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Effective Use Bagasse Ash of Omo-Kuraz Sugar Factory as a Sustainable Partial Substitute of Cement in Concrete for Constructions in Ethiopia

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Abstract

This study deals with the recycling of sugar cane bagasse ash of the Omo-Kuraz sugar factory of Ethiopia as a substitute of cement in concrete that provides appropriate remedy to waste disposal and greenhouse gas emission related environmental challenges. The influence of bagasse ash as a cementing material in concrete was examined by performing several strength and durability experiments. From a strength perspective, compressive and splitting tensile strength were tested. As part of durability properties, carbonation and chloride penetrability of bagasse ash concrete was studied. Bagasse ash-based concrete mixes were made with varying cement replacements (10% - 40%) and were tested at various curing periods. As per the strength and durability test results, bagasse ash can be utilized as a cementing material in concrete with 10% cement replacement as the optimum quantity. The durability test results revealed bagasse ash doesn't have adverse effects from carbonation and chloride penetrability perspective on concrete. This indicates that the Ethiopian construction industry can consider bagasse ash as non-conventional cementing material.

Keywords: Bagasse Ash, Compressive Strength, Sorptivity, Tensile Strength, Workability, Ethiopian Construction Industry

I. Introduction

Sugarcane iia a major agricultural product cultivated in approximately110 countries and providing as estimated annual production of 1500 million tons. In the case of Ethiopia, data from the Ethiopian Sugar Corporation reveals that the nation currently operates eight sugar factories: Wonji Shoa, Metehara, Finchaa, Tendaho, Arjo-Dedesa, Kessem, Omo-Kuraz II, and Omo-Kuraz III. Jointly, these factories produce between 3.5 and 4 million quintals of sugar each year. Five additional sugar factories are under in various phases of construction. These are part of Omo-Kuraz (specifically Omo-Kuraz I and IV), Tana Beles (Tana

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Beles I and II), and Welkayte Sugar Development Projects. Once these new development and expansion projects are finalized, Ethiopia will boast a total of 13 sugar factories, providing it with the capacity to produce 2.25 million tons of sugar every year. As a result, sugarcane plantations are expanding with current area coverage of over 102 thousand hectares [1].

Sugarcane bagasse ash (SCBA) is produced as a byproduct of sugar production factories. Extraction of all economical sugar from sugarcane result into 40-45% fibrous residue is obtained which is reused in the same industry as fuel in boilers for heat generation which turns behind 8 -10 % ash as waste which is also known as sugarcane bagasse ash (SCBA) [2] [3]. Currently in Ethiopia, the overall sugarcane crushing capacity of the eight factories combined is about 74,350 tons per day which produces an estimated 2,677 tons of SCBA per day or 977,105 tons per annum. The expected SCBA obtained from 13 factories will be 1.97 million tons yearly when the expansion and development of new projects is finalized.

The SCBA comprises large quantities of silicon, un-burnt matter, calcium oxides and aluminum. The ashes produced straight from the mills are not responsive as they are not burnt in controlled conditions. The ash, therefore, becomes industrial waste and poses disposal concerns. A few studies have been carried out in the past on the utilization of bagasse ash obtained directly from the industries to study pozzolanic reactivity and their aptness as binders by partially replacing fine aggregate [4], [5]. It has been found that under a controlled burning below 700° C incinerating temperature for about 1 hour it converts the silica material of ash into amorphous silica. The responsiveness of this amorphous silica is exactly proportionate to the specific surface of the ash. The SCBA formed after the controlled burning condition is ground or pulverized to the required fineness before mixing with the blended concrete.

The present experimental investigation was done to examine the use of SCBA as a fractional substitute of cement in concrete. This would help in resolving the matters related to the disposal of SCBA and reduce the greenhouse gases emitted due to the use of cement in concrete which possess a serious threat to our environment and ecology. This experimental research investigates the workability properties of fresh concrete like slump and compressive strength and tensile strength of concrete at 7, 28 and 90 days with 0%, 10%, 20%, 30% and 40% substitution of fine aggregate with bagasse ash by weight.

