, 600℃ and 900℃ for exposure durations of 1hr, 4hr, and 8hr. As shown on table 2 as the percentage replacement of sewage sludge increases from 5% to 15%, the split tensile decreases. Replacement of 15% sewage sludge shows about 20%, 22%, 26% and 36% reduction of split tensile strength at room temperature, at 1hr, 4hr, and 8hr exposure duration respectively.

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

	Split Tensile Strength (Mpa)									
Group	RT	300℃/ 1hr.	300℃/ 4hr.	300℃/ 8hr.	600℃/ 1hr.	600/4 hr.	600℃/ 8hr.	900℃/ 1hr.	900℃/ 4hr.	900℃/ 8hr.
0	4.1	3.04	2.94	3.5	1.93	1.19	1.13	1.76	0.64	0.42
5	4.1	3.12	2.94	3.59	2.63	1.96	1.71	1.86	0.71	0.5

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10	4.0 1	2.44	2.77	3.46	2.46	1.35	1.26	1.53	0.48	0.33
15	3.2 5	2.37	2.17	2.24	1.8	1.23	1	1.16	0.37	0.3

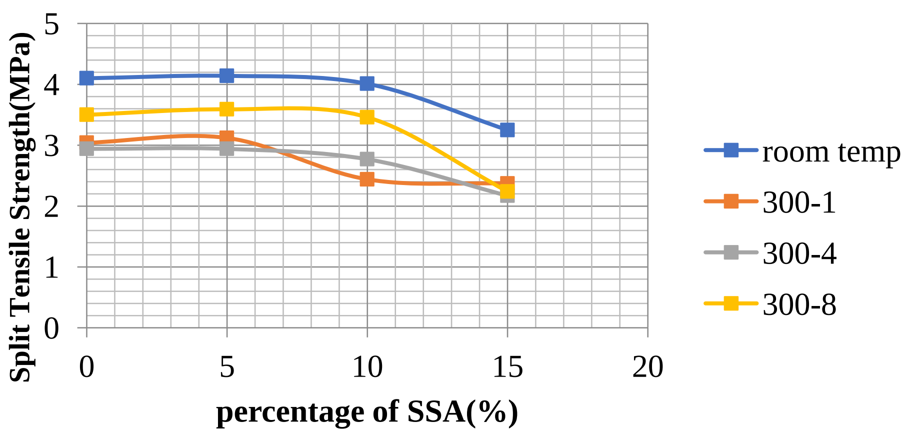

Figure 1: Effect of percentage replacement of sewage sludge on the split tensile strength of concrete at 300℃

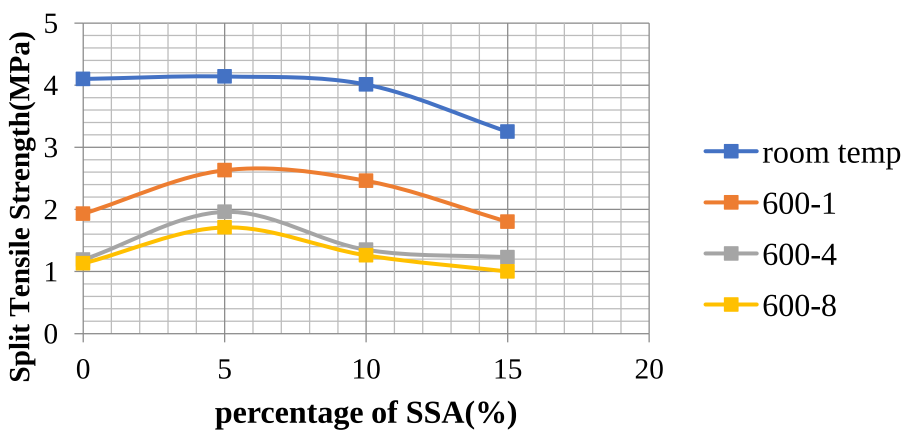

Figure 2: Effect of percentage replacement of sewage sludge on the split tensile strength of concrete at 600℃

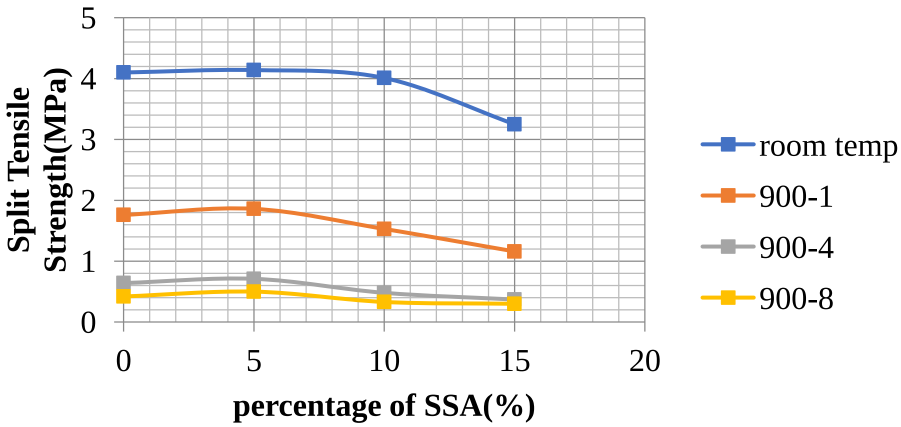

Figure 3: Effect of percentage replacement of sewage sludge on the split tensile strength of concrete at 900℃

