

Performance Evaluation of Ternary Blends of Pulverized Cow Bone Ash and Waste Glass Powder on the Strength Properties of Concrete

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Received: 7 November 2020, Revised: 31 May 2021, Accepted: 7 June 2021

Abstract

The amounts of agricultural waste in cow bone and industrial waste glass in Nigeria have been expanding significantly, thereby increasing the danger to general wellbeing particularly in urban communities. This research examined the suitability of ternary blends of pulverized cow bone ash and waste glass powder (PCBAWGP) equally combined and partially replaced Portland cement in 0, 10, 20, 30 and 40 % percentages in concrete production. Physical and chemical properties were done on the concrete constituent materials. Compressive and tensile strengths of the hardened concrete of grade M20, mix proportion 1:2.17:3.4 were tested after 7, 14, 28, 60 and 90 days. The result of the physical properties uncovered that PCBAWGP had 2.70, 2.05 % and 1364 kg/m³ for specific gravity, moisture content and bulk density, respectively. From the consequences of the compressive strength, it showed that as the curing age of the concrete increases, the compressive strength expanded, the compressive strength outcomes at 10 % PCBAWGP partially replaced concrete is 15.55, 24.15, 19.85, 27.60 and 37.98 N/mm² individually at 7, 14, 28, 60 and 90 days. At 90 days curing age, the tensile strength results for the control mix and 20 % PCBAWGP replacement was 2.72 and 1.88 N/mm², respectively. The concrete strengths improved with concrete age and this was statistically affirmed utilizing ANOVA. This investigation showed that utilizing PCBAWGP in concrete is sustainable thereby reducing the dumped wastes and lessen CO₂ outflows into the atmosphere by diminishing the extent of Portland cement in unit volume of cement produced.

Keywords: Pulverized cow bone ash, Waste glass powder, Ternary blends, Compressive strength, Tensile strength

Introduction

Concrete remains the structural material of choice for most structures and is the absolute most generally utilized material all through the world. Concrete blend is involved coarse aggregates generally rock, fine aggregates typically sand, cement, water, and any important additives. Concrete has numerous positive properties as a building material, among which are its high compressive quality and its property as a heat proof component to an impressive degree [1]. The concrete industry is making strides in its appropriateness execution, and to meet this, cement innovation is progressively moving towards the utilization of reused aggregates [2]. With the significant expense of construction over each country of the world, including Nigeria, where the construction cost is recognized to be the most elevated.

In Nigeria, investigation shows that the expense of cement speaks to a generous portion of the complete construction cost with the yearly utilization of cement put at 19.5 million tons [3]. Nigeria requires 5.070 Trillion Naira at the current pace of 3800 Naira to meet her cement needs alone for concrete creation. This is about 14.96 % of her year spending plan for the 2020 monetary year, making the cost of cement the significant supporter of the significant expense of construction; with the creation of cement expanding every year by about 3 % [4].

The creation of one ton of cement frees around one ton of CO₂ to the climate, as the consequence of de-carbonation of the limestone in the oven during assembling of cement and the ignition of non-renewable energy source [5]. This impact of cement creation on the climate has made the finding for alternative materials to cement mainstream in the most recent many years. Different works have been directed around there, by searching for materials that will absolutely or halfway supplant cement in the construction business; most particularly industrial and agro-based waste materials.

Strong waste generation is one of the significant impedances of the introduction of a perfect and green environment [6]. A great many huge amounts of these wastes are created every day, industrial, domestic and agrarian waste takes an enormous level of these strong waste. Prominent materials, from solid wastes that have been utilized or discovered by scientists to be appropriate as partial replacement for constituent materials in concrete production incorporates: Glass powder [7]; waste glass [8]; pulverized bone [9,10]; rice husk ash [11-13]; plantain peel ash [14]; bone ash powder [15,16]; waste oil palm shells [17]; palm kernel shell [18]; periwinkle shell [19,20]; pulverized snail shell [21,22]; sea shells ash [23]; cassava starch [24]; bamboo leaf ash [25,26]; banana leaf powder [27]; groundnut shell ash [28,29]; and machine crushed animal bones [30]. These materials are either utilized independently or in blend, and for various concrete mix.

Amounts of waste cow bones and waste glass have been rising quickly during the recent decades because of the high increment in industrialization and the extensive improvement in the ways of life. Shockingly, most of these waste amounts are not being reused yet rather deserted causing certain difficult issues, for example, the misuse of characteristic assets and natural contamination [31].

Usage of cow bone ash for civil engineering construction will serve various benefits to the environment. This application will decrease landfills, advance waste organization at little cost, reduce pollution by these wastes and augmentation monetary base of butchers when such wastes are sold, subsequently encouraging more production [32]. Furthermore, cow bone ash production requires less energy demand in contract to Ordinary Portland cement production and recovers the necessary new exchange spent on importation of cement and its fragments [33].

