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EFFECTIVE UTILIZATION OF OMO-KURAZ SUGAR FACTORY BAGASSE ASH AS A SUSTAINABLE PARTIAL REPLACEMENT OF CEMENT IN CONCRETE FOR THE ETHIOPIAN CONSTRUCTIONS

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Abstract

This paper presents the recycling of sugar cane bagasse ash from the Omo-Kuraz sugar factory in Ethiopia as a cement replacement in concrete that offers a suitable solution to environmental issues related to waste disposal management and the emission of greenhouse gases. 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 produced with different cement replacements (10% - 40%) and were tested at different 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***

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I. Introduction

Sugarcane is one of the main crops grown in about 110 countries with an estimated total production of over 1500 million tons. From an Ethiopian perspective, according to Ethiopian Sugar Corporation data, currently, there are about eight operational sugar factories namely Wonji Shoa, Metehara, Finchaa, Tendaho, Arjo-Dedesa, Kessem, Omo-Kuraz II and Omo-Kuraz III which are producing 3.5 to 4 million quintals of sugar annually. Other five sugar factories are under different levels of construction at Omo-Kuraz (Omo-Kuraz I and IV), Tana Beles (Tana Beles I and II) and Welkayte Sugar Development Projects. When expansion and new sugar development projects are completed, Ethiopia will have 13 sugar factories with a potential of 2.25 million tons of sugar yearly. As a result, sugarcane plantations are expanding with current area coverage of over 102 thousand hectares [1].

Sugarcane bagasse ash (SCBA) is a by-product of sugar production factories. After the extraction of all economical sugar from sugarcane, about 40-45% fibrous residue is obtained, which is reused in the same industry as fuel in boilers for heat generation leaving behind 8 -10 % ash as waste, known as sugarcane bagasse ash (SCBA) [2]. Currently in Ethiopia, the total crushing capacity of sugarcane in eight factories is about 74,350 tons per day which yields about 2,677 tons per day of SCBA or 977,105 tons per year. The expected SCBA obtained from 13 factories is 1.97 million tons annually after the extension and the completion of new projects.

The SCBA contains high amounts of silicon, un-burnt matter, calcium oxides and aluminum. The ashes produced directly from the mills are not reactive as these are not burnt under 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 [3], [4]. It has been found that under a controlled burning below 700° C incinerating temperature for about 1 hour it converts the silica content of ash into amorphous silica. The reactivity of this amorphous silica is directly proportional 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.

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The present experimental investigation was carried out to study the use of SCBA as a partial replacement of cement in concrete. This would help in resolving the issues 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. The experimental study examines the workability properties of fresh concrete such as slump and compressive strength and tensile strength of concrete at 7, 28 and 90 days with 0%, 10%, 20%, 30% and 40% replacement of fine aggregate with bagasse ash by weight.

II. Materials And Methods

Materials

Ordinary Portland Cement (OPC) of 42.5 grade and SCBA from Omo-Kuraz II sugar factory, Ethiopia, were used for this study. The SCBA obtained from the factory was further burnt at 650° C for an hour to bring down the carbon content and further ground to 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 properties of cement and SCBA are presented in table 1 and table 2.

Table I: Physical Properties of Cement and SCBA

Material	Density	Specific gravity	Fineness (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 2: 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	1.80
SCBA	87.40	3.60	4.90	2.56	0.69	0.15	0.47	0.11	8.25

Locally available angular crushed granite metal having a maximum size of 20 mm was used as coarse aggregate having a fineness modulus of 7.63 and sp.gr of 2.65, bulk density of 1468 kg/m^3 at the compacted state and water absorption of 1.2% respectively. River sand with a specific gravity of 2.5, fineness modulus of 2.8, bulk density of 1700 kg/m^3 at the compacted state and

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water absorption of 2.04% respectively were used as fine aggregate. Clean and impurities-free (acids, alkalis and oils, etc.) Potable water was used for mixing concrete and curing.

