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A Study on The Properties of Concrete Containing Blends of Bamboo Leaf Ash and Corncob Ash as Partial Cement Replacement

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Abstract

This study investigates the engineering properties of concrete produced using blends of bamboo leaf ash (BLA) and corncob ash (CCA) as partial replacements for cement. The research aims to explore sustainable alternatives to conventional Portland cement, addressing both environmental and economic challenges associated with cement production. Bamboo leaves and corncobs were collected, processed, and calcined under controlled temperatures between 600°C and 700°C to produce fine pozzolanic ashes. Experimental investigations were carried out with five replacement levels: 0%, 5%, 10%, 15%, and 20% of cement substituted with a blend of BLA and CCA in the ratio of 1:1. Tests such as slump, compressive strength, flexural strength and water absorption were conducted to evaluate the workability and mechanical performance of the concrete. The results showed that the slump values decreased with increasing ash content, indicating a reduction in workability though within medium slump ranges. The compressive strength increased with increase in the ash content with optimal performance observed when the blend is used to replace 10% of the ordinary portland cement (OPC). Also, the concrete containing blends of BLA and CCA was observed to continue to gain a more significant strength beyond 28 days than concrete containing no blend of BLA and CCA. This was observed at 60 days as the concrete containing 10% replacement has a percentage increase of 7.81% in its compressive strength from the 28-day strength as against the concrete with 0% replacement which only has a percentage increase of 2.16%. The flexural strength followed similar trend as the compressive strength. At 28 days, the 10% replacement showed the best performance in flexural strength among the ash-modified mixes, exceeding the flexural strength of the control mix by 26.3%. The water absorption of the concrete reduced with increase in ash content up to the optimum value due to better filler effect that refined more pores and started to increase thereafter due to more pozzolans being unreacted hence occupying free spaces and increasing porosity. The findings demonstrate that incorporating blend of BLA and CCA as partial cement replacements at optimal levels enhances the mechanical performance and sustainability of concrete.

1.0 Introduction

The environmental impact occasioned by the continual production of ordinary Portland cement (OPC) has necessitated research into supplementary cementitious materials which are derived from agricultural and industrial wastes. The manufacturing of cement contributes significantly to the release of greenhouse gases which cause pollution to the environment, hence, sustainable alternatives such as bamboo leaf ash (BLA) and corn cob ash (CCA) are rapidly being investigated for concrete production [1, 2]. Due to their high silica content, agricultural waste ashes have demonstrated pozzolanic properties, making them suitable for partial replacement of cement in concrete production [3, 4]. Bamboo is a tree found majorly in tropical regions of the world. Bamboo leaf ash (BLA) is obtained through the controlled combustion of bamboo leaves into fine ashes. Studies have confirmed that BLA has appreciable quantities of reactive silica capable of undergoing pozzolanic reactions with calcium hydroxide released during cement hydration [5, 6, 7]. According to [8], concrete containing BLA exhibited an improvement in the later-age compressive strength and showed a reduced permeability due to the formation of

additional calcium silicate hydrate (C–S– H). Similarly, incorporating BLA at moderate replacement levels improved durability properties and maintained acceptable workability characteristics as reported by [9]. Other studies done by some researchers have examined the microstructural and mechanical behavior of BLA-blended concrete. [10] reported that BLA improved the pore structure and long-term strength development of high-performance concrete. [11] further confirmed that optimum replacement levels ranging from 5% to 15% produced impressive compressive strength, while higher replacement levels caused reduction in strength due to insufficient cementitious compounds. On the other hand, corn cob ash (CCA) has attracted also considerable interest as a sustainable material for partial replacement of cement because of its abundance as agricultural waste. [12] reported that if CCA is properly processed, it possesses significant pozzolanic compounds and can effectively contribute to enhanced concrete performance. According to [13], improved resistance to water penetration and reduced heat of hydration was demonstrated by CCA-blended concrete when compared with conventional concrete. In a similar manner, [14] stated that the addition of agro-waste as a replacement of fine aggregate contributed to improved sustainability in concrete production and lowers environmental pollution. Several studies have reported and emphasized the environmental and economic benefits associated with the use of agricultural waste in concrete. [15] reported that the use of agro-waste in concrete can minimize waste disposal problems, reduce cement consumption, and lower cost of construction. Likewise, [16] further reported that improved durability performance and reduced environmental degradation associated with agricultural waste accumulation can be obtained using corn cob ash in concrete. [17] highlighted also that agricultural ashes can reduce water absorption by refining the pore structure of concrete and enhance sulphate resistance. Durability performance of concrete containing agricultural waste ashes have also received notable research attention. Agro-waste ash blended concrete exhibited lower permeability and improved resistance to aggressive environmental conditions [18]. [19] stated that pozzolanic reactions from agro-waste ashes refine the internal pores of concrete, thereby enhancing strength and durability. Similarly, [20] found that when optimum replacement percentages were adopted, concrete produced using agricultural waste ash demonstrated satisfactory mechanical properties. Despite the numerous studies on the separate use of BLA and CCA as cementitious materials, limited research has focused on the combined utilization of both ashes as blended cement replacement materials. The combined use of BLA and CCA may produce synergistic effects by balancing both their chemical composition and particle characteristics. [21] emphasized that improved sustainability and optimized concrete performance may be obtained by combining agricultural waste ashes. [22] further suggested that using blended agro-waste ashes has significant potential for producing eco-friendly concrete suitable for sustainable construction applications. Therefore, investigating the properties of concrete produced using a blend of bamboo leaf ash and corn cob ash as partial replacement for cement is essential for determining its strength characteristics, workability, water absorption, and durability performance. The study will contribute significantly to sustainable construction practices, effective agricultural waste management and environmental conservation.