As for concrete creation, waste glass can be utilized as a valuable cementitious material to supplant concrete after being ground. Waste glass powder can take an interest in pozzolanic response [34], which is helpful to the properties of the binder. If the replacement proportion is underneath 20 - 30 %, It can adequately lessen the porosity of concrete [35,36] to improve the quality and toughness [37] yet, if the substitution proportion is more prominent than 20 - 30 %, the strength properties will diminish as the substitution proportion increases [38]. The study of waste glass concrete is still at the starter stage [39] and needs further investigation.

In order to decrease solid wastes and furthermore enhance the garbage to prize activity, the impacts of cow bone ash and glass waste powder as partial replacement of cement in concrete production had been done independently in improving the mechanical properties of concrete by numerous researchers previously. This current study investigates the ternary blends of PCBAWGP and cement on the strength properties of concrete. Realizing that agricultural waste from cow bone, from which the pulverized cow bone ash is inferred and industrial glass waste, in which waste glass powder is framed, directly have no worth and furthermore establishes ecological aggravation, for instance broken glasses can be dangerous and hazardous to the community, similarly cow bone when not well maintained may cause unpleasant odor to the people living in that environment. Thus, the idea is to replace as much of the part of cement used for concrete as possible to save cost and or relief the environment of waste materials, as well, but care must be taken in order not to weaken the strength of the concrete by adding to much PCBAWGP. What will be the effects of PCBAWGP as partial replacement for cement in hardened concrete? This is the basic question about this investigation.

Cow bone ash

The ash of animal bones contains fundamentally of calcium phosphate. For quite a while, bones were the head wellspring of phosphorus and ground bones or bone dining experience is so far used as fertilizer for its phosphorus and calcium substance [15]. Over the world, cow bones comprise environmental issues in abattoirs. The foul smell radiating from groups of cow bones are normally disturbing and unwholesome any place they are unloaded. Cow bones are promptly accessible in Nigeria because of huge number of cows that are being butchered day by day to give meat. Much of the time, the bones from these cows establish squander and dirty the environment [40].

Cow bone ash, is an inorganic material gotten from cow bones, dried outside at an average temperature of 30 °C for 48 h and burnt at an extremely high temperature ranging between 900 to 915 °C in a furnace or consuming in the air and grounded to fine powder utilizing processing machine [41]. In this manner,

using this cow bone ash as a partial replacement of cement in concrete creation will upgrade managerial advancement of the environment [42]. The expense of cow bone ash when contrasted with Portland cement is lower because of accessibility of cow bones in huge amounts as side-effects in numerous abattoirs in Nigeria [42]. The structure of different kind of bone is showed up in **Table 1** underneath.

Table 1 Chemical composition of different bone ashes.

Material	Composition of bone ash				
	Ca	Mg	K	P	CO
Dogfish	37.00	0.58	0.44	16.71	3.23
Goosefish	36.90	0.55	0.56	16.98	3.19
Mackerel	36.74	0.76	0.20	17.42	2.79
Squeteague	35.68	0.12	1.31	16.97	3.11
Frog (common)	36.09	0.72	0.44	16.45	4.67
Bull Frog	36.62	0.61	0.36	16.15	4.11
Amphiuma	36.86	0.51	0.76	15.96	5.34
Siren	36.96	0.57	1.05	16.00	5.73
Turtle	35.68	0.62	0.98	14.88	5.63
Hen	37.24	0.51	-	16.40	5.50
Rabbit	36.25	0.53	0.92	15.99	5.71
Cow	36.05	0.74	0.85	15.43	4.58
Dog	35.66	0.46	1.87	15.56	5.62
Guinea Pig	35.54	0.75	-	15.78	5.03

Source: Studies of the chemical composition of bone ash, Morgulis [43].

Waste glass

Waste glass is considered as a non-decaying material that is bountiful, can be of low financial worth, frequently landfilled and dirties the general environment [8]. Glass is an amorphous material containing 75 % silica (SiO_2), sodium oxide (Na_2O), calcium oxide (CaO) and a couple added substances. It is consistently weak and optically transparent. When grounded to exceptionally fine powder (600 micron) responds with antacid in concrete (pozzolanic response) framing a cementations item that help to add to the quality advancement in concrete creation [44].

Waste glass can be conveyed from void glass jugs and pots. This waste glass is typically squashed into little pieces that take after the measures of rock and sand and can also mill into exceptionally fine particles that looks like cement. Processing of glass to miniature meter scale molecule size, will improve the responses among glass and cement hydrates, which can bring significant energy, ecological and financial advantages when cement is partially replaced with powdered waste glass for creation of concrete [45].

Therefore, an essential of the headway of new advancements is fundamental for the utilization of waste glass. As a torpid construction material, waste glass can build the strength of various construction segments for sustainable public development and decongestion of the environment [46].