II. Materials and Methods

A. Materials

A 42.5 grade Portland Cement (OPC) and SCBA from Omo-Kuraz II sugar factory, Ethiopia, were the materials used for this study. The SCBA was burnt further at 650° C for sixty minutes to decrease its carbon

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matter and was additionally milled to fine particles that pass through a 90 µm sieve. A sample of SCBA from the Omo-Kuraz II sugar factory is shown in Fig. 1. The physical and chemical behaviors of cement and SCBA are presented in Table I and II [6], [7].

Table I: Physical Properties of Cement and SCBA

Material	Density	Specific gravity	Fitness (μm)	Specific surface (m^2/kg)	Mean grain size
OPC	1.15	3.15	82	300	21
SCBA	0.42	1.71	90	890	5.2

Table II: Chemical Properties of Cement and SCBA

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	LOI
OPC	21.55	5.69	3.39	64.25	0.85	0.33	0.59	2.47	1.8
SCBA	87.4	3.6	4.9	2.56	0.69	0.15	0.47	0.11	8.25

Angular crushed granite metal found in the study area with a highest dimension of 20 mm served as the large aggregate fraction with an average fineness of 7.63 and sp.gr of 2.65, apparent density of 1468 kg/m^3 at the compressed state and water absorption of 1.2%, respectively [8]. A gravity 2.5 river sand with a 2.8 and1700 kg/m3 bulk density at the compacted state and 2.04% water absorption, respectively served as fine aggregate. Potable water that was clean and free from any impurities (acids, alkalis and oils, etc.) was utilized for concrete mixing and curing.

Fig. 1: SCBA from Omo-Kuraz II sugar factory

The mix design was done and numerous materials were designed based on the code book ACI 211. To identify the ideal proportion of SCBA in concrete as a fractional substitution of cement, five types of combinations (BA0, BA10, BA20, BA30 and BA40) were prepared by fractionally substituting cement

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with SCBA from 0% to 40%. Concrete test specimens of the above-mentioned mixes of size 150mmx150mmx150mm were cast and tested for their compressive and tensile strength at 7, 28, and 90 days. The proportions of mixture are shown below in Table III.

Table III: Mix Design and Proportion of C35 Grade Concrete

Grade	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	W/C ratio	Water (kg/m^3)	Mix proportion
C-35	452	793	910	0.42	190	1:1.754:2.013

B. Experimental Procedure

For the effective concrete production, the key determinants are proper blending, compaction, and adequate curing which were employed in the preparation process of the trail specimens [9]. The mixing was done using a pan mixer within 3 – 4 minutes. Test was carried out to investigate the workability behaviors of a fresh concrete slump. The trial samples were de-molded 24 hours after casting and sufficiently cured with potable water. The compressive strength of the trial samples was examined at three dissimilar ages i.e., 7 days, 28 days, and 90 days by using cube specimens of size 150 mm x150mmx150mm [5]. The rapid chloride permeability test (RCPT) was done with concrete discs of size 100 mm dia. x 50 mm ht [9] [10]. Each test score was averaged out from three separate trial specimen test scores. The sample of fresh concrete and trial specimen casting is displayed in Fig. 2 and Fig. 3, respectively.

Fig. 2: Fresh Concert

Fig. 3: Preparation of test sample

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III. Results and Discussions

A. Impacts of SCBA on Fresh Properties of Concrete

The consequence of the substitution of cement by bagasse ash fractionally from 0% to 40% on the workability of concrete is indicated in Table IV.