2.0 Materials and Methods

A brief description of the materials and methods used in this study are shown below:

2.1 Materials

Ordinary Portland Cement(OPC)

The cement used in this research is Ordinary Portland Cement (OPC), Grade 42.5R, which conforms to Nigerian Industrial Standard (NIS 444-1:2003) and BS EN 197-1:2011. This cement is commonly used in construction due to its high early strength and good durability.

Coarse Aggregate

The coarse aggregate used in this study consisted of crushed granite obtained from a local quarry in Okigwe. Imo State. The aggregate was cleaned to remove dust, dirt, and other impurities before use. A sieve analysis was carried out to determine the particle size distribution and ensure compliance with the requirements of BS 882:1992. Additional tests, including specific gravity, water absorption, and aggregate crushing value, were performed to evaluate the quality and strength characteristics of the coarse aggregate. These tests ensured the material's suitability for concrete production.

Fine Aggrerate

The fine aggregate used was river sand, which was sourced from a local supplier. The sand was tested to ensure it was free from organic impurities and excessive silt content. A sieve analysis was conducted to determine the particle size distribution, ensuring compliance with BS 882:1992 standards.

Bamboo Leaf Ash (BLA)

The bamboo leaves used were harvested locally from the bamboo trees in the farms at Federal University of Technology Owerri. They were then thoroughly washed to remove dust and impurities and air-dried to eliminate moisture. The dried leaves were then burnt under controlled conditions in a furnace at temperatures between 600° and 700°C. The resulting ash was allowed to cool, sieved through a 75 μm sieve to obtain a fine powder used in this study. The sample of the BLA is shown on Fig. 1.

Corn Cob Ash (CCA)

The Corn Cobs were sourced from local maize farms and market women who carry out corn shelling for commercial use of the grains. The cobs were washed thoroughly to remove sand and other impurities. It was then sun-dried to remove moisture. Thereafter, the Corn cobs were burnt at controlled temperatures between 600°C and 700°C in a furnace. After cooling, the ash produced was ground to fine powder and subsequently sieved using a 75 μm sieve to obtain fine powder particles used in this study. Figure 2 shows sample of the Corn Cob ash.

Water

Potable underground water sourced from a well in Federal University of Technology Owerri was used in this study. The water was stored temporarily in neat plastic reservoirs for few hours.

2.2 Methods

2.2.1 Concrete Mixing

Concrete mixes were prepared using a mix ratio of 1:2:4 (binder: fine aggregate : coarse aggregate), and water-cement ratio (w/c) of 0.6. Replacement levels of cement with ash (BLA + CCA) were 0, 5, 10, 15, and 20% by weight of cement. The mix ratio of BLA and CCA was 1:1.

Materials were batched by weight and concrete was mixed manually. Dry ingredients (cement/bamboo leave ash/corn cob ash, fine aggregate, and coarse aggregate) were first mixed to obtain a very homogenous mixture, water was then added gradually and mixing continued until a uniform pasty mixture was achieved.