Materials and methods

The research experiments were performed inside the Civil Engineering Project Development Centre located inside Federal University Oye- Ekiti, Ikole-Ekiti campus, Ekiti State, (Nigeria, South West Region) on latitude $7^\circ 47' 53.76''$ N and longitude $5^\circ 30' 52.17''$ E.

Sand, crushed granite and Ordinary Portland cement

Locally available sand which conformed to the requirement for concrete production according to BS8110 [47] standard was used as fine aggregate, crushed granite of 20 mm (3/4 inch) particle size for concrete production was used as the coarse aggregate which were readily available in the country. The cement utilized is Dangote Ordinary Portland Cement 3X (42.5 N), which was bought in Ikole Ekiti, Ekiti State, Nigeria.

Cow bone

Cow bone was gotten from various areas as waste inside abattoir in Ikole-Ekiti territory, Ekiti State. The cow bones were washed and freed from any earth or contaminant. The bones were then dried outside for 48 h. The ash was obtained by consuming the cow bones (**Figure 1**) opening at uncontrolled temperature for 24 h and processed in a ball milling machine to get the essential pulverized cow bone ash (PCBA) that was satisfactory for the investigation. The adequate pulverized obtained for the investigation was later sieved through 75 μm and kept in a sack pack to keep it from dampness and whatever other outer effects that can impact its property to meet the necessities of [47,48].



Figure 1 Cow bones before and after undergoing open air burning.

Waste glass

The waste glass materials were gathered in Ikole-Ekiti and processed into fine particles by utilizing ball milling machine as appeared in **Figure 2**. The formed waste glass powder (WGP) was screened through sifter size 75 μm .



Figure 2 Waste glass material before crushing and during crushing inside ball milling machine.

Pulverized cow bone and waste glass powder

The blend of both the PCBA and WGP were gotten by mixing the 2 constituents together in equivalent extent for an hour inside ball milling machine, sieved with strainer number 0.25 mm to obtain pulverized cow bone ash and glass waste powder PCBAWGP. The shade of resulting ash is dark grey as appeared in **Figure 3**.



Figure 3 Mixture of pulverized cow bone ash and glass waste powder in equal ratio.

Water

Consumable water for the study was acquired from simple faucet water, perfect and liberated from polluting influences with pH being 7.5.

Physical and chemical properties of constituent materials

The PCBAWGP have a mean pH of 9.35 (9.1 - 9.6) center. The specific gravity of Ordinary Portland concrete, PCBAWGP, crushed stone and sand are 3.15, 2.70, 2.75 and 2.64, respectively while the bulk density in kg/m^3 are recorded as 1300, 1364, 1660 and 1786 individually. The chemical composition of the constituent components utilized were examined at the chemistry laboratory of the Institute of Agriculture Research and Training (IAR&T), Moor Plantation Ibadan, Oyo State, Nigeria. This was finished by environmental investigations as demonstrated by [49]. The consequences of the chemical composition are stated in **Table 2** and the weight of element composition shown in **Figure 4**.

Table 2 Chemical composition of the concrete constituent materials.

Chemical composition	PCBAWGP	Ordinary Portland cement (42.5 R)	Crushed granite	Sand
Calcium Oxide (CaO)	4.2	62.60	7.114	0.223
Phosphate (P ₂ O)	bdl	bdl	bdl	bdl
Magnesium Oxide (MgO)	1.6	1.74	0.609	2.271
Silicon Oxide (SiO ₂)	83.6	20.34	75.830	81.484
Iron Oxide (Fe ₂ O ₃)	0.5	3.20	4.817	0.497
Aluminium Oxide (Al ₂ O ₃)	1.2	5.09	9.670	12.104
Titanium Oxide (TiO ₂)	0.08	bdl	bdl	bdl
Sodium Oxide (Na ₂ O)	7.3	0.51	5.194	0.356
Potassium Oxide (K ₂ O)	0.2	0.29	8.208	1.091
Sulphate (SO ₃)	0.07	2.19	3.701	2.130
Manganese Oxide (Mn ₂ O ₃)	Bdl	0.007	0.275	0.030
Loss on Ignition (LOI)	0.5	0	2.096	0.697
Moisture (%)	2.05	bdl	0.01	1.14