Fig 1. SCBA from Omo-Kuraz II sugar factory

As per the code book ACI 211, the mix design was carried out and several materials were designed. To find the optimum percentage of SCBA in concrete as a partial replacement of cement, five types of mixes (BA0, BA10, BA20, BA30 and BA40) were arranged by partially replacing cement 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 mix proportions have been presented in table 3.

Table 3: 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 preparation of good concrete, the vital factors are appropriate mixing, compaction, and sufficient curing which were adopted during the test sample preparation process. A pan mixture was used for the mixing process and the time for mixing was kept for 3-4 minutes. To examine the workability properties of a fresh concrete slump, the test was performed. 24 hours after casting, the test samples were de-molded and adequately cured using potable water. The test specimens were tested for their compressive strength and tensile strength at three different ages i.e., 7 days, 28 days, and 90 days by using cube samples of size 150 mm x150mmx150mm. The rapid chloride permeability test (RCPT) was conducted using concrete discs of size 100 mm dia. x 50 mm ht.

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Each test result was averaged out from three test specimen test results. The sample of fresh concrete and test sample casting is shown in Fig. 2 and Fig.3 respectively.

Fig 2. Fresh Concert

Fig 3. Preparation of test sample

III. Results and Discussions

A. Effects of SCBA on Fresh Properties of Concrete

The effect of the replacement of cement by bagasse ash partially from 0% to 40% on the workability of concrete is shown in table 4.

Table 4: 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

It can be observed from table 4 that there is no considerable loss of workability by replacing SCBA with cement by up to 20%. Increased water requirement has been described previously [5] 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.

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B. Effects of SCBA on Compressive Strength of Concrete

The effect of the replacement of cement by SCBA partially from 0% to 40% on compressive strength (in MPa) of concrete at different ages is shown in table 5.

Table 5: 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	46.2
	10%	2360	26.90	45.66	48.7
	20%	2351	20.32	35.57	38.22
	30%	2461	18.65	20.63	32.62
	40%	2335	8.78	11.62	16.22

It can be clearly seen from table 5 that the compressive strength of concrete is rising from normal concrete (0% replacement) to concrete with 10% of SCBA as partial replacement of cement. By further rising the SCBA content as a replacement for cement the compressive strength is reducing. A similar tendency of strength difference can be observed at different ages of testing i.e., 7 days, 28 days, and 90 days. It can also be seen that, with an increase in the age from 7 days to 28, and 90 days, the compressive strength increases for all types of mixes which are especially due to the delayed pozzolanic effect of SCBA in concrete. The causes for compressive strength development in SCBA blended concretes and the rise in compressive strength for up to 10% cement replacement of SCBA may be due to the high silica content, amorphous phase, fineness, degree of reactivity of SCBA, specific surface area and pozzolanic reaction between reactive silica in SCBA and calcium hydroxide in an alkaline environment. Based on the above test results, it has been established that 10% of SCBA from the Omo-Kuraz sugar factory is optimum to be used as a partial replacement of cement in the manufacturing of concrete from a compressive strength perspective.

C. Effects of SCBA on Tensile Strength of Concrete

The effect of the replacement of cement by SCBA partially from 0% to 40% on tensile strength (in MPa) of concrete at different ages is shown in table 6.

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Table 6: Effect of DCBA on Tensile Strength of Concrete

Mix	% SCBA replacement	Density (kg/m^3)	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

It can be clearly seen from table 6 that the tensile strength of concrete is rising from normal concrete (0% replacement) to concrete with 10% of SCBA as partial replacement of cement. By further rising the SCBA content as a replacement for cement the tensile strength is reduced. A similar tendency of strength difference can be observed at different ages of testing i.e., 7 days, 28 days, and 90 days. It can also be seen that, with an increase in the age from 7 days to 28 and 90 days, the tensile strength increases for all types of mixes which are especially due to the delayed pozzolanic effect of SCBA in concrete.

