

Book Chapter

Incineration of Textile Sludge for Partial Replacement of Cement in Concrete Production: A Case of Ethiopian Textile Industries

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Abstract

The rapid growth of textile industries in Ethiopia plays an important role in economic development. However, the sludge from these wastewater treatment plants, which is not an integral part of the treatment process, is often considered hazardous as it is contaminated with heavy metals of dyestuffs and chemicals. The customary transfer routines such as landfilling and incineration may not be suitable because the leachate from the landfilling destinations and the buildups from the incinerators lead to optional contamination. Moreover, such transfer choices are not financially practical. Therefore, there is a growing need to look for various applications of sludge handling for sustainable development. This study attempts to find out an environmentally friendly solution for the management of the textile sludge by incinerating the sludge and using it for partial

replacement of cement in concrete production. Concrete is a composite material formed by the combination of cement, sand, coarse aggregate, and water in a particular proportion so that concrete produced meets the needs regarding its workability, strength, durability, and economy. Typical textile sludge was having high heavy metal contents as per the United States Environmental Protection Agency (USEPA) guideline and should be properly disposed of. The sludge upon incineration at 625°C for four hours gives 78.1% moisture content, 61.2% volatile organic matter, and 59.6% inorganic ash content. The main reactive oxide elements such as SiO₂, Fe₂O₃, CaO, and Al₂O₃ were found to be 18.51, 3.19, 23.87, and 12.73% by weight in the ash. The calorific value determined from the dried sludge were found to be 1973 cal/gm. Concrete block was manufactured by replacement of cement with 10, 20, 30, 40, and 50% incinerated textile sludge ash, and the manufactured block was evaluated in terms of their compressive strengths, leaching behavior, and water absorption. The replacement cement by the ash increases the hydration time reduced, and up to 20%, sludge ash incorporation in the concrete mix design gives the designed compressive strength. Eventhough water absorption increases with increasing content of the incorporation of the ash, for the 20% replacement of cement, the lethal concentration of heavy metals was obtained to be below the permissible limit set by USEPA. Consequently, the experiment work indicates that the potential use of textile sludge ash for cement concrete gives the possibilities of reduction of heavy metal contamination to surroundings upon sludge disposal, reduces the use of raw materials for producing cement and reduces environmental pollution during cement production.

Introduction

Industry is vital to the economies of modern societies and is an indispensable means of growth. Ethiopia is in a state of transformation from an agriculture-based economy to an industry-based economy. As a result, several industries are growing from time to time. The textile industry covers the largest foreign currency earnings nowadays in Ethiopia [1]. It has a major impact not only on the nation's economy but also on

the economic and environmental quality of life [2]. Textile industries are one of the major consumers of water and dispose of a huge volume of effluent to the environment unless treated [3,4]. Sludge is an inevitable by-product discharged from wastewater treatment plants. It is hazardous as it is often contaminated with heavy metals of dyestuffs, solvents, surfactants, and chemicals [5,6]. The transfer of sludge stands out amongst the most difficult natural issues in wastewater treatment methods.

Several sludge-processing techniques are employed to treat textile mill sludge. Anaerobic digestion and aerobic digestion of sludge are one means of sludge processing; however, this process generates a great quantity of sludge that is formed by the excess of biomass and substances that were not degraded during the biological treatment [7,8]. Composting is another option of textile mill sludge processing, but sufficient digestion is not obtained as the sludge is not conducive for microorganisms and the biologically inert components of sludge remain undigested. Direct composting is not suitable for crop plants as plants get nutrients as well as toxic substances from direct composting of sludge [9]. In the past decades, sludge was mainly disposed of in landfills [6] and the seas [10]. However, space limitations on existing landfills [11] as well as increasing environmental concerns such as groundwater pollution from landfill leachate [12], effects on the marine environment [13], odor emission, and soil contamination have urged further investigation on various disposal methods. Application of textile mill sludge in agriculture has become difficult for fertilizer as standardization of the quality is difficult [14–16]. Agricultural use of sludge has been studied; however, the presence of heavy metals and pH of the sludge adjusts the soil qualities, and its effect restricts the use of sludge for agricultural purposes. An attempt also has been done to reuse the sludge in construction materials [17–20].

The application of textile effluent sludge without proper management may have adverse impacts on human health and the environment. One of the most common textile sludge disposal alternatives is incineration [21]. Textile sludge ash has been used as an additive and substitutive ingredient in cement-based

materials [22–24], blocks [5], and bricks [21,25,26]. However, the properties of sludge are varied from factory to factory due to the difference in use and dosage of the dye molecule, water, and chemical impurities utilized in the manufacturing process, and the type and level of wastewater treatment differ among factories.