*bdl: Below detection limit

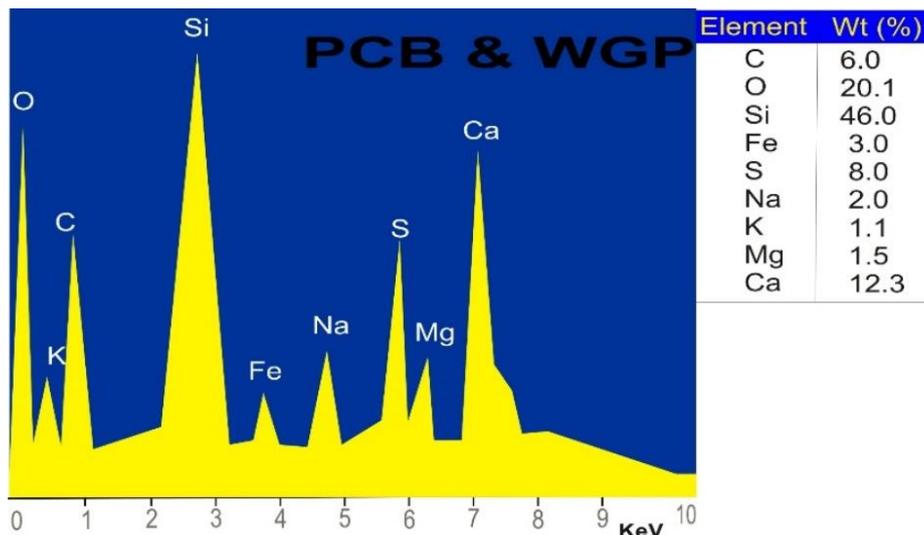


Figure 4 Weight composition of element.

Structure of pulverized cow bone ash and waste glass powder

The SEM images of combined PCBAWGP content obtained is shown in **Figure 5**, the PCBAWGP sample has irregular shaped particles with many micro-pores. Foong *et al.* [50] attributed the porous morphology to the burning out of the organic component and caused higher loss on ignition (LOI) value in the PCBAWGP. Further, Nguyen [51] showed that the quality of ash, is also influenced by the porous structure of the ash particles and the specific surface area. There are also evidences that the rate of cooling affects the particle sizes of PCBAWGP.

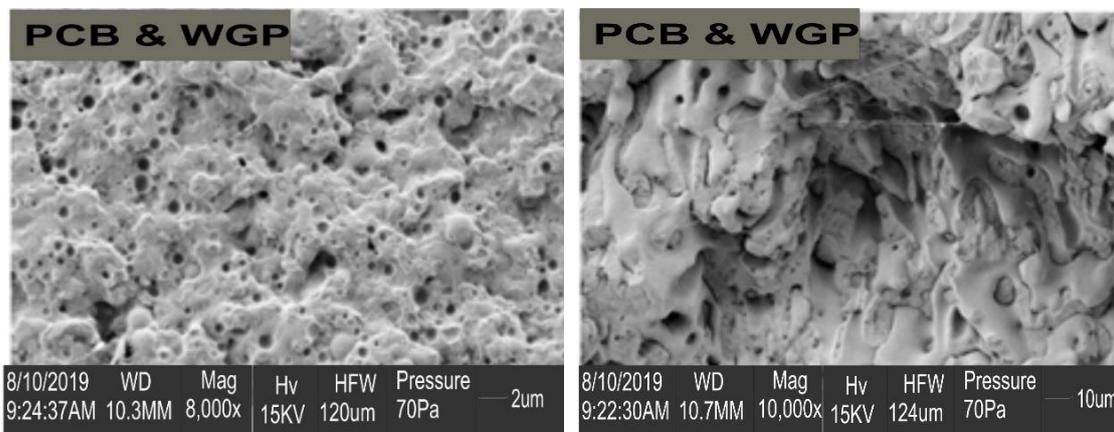


Figure 5 SEM images of PCBAWGP combined.

Laboratory test on concrete specimens

The laboratory examinations on concrete specimens were carried out utilizing the standard hardware in the Civil Engineering laboratory workshop at the Federal University, Oye Ekiti, Ekiti State, Nigeria.

The summary of laboratory examinations carried out are detailed in **Table 3**.

Table 3 Summary of laboratory examinations out on the concrete specimens.

Constituent materials combination	Laboratory examinations
OPC, PCBAWGP, sand, crushed granite	• Specific gravity
0 % PCBAWGP + 100 % cement	• Bulk density
10 % PCBAWGP + 90 % cement	• Workability
20 % PCBAWGP + 80 % cement	• Compressive strength test (7, 14, 28, 60 and 90 days)
30 % PCBAWGP + 70 % cement	• Tensile strength test (7, 14, 28, 60 and 90 days)
40 % PCBAWGP + 60 % cement	• Water absorption test (28 and 90 days)

Concrete mix design

An evaluation of M20 nominal concrete grade of 1:2.17:3.4, Ordinary Portland cement, fine aggregate (sand), and coarse aggregate, alongside water-cement ratio of 0.55 in accordance with IS10262 method [52] was embraced for this study. The constituent concrete materials were clumped by weight for estimation precision. The equivalent extent of the pulverized cow bone ash and glass waste powder combined completely for one-hour inside blender machine to form PCBAWGP. The concrete was set up by partially replaced OPC with PCBAWGP at; 0, 10, 20, 30 and 40 %. The detail of the blend proportioning of concrete constituent materials is presented in **Table 4**. Three concrete cube samples for compressive strength test and 3 cylinder samples for tensile strength test for each mix proportion were created and cured for 7, 14, 28, 60 and 90 days in the curing tank loaded up with fresh water. The average value for each mix proportion were figured and reported.

