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Strength Properties of High-Performance Concrete with Green Banana (Musa acuminata) Peel Ash as Partial Cement Replacement.

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Abstract

This study investigated the suitability of using green banana peel ash (GBPA) as a partial replacement for cement in high-performance concrete (HPC). Green banana peels were collected, dried, and burned at a controlled temperature of 800°C to produce ash, which was then ground and sieved through a 75 μm sieve. The physical and chemical characteristics of GBPA were evaluated through particle size analysis, X-ray fluorescence (XRF), and X-ray diffraction (XRD) analyses. The XRF results showed SiO_2 content of 29.989%, Al_2O_3 of 3.706%, and Fe_2O_3 of 1.294%. The physical properties revealed a specific gravity of 2.34 and moisture content of 1.0%. Concrete mixes were prepared with GBPA replacing cement at 0% (control), 5%, 10%, 15%, and 20% by weight, maintaining a constant water-cement ratio of 0.30 and total binder content of 450 kg/m³. A total of 90 specimens were cast and tested for compressive strength and splitting tensile strength at 7, 14, and 28 days of curing. The control mix achieved compressive strength of 55.87 MPa at 28 days, while the 5% GBPA replacement achieved 48.51 MPa, 10% achieved 39.34 MPa, 15% achieved 30.45 MPa, and 20% achieved 28.31 MPa. Splitting tensile strength followed a similar trend, with the control achieving 4.64 MPa at 28 days, while GBPA-modified mixes ranged from 3.11 MPa to 3.96 MPa. The relationship between compressive and splitting tensile strengths showed strong correlation with an R^2 value of 0. 9797.The study concludes that all GBPA replacement levels resulted in reduced mechanical properties compared to the control mix, with the 5% replacement showing the highest strength among GBPA mixes at 48.51 MPa (13.2% lower than control and 3.2% lower than the target). Characterization of GBPA showed pozzolanic properties below the standard requirements. The findings indicate that GBPA at 5% replacement achieved 48.51MPa of compressive strength which is almost comparable to the target strength for HPC (50MPa). Additionally, it showed having acceptable tensile strength at 28 days of curing.

Keywords: Green banana peel ash, high-performance concrete, compressive strength, splitting tensile strength, sustainable construction.

1 INTRODUCTION

Concrete is often used as a construction material worldwide, owing to its versatility, strength, and durability compared with other materials. It has been a main component of sturdy and dependable engineering structures for a very longtime. And it is usually used in most building projects, including foundations, architectural structures, dams, homes, towers, roads, and pavements (Badogiannis *et al.,* 2015). According to Bagheri (2022), concrete is the second most consumed resource in the world after water, and it has been the most widely used construction material for the past few decades.

In civil engineering, the project's progress depends on the appropriate use of building materials. As science and technology advance, more diverse materials will be used in home building to increase efficiency (Baroghel-Bouny *et al.,* 2021). In order to achieve a compressive strength of 50 MPa (7,250 psi) or above, high-strength concrete is normally mix with additional cementitious materials and admixturesWith its simpler mix design and lower compressive strength of 20–40 MPa (2,900–5,800 psi), conventional concrete is the material of choice for standard building applications (Gangwar, 2020).

High-performance concrete (HPC) has emerged as a promising solution to meet the demand for structures with superior mechanical properties, extended service life, and reduced environmental footprint (Shannag and Shaia, 2018). High-performance concrete is referred to as concrete that meets special efficiency and uniformity requirements that are rarely feasible by using conventional materials and regular mixing, placing, and curing practices (Shannag and Shaia, 2018). When compared to traditional concrete mixes, HPC shows improved strength, durability, and resilience to a variety of environmental variables.

Chemical and mineral admixtures are the primary means by which high-performance concrete's pore structures are enhanced (Bagheri *et al.,* 2022; Benz *et al.,* 2020). Mineral admixtures have been thoroughly researched and used to enhance concrete performance while lowering its environmental effect. Examples of these admixtures include fly ash, silica fume, metakaolin, rice husk ash, and slag. Each of these substances has special properties that have different effects on the properties of concrete (Khan *et al.,* 2014).