Table IV: Slump values of different Concrete Mixes

Sr. No.	Proportions of SCBA	Concrete slump (mm), to nearest 5mm
1	0%	45
2	10%	40
3	20%	40
4	30%	35
5	40%	28

Table IV shows that there is no considerable loss of workability by replacing SCBA with cement by up to 20%. Increased water requirement has been described previously [9] when SCBA replaces cement, which is mostly due to the porous nature of the fine particles, high surface area and the un-burnt carbon content. Furthermore, the irregular shapes and angularity of the SCBA also increase the water requirement by providing particle catch points that need extra water to permit them to unlock hydraulically.

B. Effects of SCBA on Compressive Strength of Concrete

The results of the substitution of cement by SCBA fractionally from 0% to 40% on compressive strength (in MPa) of concrete at varying days of curing is indicated in Table V below.

Table V: Effect of SCBA on Compressive Strength of Concrete

Mix	% SCBA replacement	Density (kg/m^3)	Compressive strength at different age		
			7 days	28 days	90 days
C35	0%	2359	25.30	40.78	46.20
	10%	2360	26.90	45.66	48.70
	20%	2351	20.32	35.57	38.22
	30%	2461	18.65	20.63	32.62
	40%	2335	8.78	11.62	16.22

As shown in Table V above, the compressive strength of concrete is increasing from ordinary concrete (0% replacement) to concrete with 10% of SCBA as fractional substitution of cement similar to the study done

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with rice husk ash by [9]. By additionally increasing the SCBA content as a substitution for cement, the compressive strength decreases again similar to the case of the rice husk ash study [9]. An identical propensity of strength variation is noted at various ages of testing i.e., 7 days, 28 days, and 90 days similar to [9]. It is also observed that, when the days of curing increase from 7 days to 28, and 90 days, the compressive strength simultaneously increases for all types of mixes mainly due to the delayed pozzolanic effect of SCBA in concrete [9]. The reasons for compressive strength growth in SCBA mixed concretes and the increase in compressive strength for up to 10% cement substitution of SCBA may be because to the high silica content, amorphous phase, fineness, degree of reactivity of SCBA, particular surface area, and pozzolanic reaction between reactive silica in SCBA and calcium hydroxide in an alkaline setting as in the case of the rice husk ash study [9]. According to these test results, it can be deduced that 10% of SCBA from the Omo-Kuraz sugar factory is ideal to be employed as a fractional substitution of cement in the production of concrete as far as compressive strength is concerned.

C. Effects of SCBA on Tensile Strength of Concrete

The consequence of the substitution of cement by SCBA fractionally from 0% to 40% on tensile strength (in MPa) of concrete at various ages is shown in Table VI.

Table VI: Effect of DCBA on Tensile Strength of Concrete

Mix	% SCBA replacement	Density (kg/m3)	Tensile strength at different age		
			7 days	28 days	90 days
C35	0%	2359	2.89	3.36	3.54
	10%	2360	2.90	3.81	4.11
	20%	2351	1.70	2.38	2.68
	30%	2461	1.49	2.09	2.21
	40%	2335	1.45	1.58	1.84

Table VI clearly shows that the tensile strength of concrete is increasing from ordinary concrete (0% substitution) to concrete with 10% of SCBA as fractional substitution of cement similar to the rice husk substitution study by [9]. By additionally increasing the SCBA content as a substitution for cement the tensile strength is decreased similar to the case of rice husk ash [9]. An identical propensity of strength difference can be seen at varying ages of testing i.e., 7 days, 28 days, and 90 days just like the rice husk ash case [9]. It is also observed that, when the age increases from 7 days to 28 and 90 days, the tensile strength

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increases for all categories of mixes mainly due to the delayed pozzolanic effect of SCBA in concrete again similar to the findings of the rice husk ash study by [9].

It can be concluded based on these results that 10% of SCBA from the Omo-Kuraz sugar factory is ideal to be employed as a fractional substitution of cement in the production of concrete with regards to tensile strength.