Table 4 Mix proportions of M20 concrete grade with W/C ratio of 0.55.

% PCBAWGP replacement	Water (kg/m ³)	Mass of constituent materials (kg/m ³)			
		Cement	PCBAWGP	Sand	Crushed granite
0	4.21	7.65	0.000	16.60	26.01
10	4.21	6.90	0.765	16.60	26.01
20	4.21	6.12	1.530	16.60	26.01
30	4.21	5.40	2.295	16.60	26.01
40	4.21	4.59	3.060	16.60	26.01

Results and discussion

Density of concrete specimens

The mean density of concrete samples at various mix proportion extent is shown in **Table 5** and **Figure 6**. The density of the samples went from 2093.52 to 2505.33 kg/m³. This is inside the scope of 2200 to 2600 Kg/m³ indicated as the thickness of ordinary weight concrete [14]. The control mix produced concrete specimen with the highest mean density of 2505.33 Kg/m³, trailed by 20 % PCBAWGP partial replacement with mean density estimation of 2489.70 kg/m³.

Table 5 Mean density of concrete specimens.

% PCBAWGP replacement	Curing period (days)	Mean Density (kg/m ³)	Standard deviation	Range (kg/m ³)	Minimum (kg/m ³)	Minimum (kg/m ³)
0	7	2356.67	5.69	11.00	2352.11	2363.00
	14	2279.00	2.00	4.00	2277.07	2281.06
	28	2505.33	5.86	11.00	2501.20	2512.21
	60	2327.33	15.57	31.00	2311.09	2342.17
	90	2296.33	6.43	12.00	2289.02	2301.01
10	7	2149.11	16.22	28.81	2139.00	2167.81
	14	2212.82	2.03	3.88	2210.53	2214.41
	28	2375.36	4.75	9.02	2369.99	2379.01
	60	2215.19	1.63	3.26	2213.65	2216.91
	90	2435.63	4.44	8.89	2431.11	2444.00
20	7	2250.83	4.88	9.09	2247.32	2256.41
	14	2206.04	2.73	5.20	2203.91	2209.11
	28	2167.34	1.00	1.99	2166.33	2168.32
	60	2489.70	9.62	19.05	2480.97	2500.02
	90	2319.10	4.22	8.42	2314.67	2323.09
30	7	2350.95	15.22	30.22	2336.88	2367.10
	14	2093.52	5.76	10.66	2089.45	2100.11
	28	2350.33	3.96	7.77	2346.01	2353.78
	60	2285.82	6.01	11.86	2279.34	2291.20
	90	2288.19	9.96	19.69	2279.23	2298.92
40	7	2441.53	2.53	5.01	2439.30	2444.31
	14	2096.25	6.36	11.21	2088.91	2100.12
	28	2278.18	4.97	4.97	2276.12	2281.09
	60	2340.85	0.78	1.55	2340.12	2341.67
	90	2425.53	5.42	9.76	2422.01	2431.77

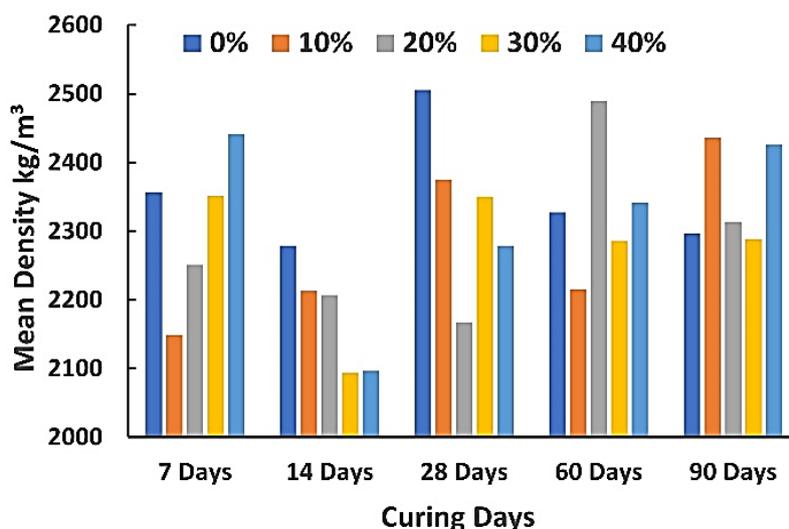


Figure 6 Bar chart showing the mean density of concrete samples at different curing days.

Effect of pulverized cow bone ash and waste glass powder on workability

The concrete workability was carried out in accordance with ASTM C143 [53]. The aftereffects of the slump values as appeared in **Figure 7** uncovered that the PCBAWGP goes about as a retarder, the workability of concrete diminished with expanded in PCBAWGP inferring that the water-cement proportion ratio with increment in level of PCBAWGP. This was maybe because of the state of the particles of the PCBAWGP subsequently influencing the cohesiveness of the concrete mix accordingly and causing collapse slump [54].