Uganda is the world's top consumer of green bananas, using 240 kg annually per person, and the world's second-largest producer, with 11.1 million tons produced per year (Yusuf, 2020). A type of banana that is native to Uganda, matooke (green banana) is the most important staple crop that is consumed by humans. Green banana possesses pozzolanic properties similar to other mineral admixtures and has the potential to positively influence the engineering properties of concrete when incorporated into its mix design (Patil and Kumbhar, 2022).

To determine green banana peel ash's (GBPA) potential for use in concrete applications, further research into the material's pozzolanic properties is required. Because of their high silica content, pozzolanic materials such as fly ash and silica fume increase strength and durability when they react with calcium hydroxide during cement hydration to form calcium silicate hydrate (C-S-H) (Mehta and Monteiro, 2014; Li *et al.,* 2020). Similar to this, GBPA has a sizable amount of reactive silica and alumina that, when calcined at the right temperatures, enhance its pozzolanic activity (Patil and Kumbhar, 2022).

Green banana peel ash, which is obtained from the residue left over after frying bananas, has gained attention as a possible addition to cementitious materials used to improve concrete's technical qualities, lessen environmental impact, and provide solutions for waste management in places like Uganda. 61.8 kg of matooke peels are generated annually per person in Uganda and end up as garbage because of poor storage conditions and careless disposal. This enormous volume of garbage puts greenhouse gases into the atmosphere and causes health issues (Yusuf, 2020).

Green banana peel ash (GBPA) has a number of possible drawbacks and hazards when used in high-performance concrete (HPC). The chemical composition of BPA can vary greatly, and this is a significant cause for concern various factors can affect this composition, including the type of banana, growing conditions, and ash production method (Celik *et al.,* 2018). According to Patil and Kumbhar (2022), this variability may have an impact on the consistency of pozzolanic activity, which could result in uneven concrete properties like strength and durability.

According to studies (Celik *et al.,* 2018; Sotonye *et al.,* 2021) GBPA has a chemical composition similar to that of traditional admixtures, with SiO_2, AlO_3, and FeO_3 content required for pozzolanic reactivity. To compare its behavior to well-established materials like fly ash, more research is necessary due to the variability in its composition, which is influenced by variables like burning temperature and banana type (ACI Committee 232, 2012). Furthermore, by lowering CO_2

emissions, GBPA may have positive environmental effects, making it a viable substitute for sustainable concrete production (Marvila *et al.,* 2021).

This study will aim at utilization of residues from agricultural activities at domestic level and integrating it into generation of concrete for sustainable construction. Thus, this research will aim at developing green banana peel ash to and analyzing its properties for enhancement on the concrete properties. To achieve the result of this study the following three objectives were set.

i. To Characterize the physical properties of green banana peel ash.
ii. To Characterize the chemical properties of green banana peel ash.
iii. To evaluate the effect of green banana peel ash on the compressive and split tensile strength properties of high-performance concrete.

2 MATERIAL AND METHODS

2.1 Materials

2.1.1 Cement

Traditional Tororo cement of grade 42.5 was used throughout the experimentation. The cement was obtained from local suppliers**.** Tests to determine characteristics like specific gravity and fineness and all experimental tests were performed in accordance with ASTM C150 (2011).

2.1.2 Fine Aggregate

The fine aggregate was obtained from Black company suppliers along Bushenyi Ishaka municipal council. The determination of physical properties such as specific gravity, moisture content and particle size analysis was carried out in accordance with the requirements of ASTM C33/33M-18.

2.1.3 Coarse Aggregates

The coarse aggregate is a normal weight aggregate with a size in the range of 10-14mm. It was obtained from Black company suppliers along Bushenyi Ishaka municipal council. The determination of physical characteristics like particle size, specific gravity, aggregate crushing and impact values analysis were carried out in accordance with the requirements of ASTM C33/33M-18.

2.1.4 Green banana Peel Ash (GBPA)

Green banana peels were collected, dried, and burned at a controlled temperature of 800 °C to produce ash. The ash is to be ground to a fine powder and then sieved through a 75 µm sieve to achieve a uniform particle size, in accordance to ASTM C618 and BS 8615-1 (2019). Tests to characterize GBPA were carried out accordance with ASTM C618.

