Waste Reduction and Recycling in Construction: Utilizing Sugar Cane Bagasse Ash as a Cement Replacement Material

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Abstract- The rising cost of living devastates world economies as prices of basic commodities continue to rise. The construction industry is not left out as construction materials like cement, reinforcements, and so on, have witnessed exponential price increases. The study aimed at reducing the cost of concrete by using sugar cane bagasse ash (SBA), a by-product of sugarcane after all useful sugar has been extracted, as an alternative binder for partial cement replacement in concrete. Cement was partially replaced with SBA at an SBA-to-cement percentage of 0%, 5%, 10%, 15%, and 20%. Results show that the highest strengths of $19.74N/mm^2, 28.75N/mm^2$ and $31.34N/mm^2$ for 7 days, 14 days, and 28days curing respectively were obtained from plain concrete, while the least strength of $12.69N/mm^2, 14.69N/mm^2$, and $15.01N/mm^2$ were obtained from concrete containing 20% SBA. Although SBA possesses pozzolanic properties and improves concrete's workability, a continuous increase of SBA in concrete does not guarantee a constant strength increase.

Indexed Terms- Compressive Strength, Concrete, Partial Replacement of Cement, Pozzolan, Sugar Cane Bagasse Ash.

I. INTRODUCTION

Sugarcane is an agro-industrial product that is grown on large hectares of land, the world over. In Nigeria alone, it is grown on about thirty thousand (30,000) hectares of land (Mahesh et al., 2017,Xu et al., 2018). Sugarcane bagasse ash (SBA) is a by-product of sugar factories found after burning sugarcane. Bagasse itself is seen after the extraction of all economic sugar from sugarcane(*Hailu and Biruk 2012*, Olutoge et al., 2015, Shafiq et al., 2018). On average, about 34 tons of bagasse is produced per hectare of land(Davoudi, 2020). The disposal of sugarcane bagasse is already causing environmental problems in sugar factories (*Hailu and Biruk 2012*). These problems include landfill volumes, underground water pollution, global warming, and methane gas emissions, which cause degradation of the ozone layer.

Clinker present in cement is responsible for high emissions of CO_2. Shafiq et al. (2018) opined that cement production is responsible for 5% of global carbon dioxide emissions. There has been over a 50% increase in the cost of cement in Nigeria. This has made the need for alternative binders in the construction industry inevitable.

The use of sugarcane bagasse as a partial replacement for cement has enormous environmental and economic benefits (Berenguer et al., 2020), It can be used for the enhancement of concrete strength as SBA is predominantly silicon dioxide (SiO_2), a chemical compound that has pozzolanic properties, which, when added to concrete, can increase the strength gain with time (Salim et al., 2014). This predominant chemical composition led to the possibility of using SBA as a partial replacement for cement in concrete.
This research investigates the cement mix ratio that will produce optimal concrete strength, with the corresponding quantity of SBA as a partial replacement for cement.

CHEMICAL COMPOSITION OF SBA

Sugarcane bagasse ash is predominantly composed of silicon dioxide. Other chemicals in SBA are alumina, ferric oxide, calcium oxide, and sulphur trioxide. Details are shown in Table I. The pozzolanic properties of SBA react with silicon and alumina present, and calcium oxides in cement(Attah et al., 2020)

Table I: CHEMICAL COMPOSITION OF SBA

S/N	Component	% by Mass
1	Silicon Oxide (SiO_2)	66.89
2	Alumina (Al_2O_3)	29.18
3	Ferric Oxide (Fe_2O_3)	
4	Calcium Oxide (Ca O)	1.92
5	Magnesium Oxide (MgO)	0.83
6	Sulphur Tri Oxide (SO_3)	0.56
7	Loss of Ignition	0.72

Source: Mahesh et al., (2017)

II. MATERIALS AND METHODS

Sample Materials

The materials used for the concrete are Portland limestone cement, fine quartz sand, natural coarse pebble gravel aggregate, and sugarcane bagasse ash (SBA). The coarse aggregates are crushed particles with a particle size between 5mm and 20mm. This coarse aggregate is classified as a small aggregate as shown in Table II.

Table II: SIZES OF COARSE AGGREGATES FOR MASS CONCRETE

S/N	Class and Size	IS Sieve Designation	Percentage Passing
1	Very large, 150 to 80 mm	160 mm	90 to 100
		80 mm	0 to 10
2	Large, 80 to 40 mm	80 mm	90 to 100
		40mm	0 to10
3	Medium, 40 to 20mm	40 mm	90 to 100
		20mm	0 to 10
4	Small, 20 to 4.75 mm	20 mm	90 to 100
		4.75mm	0 to 10
		2.36mm	0 to 0.2

Source: IS-383, (2016)

Sugar cane bagasse was dried and burnt in the open air to produce SBA. Water was also used.