2.2.2 Workability

Ater mixing, the slump test was carried out to determine the workability of the concrete. This was done in accordance with BS EN 12350-2:2019 with a metal mold in the shape of a truncated cone (slump cone) with the following dimensions: (i) Bottom diameter: 200 mm (ii) Top diameter: 100 mm (iii) Height: 300 mm, a flat non-absorbent base plate to support the cone, a tamping steel rod, 16 mm in diameter and 600 mm in length with a hemispherical end, a steel tape or measuring the slump. The slump cone and the base were cleaned, the inside of the cone was made wet to ensure non sticky nature and the cone placed on a flat, non-absorbent surface. Thereafter, the cone was filled with the concrete in three layers with each layer compacted with 25 blows using the tamping rod and allowing the rod to penetrate slightly into the layer below. When tamping of the third layer was completed, the top was levelled by striking off excess concrete. The cone was then carefully lifted vertically and the difference between the original height of the cone and the highest point of the slumped concrete was measured using a meter rule to determine the slump.

2.2.3 Compressive and Flexural Strength

Standard concrete cube molds of 150mm x 150mm x 150mm were used for the compressive strength test while cubiod mould of 100mm x100mm x 450mm were used to produce the beams used for the flexural strength test. The fresh concrete was placed in three layers in the molds, each layer compacted with a tamping rod making 30 strokes per layer. The surface was leveled and smoothed. A total number of 30 cubes were produced while 20 cuboids were produced. Figure 3 shows the sample of the cubes and beams being cast.

Specimens were left in the molds to set for 24 hours at room temperature and then demolded. After demolding, the specimens were weighed and the masses recorded. They were thereafter submerged for curing in a water tank at 20°C until the testing age (14 and 28 days). Upon completion of the curing period, the cubes were brought out from the curing tank, allowed to dry, and subsequently tested.

For the compressive strength, the cubes were placed in the universal testing machine and load applied gradually vertically until failure. Three cubes were tested for each sample set and the average crushing load was used. The compressive strength was calculated using the formula given in Eq. 1.

$$F_c = \frac{P}{A} \, . \tag{1}$$

Where:

$$P = \text{Average crushing load}$$

$$A = \text{ Cross sectional area of the cube}$$

Fror the flexural strength test, the Universal testing machine was used. This was achieved by the third point loading method. The bottom rollers of the flexural testing device were placed at 75mm mark from both ends of the beam, creating a span of 300mm. the two top rollers were then placed on top of the beam, such that they act at the ends of the middle third portion of the beam span. This means the distance between the two top rollers is 100mm and each is also 100mm away from the bottom roller closer to it. Loading is then gradually applied through the top rollers until the beam cracks. The flexural strength was then calculated using the formula given in Eq. 2.

$$R = \frac{PL}{bd^2} \, . \tag{2}$$

Where:

$$P = \text{Maximum applied load}$$

$$L = \text{ Span of the beam}$$

$$b = \text{ Width of the beam}$$

$$d = \text{ Depth of the beam}$$

2.2.4 Water Absorption

To assess the porosity of the hardened concrete specimens, a water absorption test was conducted after the designated curing period. This provides insights on the concrete's susceptibility to water damage and its overall durability. The procedure involved measuring the initial weight of samples after oven drying, then submerge the sample fully in water for 24 hours, thereafter, remove the sample and wipe dry, then measure the final weight of the sample. The water absorption was then calculated as the percentage increase in weight compared to the initial weight.

3.0 RESULTS AND DISCUSSION

3.1 Workability

The slump values of the fresh concrete are as presented on Table 1, while Fig. 4 shows a graph of the slump against the percentage replacement of cement with CCA + BLA.

Table 1
Slump values for different percentage replacement.

S/N	Replacement (%)	Slump (mm)
1	0	82
2	5	78
3	10	75
4	15	71
5	20	65

The slump test results indicate a decreasing trend in workability with increasing percentages of bamboo leaf ash and corn cob ash replacement. The slump values ranged from 65 mm to 82 mm, indicating medium slump whose workability is suitable for reinforced concrete applications according to ASTM C143.

The control mix (0%) had the highest slump (82 mm), showing maximum ease of flow, while increasing the ash content generally reduced workability, with slump values decreasing progressively to 65 mm at 20% replacements. This reduction can be attributed to higher water demand due to the increased surface area of the pozzolanic ash.

3.2 Compressive strength

Table 2 shows the average compressive strength value gotten from the different blends of CCA and BLA at 14, 28 and 60 days.