2.1.5 Water

Potable water, conforming to BS EN 1008 (2002) specifications, was used for mixing, specimen preparation and curing of the blended concrete specimens.

2.1.6 Superplasticizer

The Superplasticizer was used for this research work is Sikament NNG KE. No any test is to be carried out on it.

2.2 Area of the study

This research was carried out at Kampala International University Western Campus (KIUWC), Construction Materials Laboratory. Green banana peel ash was obtained from hotels in Ishaka.

2.3 Methods

2.3.1 Experimental Program

The experimental program involves investigating the strength properties of high-performance concrete incorporating green banana peel ash (GBPA) as a partial replacement of cement. Materials selected include OPC, GBPA, water, fine and coarse aggregates and superplasticizer. Concrete mixes were included a control without GBPA and variations with GBPA replacing cement at different percentages ranging from 0-20%. After batching and mixing, specimens was cast and cured under controlled conditions for compressive and splitting tensile tests for 1,2, and 4weeks. Tests of compressive strength were conducted using standard-sized 150 mm x 150 mm x 150 mm cubic specimens. For each mix or test condition, at 3 cubic specimens were normally be cast; thus, 45 cubic specimens were produced overall for the 5 experimental runs. Cylindrical specimens with a standard size of 100 mm in diameter and 200 mm in height was cast for splitting tensile strength tests. Similar to this, each mix or test condition were result in the casting of at 3 cylindrical specimens, for a total of 45 cylindrical specimens for the 5 experimental runs.

2.3.2 Mix Design

HPC grade 50 mix design in accordance with IS 10262: 2019 and IS 456: 2000. For the High-Performance Concrete (HPC) mix design of grade 50, the target compressive strength is set at 50 MPa. A water-cement ratio of 0.30 Extreme exposure is chosen to balance strength and workability IS 456: 2000, with a slump of 75 - 100 mm to ensure high workability. The cement content for the mix is 450 kg /$m^3$of concrete. The design calculation is shown in Appendix II.

2.3.3 Experimental Design.

Experimental design is an organized methodology utilized to plan, execute and analyze tests aimed at assessing the impact of various variables in an efficient manner. It guarantees that experiments yield significant data while maximizing the use of resources. In this research, the experimental framework is designed to explore the performance of high-performance concrete incorporating green banana peel ash (GBPA) as partial substitute for cement. The mixture design method is used to optimize the proportions of cement and green banana peel ash (GBPA) while keeping the water and aggregate contents constant. This method is chosen because it effectively identifies the ideal mix proportions needed to satisfy specific performance criteria such as the strength. The study includes Five runs that systematically alter the amounts of cement and GBPA, while maintaining consistent levels of water and aggregate. By varying these critical factors, a detailed analysis of their impact on the properties of concrete is conducted. The findings are contrasted with control mixes, confirmed through replication, and illustrated with graphs and charts. This organized approach guarantees a thorough evaluation of high-performance concrete mixtures, offering insights into the ideal proportions of GBPA that improve concrete characteristics while supporting sustainability.

2.3.3.1 Summary of Mix Design Calculation Procedure

Calculation Sample for 5% GBPA Replacement

$$\text{Total cementitious content} = 450\ \text{kg/m}^3$$

$$\text{GBPA (5\%)} = 0.05 \times 450 = 22.5\ \text{kg/m}^3$$

$$\text{Cement} = 450-22.5 = 427.5\ \text{kg/m}^3$$

$$\text{Water} = 0.3 \times 450 = 135\ \text{kg/m}^3$$

$$\text{Superplasticizer} = 2\% \times 450 = 9\ \text{kg/m}^3$$

Fine and Coarse aggregate quantities remain constant as determined for the control mix based on trial workability and density:

$$\text{Fine Aggregate} = 719.2 \text{ kg/m}^3$$

$$\text{Coarse Aggregate} = 1213.13 \text{ kg/m}^3$$

This calculation process was followed for mix variations, adjusting the GBPA and cement contents accordingly while maintaining the total binder at 450 kg/m^3. All materials were batched by weight.