Based on the above test results, it has been established that 10% of SCBA from the Omo-Kuraz sugar factory is optimum to be used as a partial replacement of cement in the manufacturing of concrete from a tensile strength perspective.

D. Relationship between Compressive and Tensile Strength of SCBA Concrete

Mathematical equations have been derived to express split tensile strength and compressive strength of concrete (in MPa) with different percentages of bagasse ash. Fig 4. shows the relationship between split tensile strength and compressive strength at 28 days. The equation obtained is as shown below:

For 0 up to 40% replacement of bagasse ash,

TS = 0.056* CS + 0.8175 and 'R^2'= 0.8935

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

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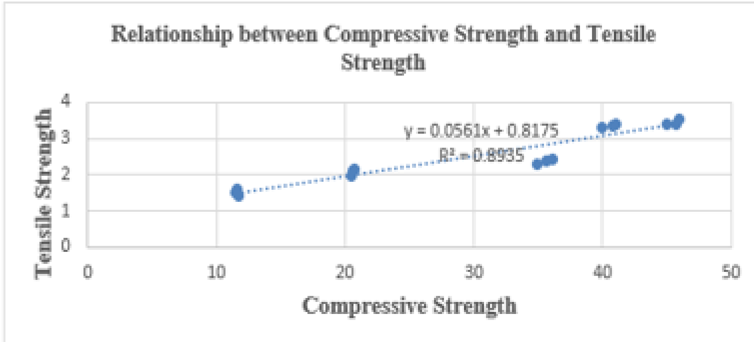

Fig. 4. Relationship between Compressive Strength and Split Tensile Strength

E. Effects of SCBA on Chloride Permeability of Concrete

The effect of the replacement of cement by SCBA partially from 0% to 40% on charge passed by Columbus and chloride permeability of concrete at 28 days curing period is shown in table 7.

Table 7: Chloride Penetration in Concrete Mixes

Type of mix	Charge passed in coulombs	Chloride ion penetrability as per ASTM C1202
RCPT-0	2637.77	Moderate
RCPT-10	1885.61	Low
RCPT-20	1384.64	Low
RCPT-30	2121.05	Moderate
RCPT-40	2823.25	Moderate

From table 7, it can be observed that with partial replacement of cement with bagasse ash of up to 20%, the permeability of concrete is decreasing compared to the controlled concrete. However, beyond 20% of cement replacement with bagasse ash, the permeability of concrete is increasing as compared to the controlled concrete. The decrease in the charge passed with the increase in bagasse ash is mainly because of the pozzolanic effect of bagasse ash that makes the concrete impervious by consuming the calcium hydroxide, which is the main cause of making concrete previously, produced from the hydration of cement. 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 [5] and thus demonstrates that these have a good ability to resist

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chloride ion penetration. It is also expected that with the increase in age when most of the hydration of concrete with bagasse completes, the chloride permeability of concrete will decrease drastically.

F. Effects of SCBA on Carbonation of Concrete

The carbonation test was conducted for various mixes and no carbonation depth was seen for any of the mixes. This indicates that these mixes are not affected by the local environmental conditions. Fig. 5. Shows the concrete cylinders subjected to carbonation test.

Fig. 5. Concrete Cylinders Subject to Carbonation Test

IV. Conclusions and Recommendations

Based on the present experimental investigation carried out, the following conclusions have been made.

- The use of SCBA as a partial replacement of cement in concrete helps in addressing the dumping-related issues of sugar factories and reduces environmental impacts.
- The optimum percentage of SCBA in concrete as a partial replacement of cement in concrete from a strength perspective is found to be 10%.
- Water demand for SCBA blended concrete increases with an increase in the SCBA content.
- With the inclusion of bagasse ash as a cementing material in concrete by up to 20%, the permeability of concrete is decreasing compared to the controlled concrete.
- There is no effect of carbonation in SCBA-based concrete.

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