Table 2
Compressive strength values for different percentage replacement.

% Replacement (CCA + BLA)	Average Compressive Strength (N/mm²)		
	14 days	28 days	60 days
0% (100% Cement)	21.26	24.08	24.60
5% (2.5% CCA + 2.5% BLA)	20.75	24.59	25.58
10% (5% CCA + 5% BLA)	19.15	25.85	27.87
15% (7.5% CCA + 7.5% BLA)	18.86	22.70	23.76
20% (10% CCA + 10% BLA)	17.52	20.42	21.35

The compressive strength test was done in accordance with BS EN 12390-3:2019 using a universal testing machine with a capacity of 1000 KN.

Figure 5 shows a plot of the graph of compressive strength against percentage replacement of cement with blends CCA and BLA.

At 14 days, the strength values generally decreased with increasing ash content with a least value of 17.52 MPa occurring at 20% replacement and the highest value of 21.26 Mpa occurred with the control (0% replacement).

The reduction at higher replacements is attributed to the lower cement content coupled with slower pozzolanic reaction of the ashes and lower heat of hydration as pozzolans generate lesser heat than OPC. These factors limit early strength gain. However, at 28 days, it was observed that the strength increased to an optimum value of 25.85 Mpa at 10% replacement and then decreased at higher values of replacement. This gain in strength at later day could be attributed to the formation of C-S-H gel from the pozzolanic reaction of the ashes as they use up the Calcium hydroxide ($Ca(OH)_2$) produced during cement hydration. Also, at higher values of replacement beyond 10%, the reduction in strength could be attributed to insufficient Calcium hydroxide available for pozzolanic reaction with the pozzolans due to reduced cement content undergoing hydration. Thereby, making the excess pozzolans act just like an inert filler instead of an active binder. Also, reduced workability due to stiffer mix with increased ash content affects compaction adversely and this could contribute to reduced strength. At 60 days, strength increased progressively in all mixes but with the least increase in the control mix with a percentage increase of 2.16% and the highest percentage increase was recorded at 10% replacement with a value of 7.81%. This is due to continued pozzolanic activity at later dates associated with the ashes.

3.3 Flexural strength

The result of the flexural strength test is given in Table 3 and the graph of flexural strength against percentage replacement of the cement with different blends of CCA and BLA is as shown in Fig. 6.

Table 3
Flexural strength values for different percentage replacement.

% Replacement (CCA + BLA)	Average Flexural Strength (N/mm²)		
	14 days	28 days	60 days
0% (100% Cement)	2.57	3.76	3.99
5% (2.5% CCA + 2.5% BLA)	2.23	3.98	4.21
10% (5% CCA + 5% BLA)	2.04	4.75	4.96
15% (7.5% CCA + 7.5% BLA)	1.86	3.42	3.84
20% (10% CCA + 10% BLA)	1.40	2.86	3.35

The flexural strength followed similar trend like the compressive strength. The flexural strength decreased at 14 days as ash content increased, with the lowest value being 1.40 MPa at 20% replacement. This early-age strength reduction is due to reduced cement content and slow pozzolanic reactions. By 28 days, all mixes gained strength, and the 10% replacement showed the best performance among the ash-modified mixes, exceeding the flexural strength of the control mix by 26.3%. This increase in strength at higher pozzolanic content is due to increased reaction of the pozzolans with Calcium hydroxide released from the hydration of cement. At higher values of ash addition above the optimum value of 10%, there was a reduction in flexural strength. This is attributed to excess pozzolans in the matrix, hence some acting as inert fillers instead of binders, and not having enough calcium hydroxide to react with due to reduced cement hydration as cement content is low. Also reduced workability at higher ash content which affects compaction could be another reason for reduced strength. Flexural strength generally increased at 60 days with more increase on concrete containing ashes due to continued pozzolanic reactions.

3.4 Water absorption

The water absorption result is presented on Table 4 and the graph of water absorption in percentage against the percentage replacement is shown on Fig. 7.

Table 4
Water absorption values for different percentage replacement.

% Replacement (CCA + BLA)	Water Absorption at 28 Days (%)
0	3.10
5	2.67
10	2.05
15	2.75
20	3.54

The water absorption was observed to decreased with increase in ash content up to the optimal value of 10% and then decreased at replacement higher than the optimal value. The reduction in water absorption could be attributed to the filler effect of the ashes, thereby making more pores to be refined, hence improving particle packing and reducing pore connectivity. However, at higher value of ash replacement above the optimal value, the increase in water absorption could be attributed to having excess unreacted pozzolan particles which creates incomplete reactions that results to increase in porosity and weaker bonding.