Experimental Process

Concrete of a water/cement ratio of 0.65 was cast into cubes of 100mm x 100mm x 100mm prepared in the mix ratio of 1:2:4 by weight. Cement was then partially replaced with Sugar cane bagasse ash at 5%, 10%, 15%, and 20% as shown in Table III, to test its effect on concrete strength.

Table III: CONCRETE MIX RATIO BY MASS

SBA (g)	CEMENT (g)	SAND (g)	GRAVEL (g)
0	100	200	400
5	95	200	400
10	90	200	400
15	85	200	400
20	80	200	400

The experimental study examined concrete setting time, workability, and compressive strength. The main constituent of concrete was Portland cement, SBA, coarse aggregate, river sand, and water. The maximum compressive strength gained after 7 days, 14 days, and 28 days of curing with the corresponding partial replacement of cement with SBA was noted.

Workability of Concrete Paste

Slump tests were carried out using a slump cone with BS EN 12350-2. Slump cone specimens were cast for each concrete mixture, and the slump or reduction in height of the cone was considered a measure of workability.

Setting Time of Concrete

The Vicat Apparatus was used to investigate the setting time of given cement pastes. A prescribed trial mix of cement pastes of similar consistency was made to investigate the initial and final setting time in the presence of SBA.

Compressive Strength of Concrete

All concrete mixes were cast into concrete cubes. After 24 hours, the cubes were unmoulded and placed in a curing bath. The compressive strength was obtained by crushing the unmoulded concrete cubes at intervals of 7, 14, and 28 days after curing per BS EN 12390. The compressive strength of concrete was determined using Equation 1:

$$S = \frac{P}{A} \quad (1)$$

Where $S =$ Comprehensive Strength,
$P = test\ failure\ load$
$A = surface\ area\ of\ cube$

III. RESULTS AND DISCUSSION

Comparing results obtained from plain concrete (0% SBA) and those of concrete containing SBA, it was observed that the highest strengths of 19.74N/mm2, 28.75N/mm2, and 31.34N/mm2 for 7 days, 14 days, and 28days curing respectively were obtained from plain concrete, while the least strengths of 12.69, 14.69 and 15.01N/nn2 were obtained from concrete containing 20% of SBA as shown in Figure 1. This shows that partial replacement of cement with SBA will not lead to the desired increase in compressive strength (Mahesh et al., 2017).

Table IV: VARIATION IN STRENGTH GAIN OF CONCRETE FOR VARIOUS MIX RATIOS

SBA (g)	Cement (g)	7-day strength (N/mm^2)	14-day strength (N/mm^2)	8-day strength (N/mm^2)
0	100	19.786	31.64	30.66
		19.455	28.83	32.22
		19.968	25.78	31.15
5	95	17.791	21.78	20.127
		16.989	20.011	21.508
		17.972	17.74	18.687
10	90	22.45	21.29	22.28
		22.54	20.46	22.49
		22.36	22.42	21.78
15	85	13.132	19.59	20.011
		12.546	19.662	17.74
		13.76	19.522	22.282
20	80	12.693	14.653	15.01
		11.498	14.162	15.701
		13.873	15.268	14.332

Table V: VARIATION IN SETTING TIME OF CONCRETE

SBA (g)	Cement (g)	Initial Setting Time (min)	Final Setting Time (min)	Slump (mm)
0	100	20	300	20
5	95	22	310	22
10	90	25	320	25
15	85	30	330	24
20	80	43	350	26

Table VI: AVERAGE STRENGTH GAIN OF CONCRETE FOR VARIOUS MIX RATIOs

SBA	Cement	Sand	Gravel	7-days strength $(N/mm$	14-days strength $(N/mm$	28-days strength $(N/mm$
0	100	200	400	19.74	28.75	31.34
5	95	200	400	17.58	19.84	20.11
10	90	200	400	22.45	21.39	22.18
15	85	200	400	13.15	19.59	20.01
20	80	200	400	12.69	14.69	15.01

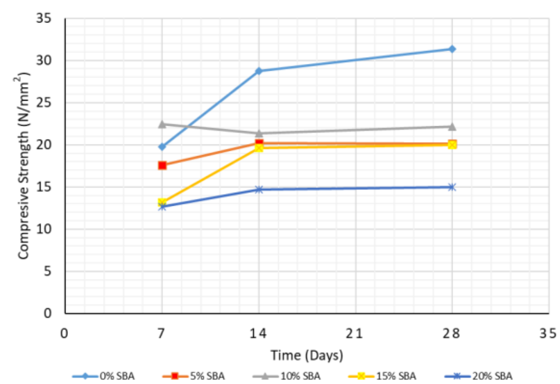

FIGURE I: Variation in strength gain of concrete for various SBA: Cement ratios

CONCLUSION

The determination of the maximum compressive strength gained after 7 days, 14 days, and 28 days of curing with the corresponding partial replacement of cement with SBA did not show an increase in compressive strength. Though SBA possesses pozzolanic properties and improves the workability of concrete, a continuous increase of SBA in concrete does not guarantee an increase in strength.

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