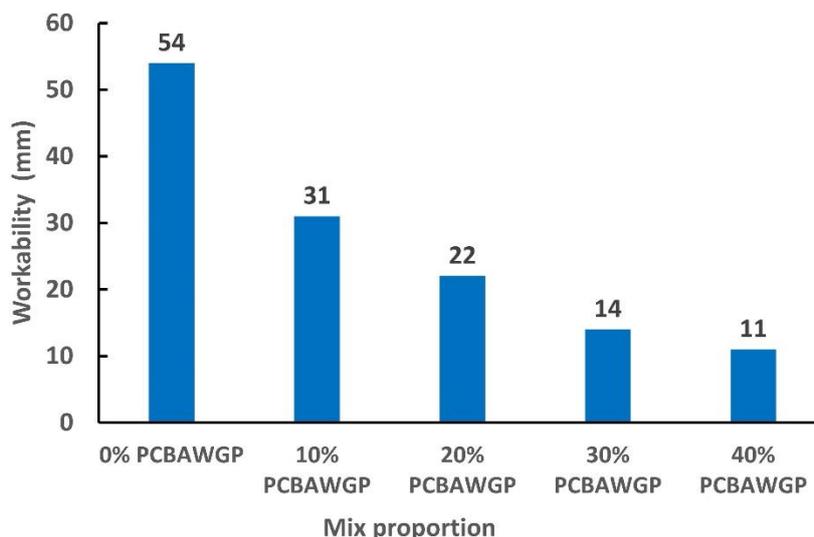


Figure 7 Slump test plot of PCBAWGP as partial replacement for cement in concrete.

Effect of pulverized cow bone ash and waste glass powder on compressive strength

The specified characteristics compressive strength for concrete grade M20 is 17 - 20 N/mm² at 28 days in accordance to ASTM C109 [55]. The compressive strength outcomes acquired for the concrete cube samples are displayed in **Table 6** and **Figure 8**. It was revealed that there was a drop-in strength for all samples containing PCBAWGP at 28days. This drop-in compressive strength can be credited to the decrease of Calcium Oxide (CaO) in the lattice of PCBAWGP because of the decrease in the volume of OPC in the concrete mix [56]. The outcomes additionally showed an improvement in the compressive strength of samples containing PCBAWGP at later age of curing period, with the most satisfactory results acquired at both 10 and 20 % PCBAWGP.

Table 6 Compressive strength of concrete.

% PCBAWGP replacement	Compressive strength of concrete (N/mm ²)				
	7 days	14 Days	28 days	60 days	90 days
0	25.39	23.71	27.23	40.45	45.51
10	15.55	24.15	19.85	27.60	37.98
20	15.40	13.24	18.45	33.52	28.19
30	15.05	13.24	18.69	26.63	20.31
40	6.51	11.77	15.68	14.21	22.31

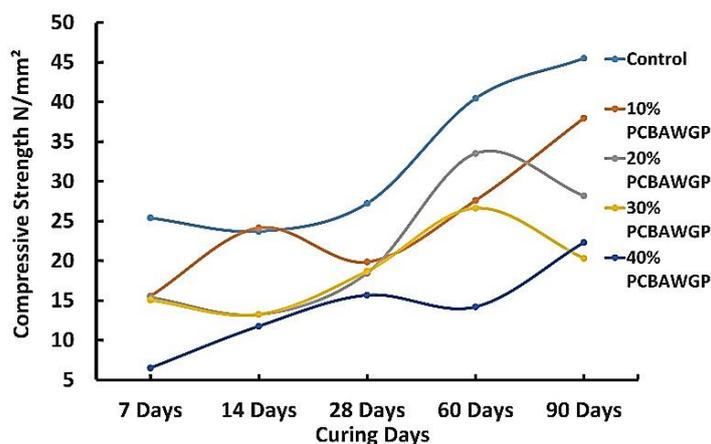


Figure 8 Compressive strength of concrete specimens at different curing days.

Effect of pulverized cow bone ash and waste glass powder on tensile strength

In accordance with ASTM C496 [57], the minimum recommended tensile strength for concrete grade M20 is 1.5 - 2 N/mm² at 28 days. The result, as shown in Table 7 and Figure 9, indicated that samples containing PCBAWGP have tensile strength, not as much as that of the control test. Since tensile strength is to a great extent subject to the bonding capacity of the concrete constituent materials, the decline in tensile strength for samples containing PCBAWGP can be ascribed to the shortfall of the pozzolanic property of PCBAWGP which decreases the volume of OPC and resultantly, the bonding capacity of the concrete mix [58]. The outcomes likewise indicated the tensile strength of samples containing PCBAWGP at 10 and 20 % cement replacement expanded progressively and within the recommended tensile strength for concrete grade M20.