4.0 Conclusion

The following conclusions can be drawn from the study:

1. Based on the experimental results, a blend of Bamboo Leaf Ash (BLA) and Corncob Ash (CCA) as partial replacement to ordinary Portland cement can improve the compressive and flexural strengths of the concrete, hence, can serve as suitable supplementary cementitious materials when properly processed.
2. The optimal performance was obtained when the blend is used to replace 10 percent of the OPC. Also, the BLA and CCA are mixed in equal proportions to form the blend.
3. The incorporation of a blend of BLA and CCA generally reduces the workability of fresh concrete due to increased water demand. However, all mixes remained within medium workability range, suitable for reinforced concrete applications.
4. Strength development continued to improve beyond 28 days, more significantly for concrete that contained blends of BLA and CCA, with highest improving seen in the concrete with the optimal replacement of 10%. This confirms ongoing pozzolanic reaction at later days.
5. The addition of blends of CCA and BLA in concrete up to the optimal value can reduce the water absorption of the concrete, thereby, indicating that durability is not compromised at moderate replacement levels.
6. The combined use of BLA and CCA to produce blends used as partial replacement to OPC has no adverse effect from the reaction between both ashes but offers a practical approach to reducing cement consumption, lowering construction costs, and promoting sustainable waste management. This supports the potential adoption of agricultural waste ashes in eco-efficient concrete production.

Declarations

Funding

No funding was received for this study.

Clinical trial number

Not applicable

Ethics Approval

Not applicable

Consent to participate.

Not applicable

Consent for publication.

Not applicable

Competing interest

No competing interest is declared by the authors.

Data Availability

The data for this study will readily be made available upon request by the corresponding author.