Hence, this study was aimed at characterizing the raw textile sludge obtained in selected textile industries in Ethiopia and incinerated ash for the replacement of cement in the mix design of the concrete production. As per the results, up to 20% cement substitution was achieved.

Materials and Methods

Materials

Textile Sludge

Textile mill sludge was collected from Bahir Dar Textile Share Company and Kombolcha Textile Share Company, Amhara, Ethiopia, in the dumping area of sludge from those textile industries whose primary products were dyed and printed 100% cotton products. These factories are integrated textile mills comprising spinning, weaving, and wet processing, and they do have wastewater treatment plants. An amount of 2.5 kg sludge was collected in the sludge drying bed of those companies using a plastic bag and stored in a dry storeroom every two weeks for a year. Sludge waste was then thoroughly mixed to get a homogenous sample and air-dried before experimentation. The sludge was oven-dried at 100°C for 24 hours to remove the excess moisture so that it does not affect the incineration process. Following the drying of the sludge, it was incinerated using a muffle model-48000 at a temperature of 625°C for about 4 hours [21,27,28]. The resulting ash was then grinded into fine particles in powder form before it was mixed with concrete mix ingredients. The fine ash was sieved using a sieve shaker with a 150 μm sieve, and only ash passing this sieve size was used for mix design.

Cement

Ordinary Portland cement (OPC), grade 42.5 as per ASTM C 150 depending upon the strength of the cement at 28 days, was used for this work.

Fine Aggregate

Locally available fine aggregates with a fineness module of 2.95 as per ASTM C-136 and a specific gravity of 2.63 as per ASTM C-128 with water absorption of 3.53% were collected from Pawi Andreb, Amhara, Ethiopia. The silt content of the fine aggregate was 3.21% as per ASTM C87 M and the organic impurities were class II as per ASTM C 33-03.

Coarse Aggregate

Locally available 37.5 mm down size coarse aggregate with a fineness module of 3.62 as per ASTM C-136a and specific gravity of 2.62 as per ASTM C-127, which has a flakiness index of 30.13% with water absorption of 1.54%, were obtained from Addis Zemen, Amhara, Ethiopia.

Water

The water that was used in the mixing of concrete and curing of the specimen was free from organic and inorganic impurities, soluble salt, sulfate, and silt with a pH of 7 and conforming to IS 456-2000.

Methods

In this project work, once the sludge was collected from the ETP (effluent treatment plant) sludge drying bed of typical textile industries, the physio-chemical properties of sludge were first characterized to design appropriate method and condition of incineration. Then, the sun-dried and oven-dried sludge was thermally processed by incineration. Upon incineration, the volatile matters were removed as a char and the inorganic materials were obtained in the form of ash, and the resulting

ashes were characterized. Based on the information gained on the ash, a portion of cement was replaced by the ash in the concrete mix-design preparation and manufacturing. Lastly, the properties of concrete such as compressive strength and water absorption were assessed to evaluate the performance. The method followed under these works is illustrated in Figure 1.

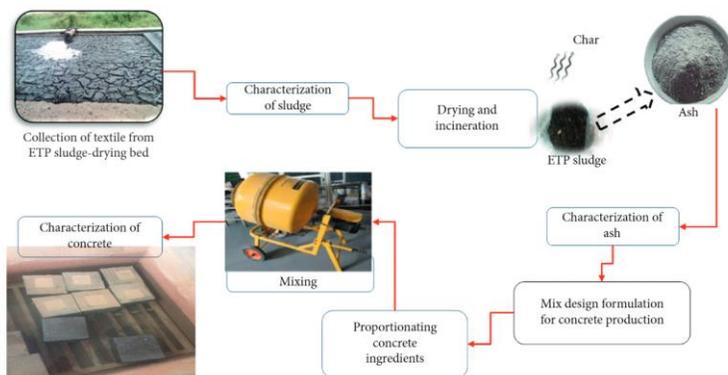


Figure 1: General work steps of the project.

Proximity Analysis

The proximity analysis was done by incineration of the sludge using a 48000-muffle furnace. The analysis was done following ASTM E871-82 for moisture content, ASTM E872-82 for volatile organic matter, and ASTM D1102-84 for ash content. The calorific value of textile sludge was determined using an adiabatic oxygen bomb calorimeter (1241EF, PARR MOLINE ILLINOISE, USA) following ASTM D 2015–96 test methods.