Table 7 Tensile strength of concrete.

% PCBAWGP replacement	Tensile strength of concrete (N/mm ²)				
	7 days	14 days	28 days	60 days	90 days
0	1.46	1.21	2.18	1.93	2.72
10	1.08	1.62	1.71	1.97	2.19
20	0.71	0.76	1.24	1.88	1.88
30	0.81	0.90	1.17	1.56	1.38
40	0.38	0.82	0.70	1.06	1.55

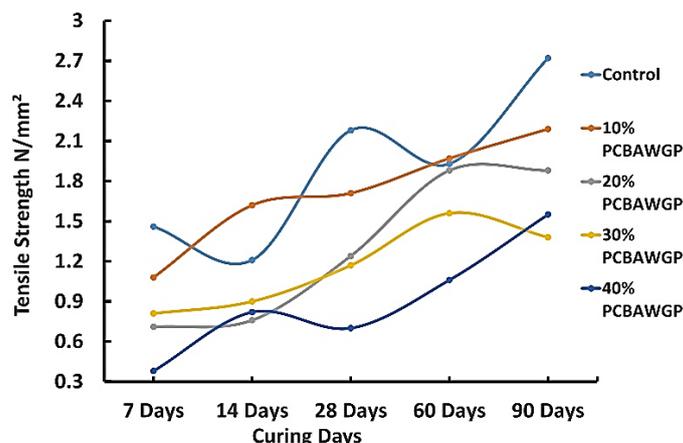


Figure 9 Tensile strength of concrete specimens at different curing days.

Analysis of variables (ANOVA)

A single direction ANOVA investigation was utilized to communicate the contrasts between the recommended compressive and tensile strengths and those acquired from the research tests at 28 days and 90 days for the various mix ratios.

Tables 8 to 10 showed the consequences of the analytical investigation for both compressive and tensile strength. From the outcomes acquired, it is seen that F has been more noteworthy than F_{crit} always. This shows that the mean of the results is not equivalent and that there is a significant evidence between the recommended compressive and tensile strengths and those acquired from the distinctive mix ratios. The aftereffect of the investigations consequently demonstrates that PCBAWGP is fundamentally sufficient for concrete production.

Table 8 Compressive and tensile strengths for the different mix proportions.

% PCBAWGP replacement	Compressive strength (N/mm ²)			Tensile strength (N/mm ²)		
	Recommended	28 days	90 days	Recommended	28 days	90days
0	20	27.23	45.51	2	2.18	2.72
10	20	19.85	37.98	2	1.71	2.19
20	20	18.45	28.19	2	1.24	1.88
30	20	18.69	20.31	2	1.17	1.38
40	20	15.68	22.31	2	0.70	1.55

Table 9 Summary output of Anova for compressive strength.

Groups	Count	Sum	Mean	Variance
Recommended	15	300	20	0
28 days	15	299.73	19.982	16.09917
90 days	15	462.98	30.86533	97.91526

ANOVA						
Source of Variation	SS	df	MS	F	p-value	F crit
Between Groups	1182.514	2	591.2568	15.55742	8.7926E-06	3.219942
Within Groups	1596.202	42	38.00481			
Total	2778.716	44				

Table 10 Water summary output of Anova for tensile strength.

Groups	Count	Sum	Mean	Variance
Recommended	15	30	2	0
28 days	15	21	1.4	0.264586
90 days	15	29.22	1.948	0.251989

ANOVA						
Source of Variation	SS	df	MS	F	p-value	F crit
Between Groups	3.31504	2	1.65752	9.626031	0.000362	3.219942
Within Groups	7.23204	42	0.172191			
Total	10.54708	44				

Water absorption test

Water absorption test on concrete are directed to decide durability property of concrete, such as level of consuming, strength and conduct of concrete in weathering. A concrete with water assimilation of under 7 % gives better protection from harm from freezing [59]. The degree of preservation of concrete can be gotten by water absorption test, as water is consumed by pores in concrete. The water absorption test was carried out in accordance with BS 1881 [60] and the aftereffect at 28 and 90 days is displayed in **Table 11**

and **Figure 10**, from the outcomes, it is very clear that all the concrete samples containing PCBAWGP built up a superior protection from harm by freezing as their results were all under 7 % recommendation.

Table 11 Water absorption of concrete at 28 days and 90 days.