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Figures



Figure 1

Bamboo Leaf Ash



Figure 2

Corn Cob Ash



Figure 3

Cubes and Beams produced using blends of CCA and BLA

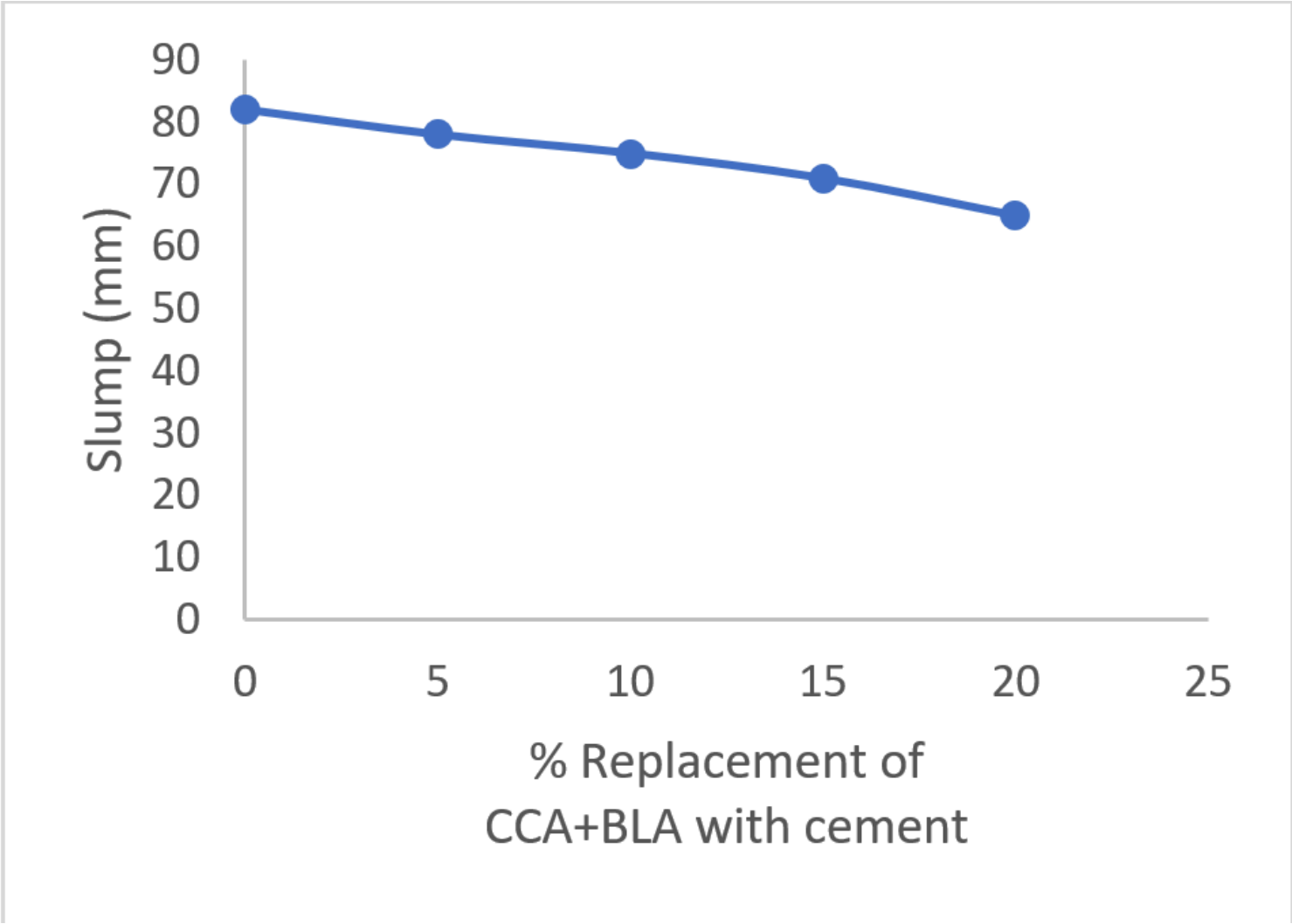


Figure 4

Slump values of the concrete mix

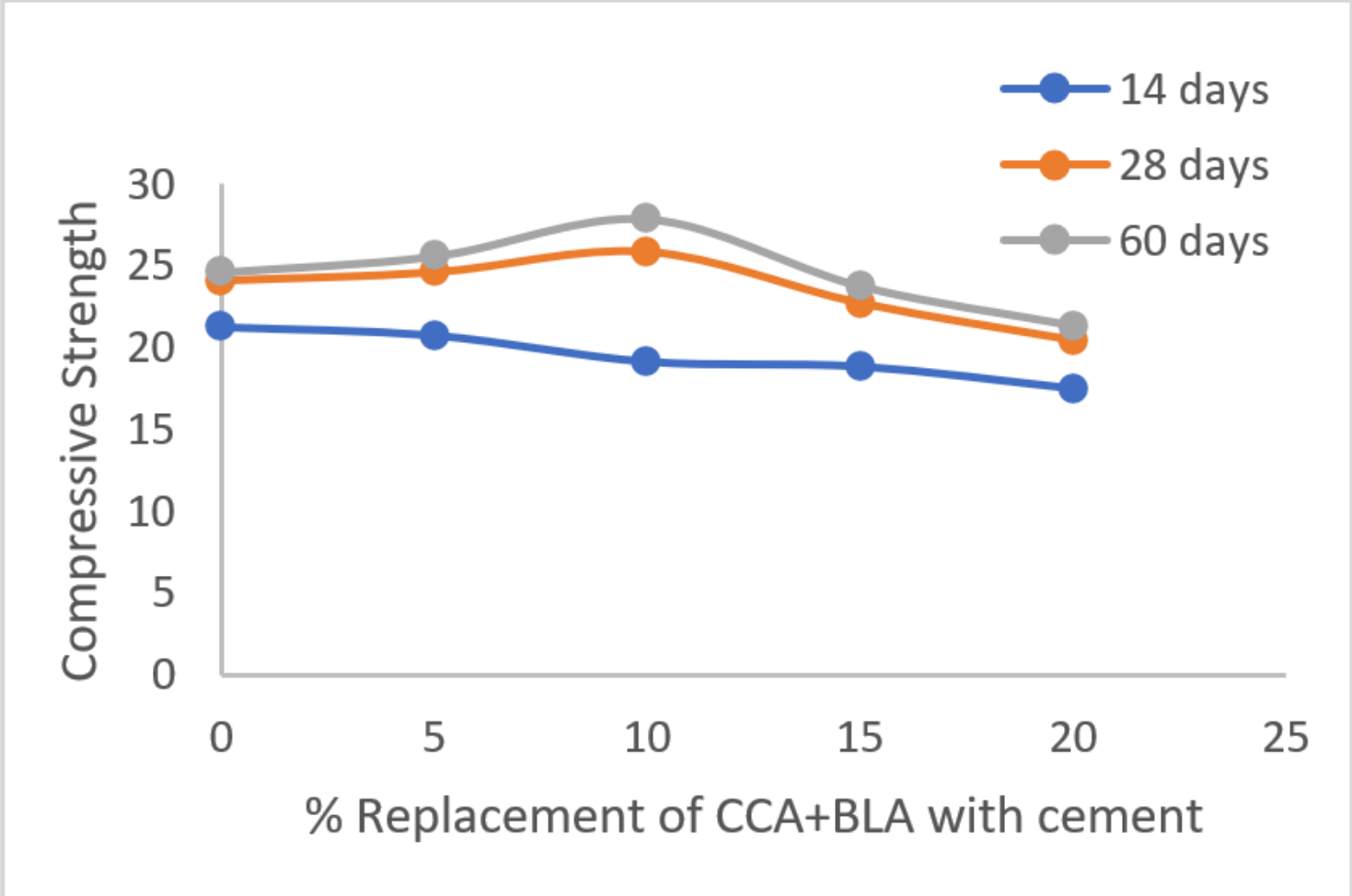


Figure 5

Compressive strength of concrete.