Table 1: Mixture Design Table for the Experiments

Mix ID	W/C	Cement (kg/m^3)	GBPA (kg/m^3)	Water (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	SP (kg/m^3)
Control	0.3	450	0	135	719.2	1213.13	9
5%	0.3	427.5	22.5	135	719.2	1213.13	9
10%	0.3	405	45	135	719.2	1213.13	9
15%	0.3	382.5	67.5	135	719.2	1213.13	9
20%	0.3	360	90	135	719.2	1213.13	9

2.4 Laboratory work

2.4.1 Mixing and Casting

The concrete was prepared by batching the constituent materials cement, fine and coarse aggregates, water, superplasticizer, and Green Banana Peel Ash (GBPA) for the replacement mixes followed by a dry mixing phase for approximately 3 minutes. Water and the superplasticizer were then gradually incorporated during an additional 3 to 5 minutes of wet mixing until a uniform consistency was achieved. The fresh concrete was subsequently placed into oiled molds and compacted to ensure proper consolidation, resulting in the preparation of the following specimens.

- Compressive strength: forty-five (45) of 150mmx150mmx150mm cubes comprising of three samples for each of 5 runs at ages of 7,14 and 28 days respectively,

- Splitting tensile strength: forty-five (45) of 100mmx200mm cylinder comprising of tree samples for each of 5 runs at ages of 7, 14, and 28days respectively.

2.4.2 Compressive Strength

The test was performed in relation to the requirements of BS EN 12390-4 (2000). The load was applied gradually until failure, while measuring load and deformation continuously. Compressive strength is calculated by dividing the maximum load by the cross-sectional area of the specimen as in equation (3.1).

$$\textbf{Compressive strength} = \frac{failure\ load\ (p)}{cross\ sectional\ area\ (A)}$$

2.4.3 Splitting Tensile Strength

The procedure for determining the splitting tensile strength of concrete involves preparing cylindrical or prismatic specimens with smooth ends, curing them under controlled conditions, and then subjecting them to a compressive load in a testing machine until failure occurs by splitting. Specimens are positioned horizontally on the machine's lower bearing block, ensuring alignment and contact with the loading platens. Until the specimen splits along its diameter, a uniform load is applied at a steady pace. Both the applied load and related deformations are tracked and recorded throughout the test, Following failure. The splitting tensile strength (ft) is computed using equation (3.2) and the maximum load (P) is measured.

$$\textbf{Split Tensile strength} = \frac{2p}{\pi \times d \times h}$$

where d is the diameter and h are the height of the specimen. This test is crucial for assessing concrete's resistance to tensile stresses, which is vital for structural applications like beams and pavements.

3 RESULT AND DISCUSSION

This chapter presents the results obtained from the various tests conducted on High-performance concrete incorporated green banana peel ash (GBPA) as partial replacement of cement. These results are encompassing the results of characterization tests carried out on the GBPA and other materials, as obtained using ASTM C 618 (2012) specifications, and the results of performance evaluation tests of the mineral admixtures in HPC. The chapter covers the characteristics of GBPA, Tests on fresh properties of HPC and Tests on harden properties of HPC. Graphs and tables are used to illustrate the variations in performance due to the replacement levels of GBPA.

3.1 Characterization Results

This section presents results of physical and chemical characterization of the materials in accordance with ASTM C 618-12, as shown Table 2.

3.1.1 Green Banana Peel Ash

The results of physical of GBPA has specific gravity 2.34, moisture content of 1.0% and a light gray in color. This shows that GBPA is less density than cement, and passed the moisture content requirement limit set by ASTMC 618(2012).

The result of particle size analysis is presented Table 2. 100g of GBPA was used for the test, and maximum amount of GBPA was retained on sieve size 150µm, followed by sieve size 212 µm, followed by sieve size 75 µm, and finally sieve size 300 µm. A bout 13.5% of the ash passed through the 75 µm sieve and got retained on the pan.