Heavy Metals on Sludge

The heavy metal analysis was conducted using Flame Atomic Absorption Spectrophotometry (PG 990, FAAS Hydride, and cold Hg technique, Germany). The organic matrix of the sludge was incinerated and the sample was prepared from the remaining ash using the acid dilution method. Hence, to free organic matter interferences of sludge for both raw and incinerated ash, the specimens were digested using nitric acid.

Physio-Chemical Analysis of Textile Mill Sludge

The chemical composition of sludge was determined employing X-ray fluorescence (Thermo Fisher ARL 9900, United States) using ASTM test method C 114. After incineration, the specific gravity of textile mill sludge ash was determined as per ASTM C188 employing a laboratory pycnometer.

Mix Design of Concrete

Once the standard tests are done for confirmation of characteristics of mix ingredients, concrete strength of C-25 with a mix ratio of 1:1.5:3.5 with a gauge box size of 18 mm * 40 mm * 50 mm was cast to find out the compressive strength of concrete. Different concrete cubes of C-25 strength of concrete were also cast by partial replacement of cement by incinerated ash of textile sludge. Concrete block was manufactured by blending the ash with cement and the content of the ash was 10%, 20%, 30%, 40%, and 50%, respectively. A 0.5 water-cement ratio was used. To account for the variations in the laboratory and the site exposure condition, a safety margin of 1.5% is considered in all trial batches.

Compressive Strength of Concrete

Compressive strength tests were conducted after 7, 14, and 28 days of moist curing following the procedures described in ASTM C 39.

Leaching Test

To know the concentration of the toxicity of heavy metals leached out from the concrete, a leaching test was conducted for a 28 day cured concrete employing the ICP-OES analysis examination method as per EN 13657–2002.

Water Absorption Test

For the water absorption test, the concrete cube size 150 mm was dried at 105°C in an oven and then put in desiccators to cool

down to room temperature, and the dry weight was recorded as w_1 . Then, the dry sample was immersed in water for 48 hours, and the specimens were taken out and wiped with a cloth and the weight of the specimen in wet condition was recorded as w_2 . The percentage of water absorption was calculated as

$$\text{water absorption (\%)} = \frac{(W_2 - W_1)}{W_1} * 100. \quad (1)$$

Result and Discussion

Physio-Chemical Properties of Sludge and Ash

The heavy metals in row sludge and incinerated ash are tabulated in Table 1. The presence of heavy metals on ETP sludge was assumed to originate from dyes, pigments, surfactants, and other auxiliaries in wet processing processes [29]. High concentrations of heavy metals were obtained in the sludge after incineration. This increase in the concentration of metals may be associated with particulates forming free metals upon incineration. The ETP sludge has high heavy metal contents as per USEPA guidelines and should be properly disposed of. The incinerated ash of textile sludge was having a specific gravity of 2.73.

Table 1: Heavy metals on the sludge.

Heavy metals (mg/l)	Row sludge	Incinerated ash at 625°C
Cu	6.23	7.31
Fe	284	286.3
Mg	3.12	4.03
Ca	2.8	3.7
Pb	1.79	1.5
Zn	41.73	44.17
Si	172.47	181.82
Cr	7.23	5.53
Cd	33.42	33.40
Ni	0.49	0.47
Mn	5.83	5.81

The average value of three replicates of each test for the oxide composition of textile sludge ash and OPC is presented in Table 2. The main reactive oxide elements such as SiO₂, Fe₂O₃, CaO, and Al₂O₃ are present in different quantities where the former three are higher in OPC and the latter one is higher in textile sludge ash. The origin of these oxides may be associated with the chemicals and auxiliaries used in the production process and by the chemicals used in the wastewater treatment plant process as a coagulant and flocculants [30]. As per ASTM C125, the existence of such amount oxides in the textile mill sludge ash plays a highly important role in the property of binding and cohesion properties to replace the cement to a certain extent.

Table 2: Chemical composition of textile sludge ash and cement.

Oxides (content by weight %)	Textile sludge ash	OPC
Fe ₂ O ₃	3.19	3.71
MgO	1.79	1.53
Al ₂ O ₃	12.73	4.56
CaO	23.87	64.07
SiO ₂	18.51	19.39
SO ₃	9.33	3.93
Na ₂ O	2.36	0.04
K ₂ O	0.31	0.66
Loss on ignition	3.47	1.65

The proximate analysis was done three times and the average values are recorded in Table 3. The test result shows that the sludge does have a high amount of inorganic component accounted 56.9% in the form of ash [30,31].