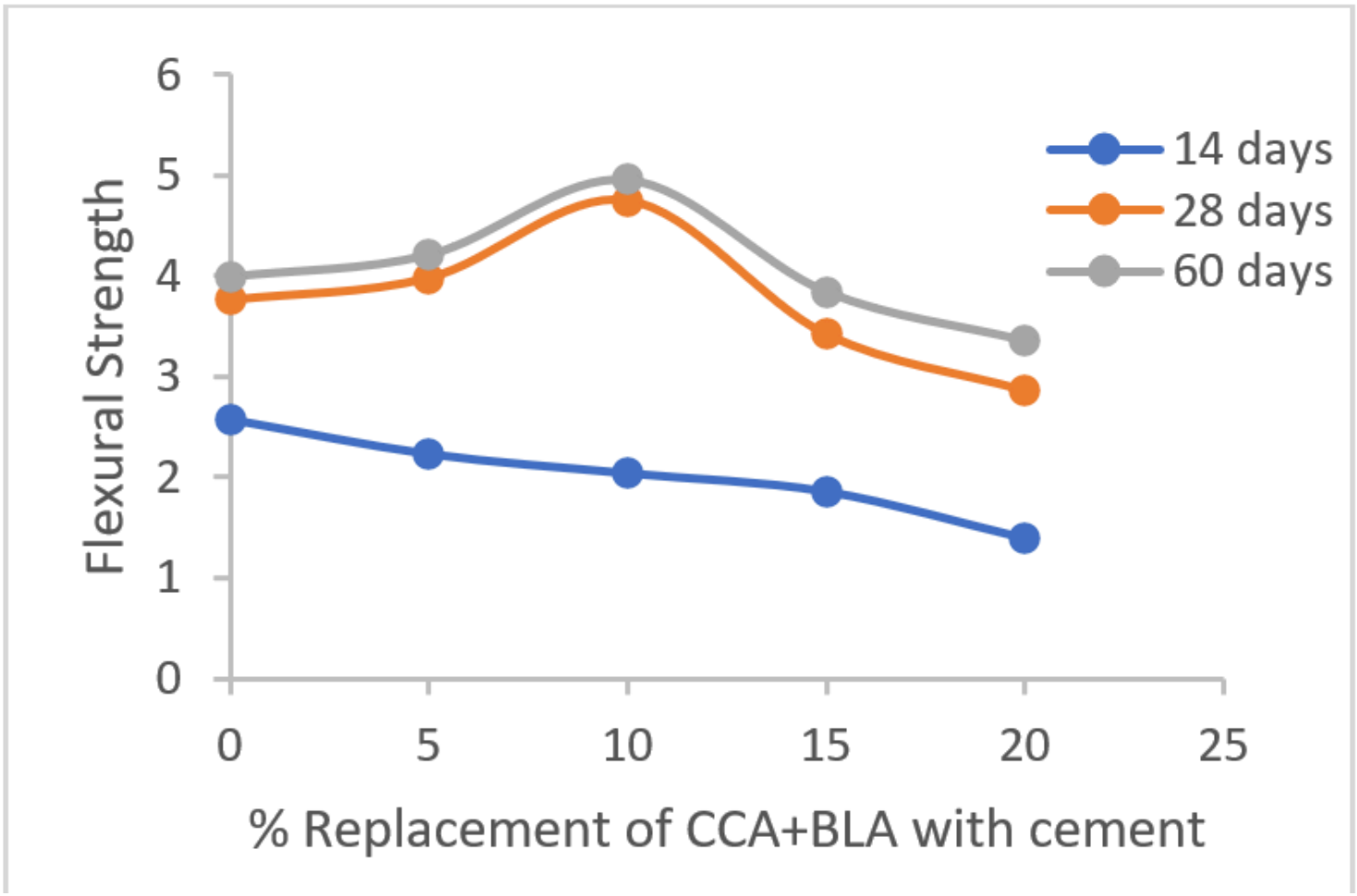


Figure 6

Flexural strength of cubes

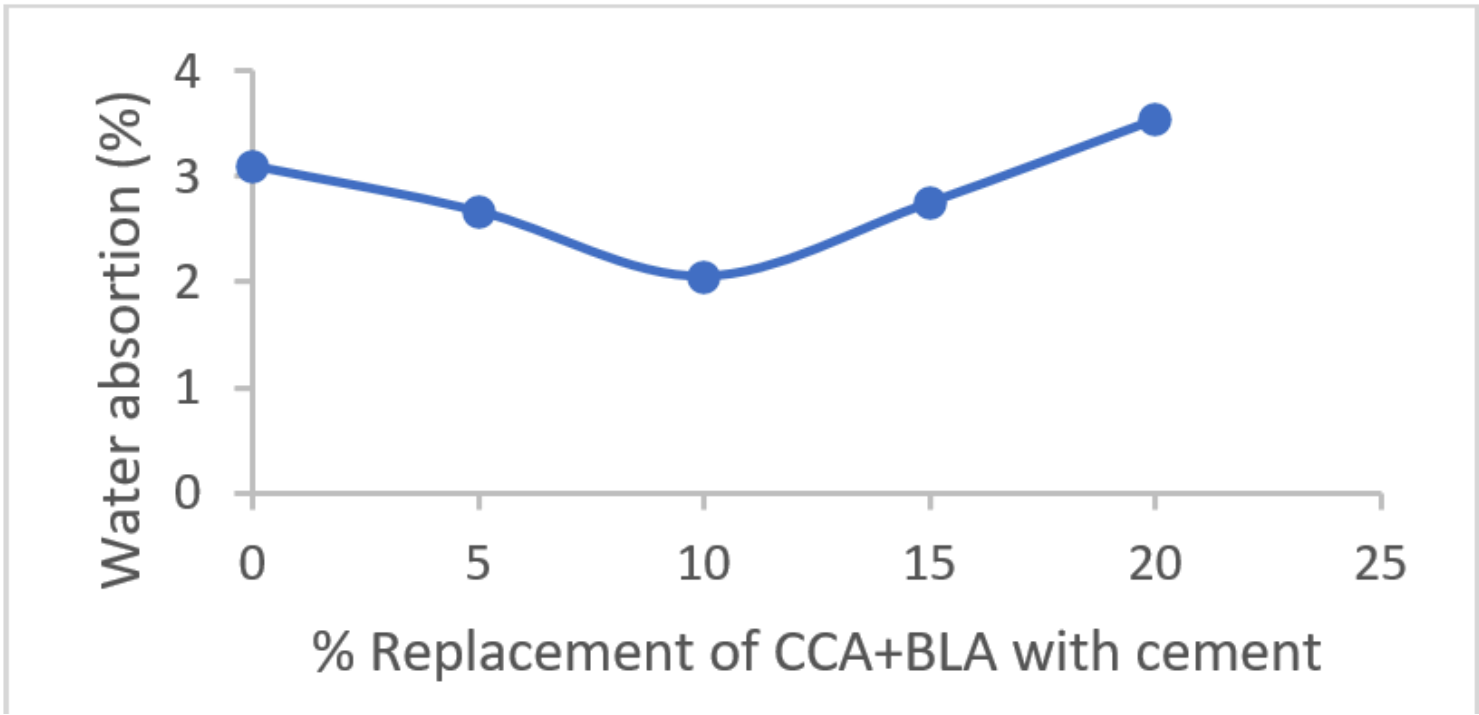


Figure 7

Water absorption of concrete