Table2: Particle size distribution of GBPA

Sieve sizes	Weight retained (g)	Percentage of total weight retained (%)	Cumulative percentage of total weight retained (%)	Percentage passing (%)
1.18 mm	0.0	0.0	0.0	100
600 µm	0.0	0.0	0.0	100
300 µm	0.1	0.1	0.1	99.9
212 µm	18.5	18.5	18.6	81.4
150 µm	50.3	50.3	68.9	31.1
75 µm	17.6	17.6	86.5	13.5
Pan	13.5	13.5	100	0.0

3.2 X-ray fluorescence Analysis

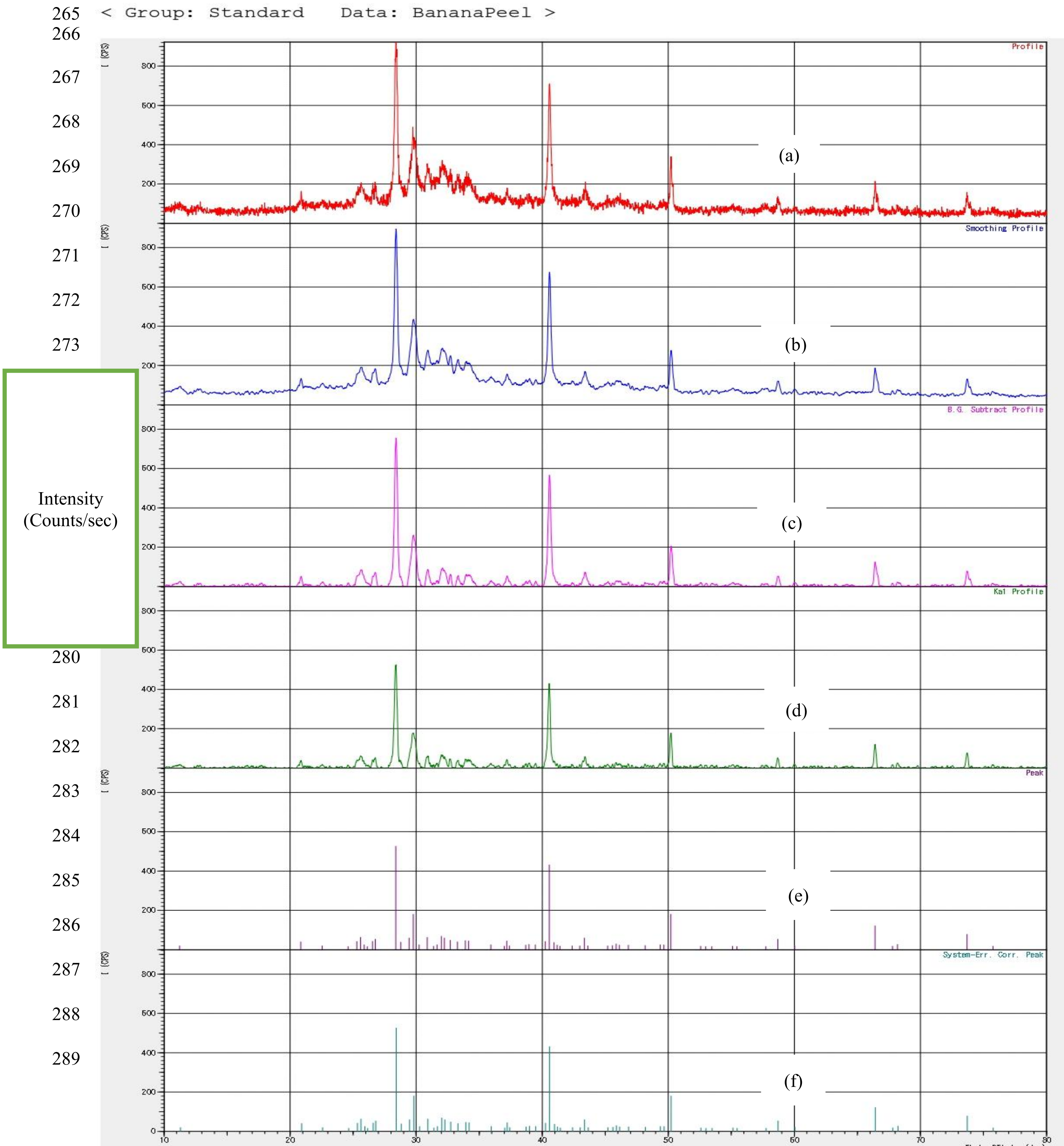
The XRF results of GBPA indicate a moderate SiO2 content (29.989%), suggesting somehow moderate pozzolanic activity compared to other SCMs. The high K2O (39.885) and CI (7.036%) could affect concrete durability, particularly in terms of alkali-silica reaction and reinforcement corrosion. Meanwhile, CaO (3.928%) and MgO (6.022%) suggest minimal self-cementing properties but some contribution to early strength. Compared to other studies on Banana Peel Ash (BPA), GBPA shows similar trends but slightly lower SiO2 and higher K2O levels(Alaneme et al., 2024). These discrepancies could be attributable to burning circumstances and raw material makeup. While GBPA has some pozzolanic potential, careful mix optimization and possibly blending with other pozzolans are necessary for optimal performance in concrete applications.