% PCBAWGP	Time (h)	28 days			90 days		
		Dry (kg)	Wet (kg)	% Change	Dry (kg)	Wet (kg)	% Change
0	12	2.21	2.36	6.79	2.30	2.48	7.83
10	12	2.21	2.34	5.88	2.34	2.46	5.13
20	12	2.07	2.24	8.21	2.17	2.32	6.91
30	12	2.37	2.53	6.75	2.34	2.42	3.41
40	12	2.02	2.16	6.93	2.18	2.30	5.50

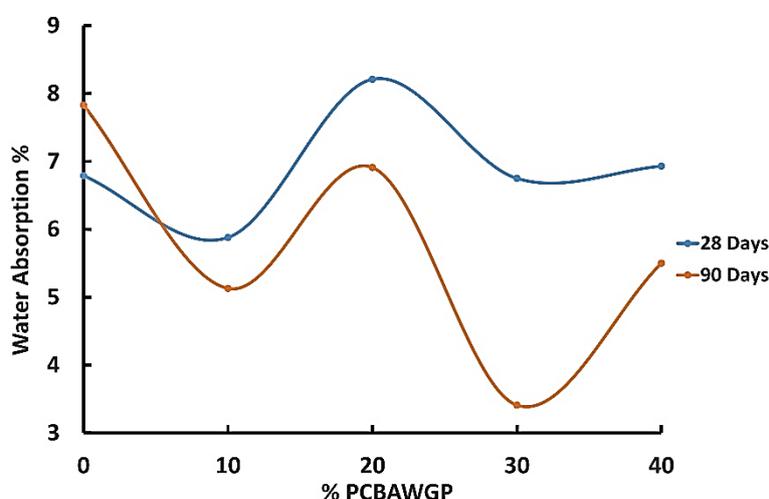


Figure 10 Water absorption of concrete samples at 28 and 90 days.

Production comparative cost analysis

After determining the structural adequacy of PCBAWGP as partial replacement of cement in concrete, it is also quite important to determine its economic advantage. In order to carry out the production comparative cost analysis, sample of PCBAWGP at 10 and 20 % partial replacement is used. The 10 % PCBAWGP content contains compressive strength of 19.85 N/mm² and 37.98 N/mm² while 20% PCBAWGP content contains compressive strength of 18.45 and 28.19 N/mm² at 28 and 90 days respectively as against 27.23 and 45.51 N/mm² at 28 and 90 days, respectively for the control mix. The production comparative cost of the concrete used in this study is derived from the cost of each of the concrete constituents as shown in **Tables 12** and **13**.

Table 12 Production comparative cost analysis per cubic meter.

S/N	Materials	Quantity (kg)	Unit cost (naira)	Total cost (naira)
1	Cement	345.00	76000/1000 kg	26220.00
2	Fine aggregate (sand)	784.00	16000/5000 kg	2508.80
3	Coarse aggregate (granite)	1170.00	30000/5000 kg	7020.00
4	10 % PCBAWGP	34.50	20/kg	690.00
5	20 % PCBAWGP	69.00	20/kg	1380.00

Table 13 Summary of production cost analysis per cubic meter.

Sample	Production cost (naira)	Production cost reduction (naira)	Production cost reduction (%)
Control	35748.80	0.00	0.00
10 % PCBAWGP + 90 % cement	33816.80	1932.00	5.40
20 % PCBAWGP + 80 % cement	31884.80	3864.00	10.80

From **Table 13**, it can be seen that there are benefits to be derived by the use of PCBAWGP, at 20 % cement replacement. The cost reduction is about 10.80 % per m³.

Conclusions

The effect of ternary blend of pulverized cow bone ash and waste glass powder (PCBAWGP) as partial replacement for cement in concrete was studied. The research revealed that the PCBAWGP acted as a retarder in the concrete. The percentages of replacement of cement of 10, 20, 30 and 40 % of PCBAWGP considering M20 grade yielded average compressive strengths in N/mm² ranging from 15.68 - 37.98. This indicates that the compressive strength of concrete reduces as % PCBAWGP increases. The compressive strength generally increases with increase in age of curing. The minimum and maximum compressive strength of concrete at 10 and 40 % PCBAWGP content for 1:2.17:3.4 concrete mix ratio at 28 and 90 days curing age are 19.85, 37.98 N/mm² and 15.68, 22.31 N/mm², respectively. Concrete containing PCBAWGP contents up to 20 % as partial replacement for cement, fulfills the strength required for normal concrete. The minimum and maximum tensile strength of concrete at 10 and 40 % PCBAWGP at 28 and 90 days curing age are 1.71, 2.19 N/mm² and 0.70, 1.55 N/mm², respectively. The result of the water absorption tests at 28 days and 90 days showed that concrete samples containing PCBAWGP built up a superior protection from harm by freezing as their outcomes were less than 7 % recommendation. From the production comparative cost analysis, concrete with PCBAWGP content, as partial substitution for cement, is cheaper than conventional concrete of equivalent strength.

In summary, utilization of PCBGW as partial replacement of cement in concrete production gives extra natural advantages, as it provides a substitute and compelling answer for the removal of agricultural and industrial wastes.

Acknowledgements

The authors gratefully acknowledge the support given by Tertiary Education Trust Fund (TET Fund) of Nigeria for the support and help that leads to this publication.

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