Table 3: Proximate test result.

Parameters	Percentage value
Moisture content	78.1
Volatile organic matter	61.2
Ash content	56.9

The heating value of the sludge was found to be 1973 cal/gm. The presence of organic chemical compounds may be helping in lowering heat energy to this level [32].

Compressive Strength of Concrete

The compressive strength of the concrete is measured, as shown in Figure 2, and observed to decrease with the incorporation of more textile sludge ash to replace the cement. Five replicates were tested for each specimen and the average values were reported in Table 4. Replacing the cement by 10%, 20%, 30%, 40%, and 50% with the ash of textile mill sludge reduced the compressive strength of the resulting concrete by 4.8%, 9.1%, 12.5%, 16.07%, and 17.3%, respectively.



Figure 2: Compressive strength test.

Table 4: Compressive strength of concrete cubes using different cement replacements.

Percentage replacement of cement by the ash of textile mill sludge	Compressive strength on cubes sample (N/mm ²)			Water absorption (%)
	7 days	14 days	28 days	
0	25.2	33.6	42.00	6.41
10	24.16	31.16	39.97	10.21
20	23.34	29.07	38.17	12.49
30	18.36	27.43	36.72	14.55
40	15.23	25.82	35.25	16.43
50	14.86	23.77	34.73	20.38

This might be due to the small quantities of reactive oxides in the textile sludge ash so that strength of cement binder is reduced when the extent of replacement of cement with textile sludge ash is higher [33].

The replacement of cement in ETP ash increases the hydration time. This is most likely due to the presence of small quantity of oxides present in the ash compared with cement.

The grade of concrete construction is selected based on structural design requirements as per BS 8500 standard test method [34–37]. Nominal mixes for grades of concrete such as C-15, C-20, and C-25 are generally used for small-scale construction. Large structures have high strength requirements; thus, they go for higher grades of concrete such as C-30 and above. The result obtained from Table 4 gives a comparative substitution of concrete as per BS 8500.

Leaching and Water Absorption

The leachability of heavy metals was tested for a 20% incorporation of ash and is reported in Table 5. The amount of all the parameters of heavy metals obtained is within the permissible limit set by the USEPA standard.

Table 5: Leach analysis results.

Heavy metals (mg/L)	Leach amount	USEPA concentration limit
Cu	0.021	100
Mn	0.072	260
Cd	0.001	1
Pb	0.037	5
Zn	1.520	500
Cr	0.031	5
Ni	0.025	1.3
Hg	0.001	0.2
As	0.001	5

The water absorption of the average value of three replicates for each specimen is tabulated in Table 4. As the percentage replacement of cement with textile sludge ash increases, the water absorption also increases. This may show that the degree of porosity and water absorptivity will increase with an increase of percentage replacement [38,39]. This increase in water absorption may result in a decrease in the strength of the concrete.

Conclusions

The textile mill sludge discharged from Ethiopian textile industries is a practical problem. In the selected textile mills, a significant quantity of sludge is generated which possesses sludge management problems. From the current project, it is confirmed that the quantity of heavy metals accumulated in sludge is beyond the permissible limit set by USEPA and pollutes the environment unless properly managed. The current approach was to utilize textile waste sludge for cement replacement after incineration which is an alternative and relatively safe method of sludge disposal mechanism over the prior arts. Different sludge ash to cement ratios were used to make sludge ash integrated concrete, and the properties of the concrete were assessed in comparison with the blank sample. The characteristics of concrete are influenced as the percentage of substitution increases, as compressive strength decreases and water absorption increases, and up to 20% cement replacement

provides a sound replacement. The leaching test revealed a very low amount of heavy metals released from the cube samples at this amount of replacement; this was marginal as compared to the required heavy metal concentration causing cellular cytotoxicity [26]. As a result, sludge ash in concrete cubes can be used without posing a significant risk of heavy metal pollution. According to the current research, the resulting composite concrete can be used for nonstructural applications per BS 8500 standard. These findings suggest that if dumped in the open, textile sludge may be hazardous to human health and the environment. Textile sludge can be used to manufacture regular and quality concrete with a 20% cement substitute, as well as have ecologically sound means of disposal, as a solution to this pressing issue.

To use it for structural applications, additional parameters of composite concrete typically bending and shear have to be tested and comparison has to be done with conventional concrete. Furthermore, the techno-economic feasibility of this project has to be detailed in the future phase of this project.

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