D. Relationship between Compressive and Tensile Strength of SCBA Concrete

We developed mathematical formula to describe split tensile strength and compressive strength of concrete (in MPa) with varying proportions of bagasse ash. Fig 4. indicated the association between split tensile strength and compressive strength at 28 days. The formula derived is as shown below:

For 0 up to 40% replacement of bagasse ash,

$$TS = 0.056 * CS + 0.8175 \text{ and } 'R^2' = 0.8935$$

Where, TS = Tensile Strength, CS = Compressive Strength, R^2 = Correlation Coefficient

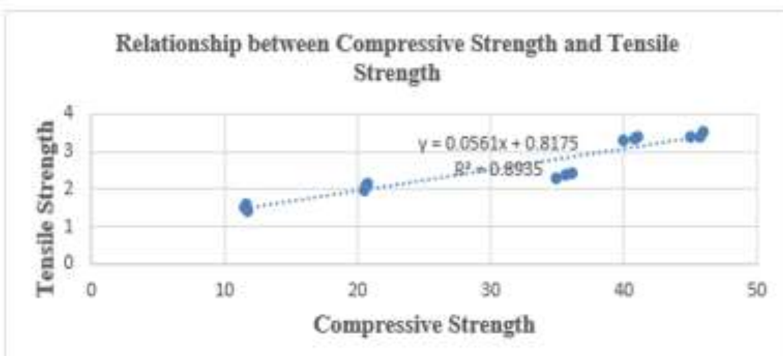

Fig. 4: Relationship between Compressive Strength and Split Tensile Strength

E. Effects of SCBA on Chloride Permeability of Concrete

The result of the substitution of cement by SCBA fractionally from 0% to 40% on charge passed by Columbus and chloride permeability of concrete at 28 days curing period [9] is indicated in Table VII.

Table VII: Chloride Penetration in Concrete Mixes

Type of mix	Charge passed coulombs	Chloride ion penetrability ASTM C1202
RCPT-0	2637.77	Moderate
RCPT-10	1885.61	Low

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RCPT-20	1384.64	Low
RCPT-30	2121.05	Moderate
RCPT-40	2823.25	Moderate

It can be understood from Table VII that with fractional substitution of cement with bagasse ash of up to 20%, the porousness of concrete is declining relative to the unconstrained concrete. Nevertheless, over 20% of cement substitution with bagasse ash, there is an increase in permeability relative to the unconstrained concrete. When the amount of bagasse ash in concrete goes up, the amount of electrical charge that can pass through the concrete goes down. This happens mainly because the bagasse ash has a pozzolanic effect, which means it chemically reacts with the calcium hydroxide in the concrete. This reaction effectively "plugs the pores" and makes the concrete much more impermeable (water-tight). The level of chloride ion penetration for concrete with bagasse ash of 10% and 20% as partial replacement of cement remains in the "Low" range as per ASTM C1202 [9] and thus demonstrates that these have a good ability to resist chloride ion penetration. It is also anticipated that with the rise in the days of curing when the majority of the hydration of concrete with bagasse is done, the chloride porousness of concrete will decline considerably.

F. Effects of SCBA on Carbonation of Concrete

The carbonation test was done for different blends and no carbonation depth was observed. This shows the blends are not influenced by the local environmental circumstances. Fig. 5. displays the concrete tubes put to carbonation test.

Fig. 5: Concrete Cylinders Subject to Carbonation Test

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IV. Conclusions and Recommendations

Based on the results of the experimental investigation done in this study, these conclusions can be drawn.

- The use of SCBA as a fractional substitution of cement in concrete assists in dealing with the waste management problems of sugar factories and lessens their environmental effects similar to the finds of [9] in case of rice husk ash.
- The ideal proportion of SCBA in concrete as a fractional substitution of cement in concrete is 10% with from the outlook of strength similar to the case of rice husk ash [11].
- Water demand for SCBA mixed concrete rises with rise in the SCBA content.
- With the inclusion of bagasse ash as a cementing material in concrete by up to 20%, the porousness of concrete declines relative to the unconstrained ordinary concrete.
- There is no effect of carbonation in SCBA-based concrete.

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