From figure 1 it is understood that at room temperature the split tensile increases as the percentage replacement of sludge increases from 0 to 5% and decreases as the replacement increases from 5 to 15%. At an exposure duration of 1hr 5% sewage blended fine aggregate concrete has high residual tensile strength than all other specimen types. In general, for all conditions 5% sewage blended fine aggregate concrete has better performance than all other concrete types. Figure 2 shows the residual split tensile strength at 600℃ due to replacement of varying amount of sewage sludge. The residual split tensile strength increases as the percentage of sewage sludge increases from 0 to 5% and starts to decline when the replacement increases from 5 to 15%. Figure 3 shows the residual split tensile strength at 900℃ due to replacement of varying amount of sewage sludge. It indicates that as the percentage replacement of sewage sludge increases from o to 5% the split tensile also increases for all exposure duration and as the replacement increases from 5 to 15% sewage replacement the residual split tensile strength decreases.

3.2 Effect of Temperature on Spalling and Cracking

When specimens are exposed to high temperature, they experience moisture loss due to increased pore pressure from evaporating water inside the concrete. This process results in an increase in internal stresses and therefore, cracks appear. During the experiments visible micro cracks on specimens appeared when temperatures of exposure were 600℃ and 900℃. As the increase in moisture loss results in appearance of fine cracks on its surface. Cylinders heated to 900 ℃exposed to 8hr had a significant increase in number and size of cracks, compared to samples exposed to 600℃. The result of this experiment showed that there is spalling of concrete observed after the elevated temperature for all concrete types.

4. Conclusions

In this research 120 concrete cylinder speciments were casted and tested to get insight into tensile strength and physical characteristic of various proportion sewage sludge as a partial replacement of fine aggregate at various levels of exposure temperatures and durations.

- At 600℃,the residual split tensile strength of 5% and 10% sewage replaced concrete has better performance than normal concrete for all exposure durations.
- The split tensile strength reduces as the exposure duration and the percentage replacement of sewage sludge increase keeping the exposure intensity constant for higher temperatures (600℃ and 900℃).
- 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.
- visible micro cracks on specimens appeared when temperatures of exposure were 600℃ and 900℃.

References

ACI 211.1-Reapproved(2009). Standard Practice for Selecting Proportions for Normal, Heavyweight, And Mass Concrete. An ACI Standard Reported By ACI Committee 211,38pp.

ASTM C150/C150-19a. (2019). Standard Specification For Portland Cement. ASTM International,West.

ASTM C496/C496M-17, A. (2017). Standard Test Method For Split Tensile Strength Of Cylindrical Concrete Specimens. ASTM International, West Conshohocken.

C. M. A. Fontes,R. D. Toledo Filho And M. C. Barbosa. (2016). Sewage Sludge Ash (SSA) In High Performance Concrete: Characterization And Application. 9.

Cenk Karakurt, Uğur Özen. (2017). Influence of Natural Lightweight Aggregates on the Properties of Concrete. 9-16.

David N. Bilow, P.E., S.E.,Old Orchard Road, Skokie,Mahmoud E. Kamara, Phd.,Orchard Road, Skokie,. (2008). Fire And Concrete Structures.

Dinku, A. (2005). The Need For Standardization Of Aggregates For Concrete Production In Ethiopian.

Maged A. Youssef, P. (2014). Fire Resistance Of Reinforced Concrete Structures. 1-27.

O.A. Johnson, M. Napiah And I. Kamaruddin. (2014). Potential Uses Of Waste Sludge In Construction Industry: A Review. Research Journal Of Applied Sciences, Engineering And Technology, 8(4), 565-570.

Srinivasan. K, Vazhviniyan. R, Mohankumar. L, Palpandi. K. (2016). Replacement of Fine Aggregate Using Sludge in Concrete. International Research Journal Of Engineering and Technology (IRJET), 3(5), 1989-1993.

T.Subramani, A.Anbuchezian. (2017). Experimental Study on Replacement of Concrete Material by Water Treatment Plant Waste Sewage. International Journal Of Application Or Innovation In Engineering & Management (IJAIEM), 6(3), 50-57.

Tomasz Drzymałaa, Wioletta Jackiewicz-Rekb, Mariusz Tomaszewskib, Artur Kuśb,. (2017). Effects Of High Temperature On The Properties Of High Performance Concrete (HPC). Modern Building Materials, Structures And Techniques,, 256 – 263.

Yehia, S. And G. Kashwani. (2013). Performance Of Structures Exposed To Extreme High Temperature—An Overview