Table 3 Oxide Composition of GBPA from XRF Test

S/N	Component	Percentage composition
1	SiO_2	29.989
2	Al_2O_3	3.706
3	Fe_2O_3	1.294
4	CaO	3.928
5	MgO	6.022
6	SO_3	1.977
7	MnO	0.225
8	K_2O	39.885
9	TiO_2	0.268
10	P_2O_5	2.368
11	Cl	7.036
12	ZnO	0.138
13	Sn	2.578

3.3 X- Ray diffraction analysis

The X-Ray diffraction analysis (XRD) of GBPA was performed using GBC MMA x-ray diffractometer with copper (Cu) radiation at a scan rate of 2.0000 (deg/min).



2 Theta (°c)

Figure 1 Shows the pattern of XRD for GBPA.

This analysis was conducted to identify the mineralogical phases—whether amorphous or crystalline present in the Green Banana Peel Ash (GBPA). Figure 1 presents the X-ray diffraction (XRD) patterns for six distinct materials: (a) raw GBPA, (b) heated (calcined) GBPA, (c) a cement blend with partial ash replacement, (d) pure cement, (e) hydrated cement containing GBPA, and (f) a standard reference showing crystalline phases. The diffraction patterns are displayed in different colors to distinguish the material compositions related to the Green Banana Peel Ash and the various cementitious mixtures.

The XRD pattern displayed the major spectrum with sharp and distinct peaks, indicating the presence of crystalline phases such as silica (SiO_2) that occurred $2\Theta = 40.6^{o}$, Potassium oxides (K_2O) at $2\Theta = 28.5^{o}$, and Calcium Oxide (CaO) at 29.8^{o}. The XRD pattern al so displayed the minor spectrum with peaks, indicating the presence of crystalline phases such as aluminum oxide (Al_2O_3) that occurred $2\Theta = 66.5^{o}$, Iron oxides (Fe_2O_3) at $2\Theta = 33.5^{o}$.

The peaks of heated or Calcined Green Banana Peel Ash (GBPA), indicate the decomposition of organic matter and the formation of reactive silica which is an essential for pozzolanic behavior.

The diffraction peaks of GBPA-Cement Blend (Ash Partial Replacement) is a combination of GBPA and cementitious materials and the presence of calcium silicate hydrates and a reduction in portlandite ($Ca(OH)_2$) peaks indicate pozzolanic activity. In Pure Cement, the characteristic peaks of common cement phases such as alite, belite, aluminate, and ferrite are observed and intensity of these peaks are comparable to the GBPA-cement blend for reactivity analysis. Hydrated Cement with GBPA, peaks is reduced which confirms the pozzolanic reaction of GBPA with calcium hydroxide which increases presence of amorphous phases indicating improved strength development over time (Avinash *et al.,* 2013).

Standard Reference (Crystalline Phases) acted as a reference standard used to compare phase identification in the other spectra. The sharp and distinct peaks served as a baseline to match the crystalline compounds present in GBPA and cementitious materials. The presence of silica content contributed to pozzolanic activity by reacting with calcium hydroxide ($Ca(OH)_2$) in cement hydration, improving strength and durability (Ferraro and Nanni,2012).

3.4 Results of Fine Aggregate

The results of tests carried out to establish the physical properties of the fine aggregate is presented in table 4.The fine aggregate has specific gravity of 2.62, water absorption value of 1.63%, moisture content of 1.0% and fineness modulus of 2.74. Table 4.3 shows Particle size Distribution of Fine Aggregate.

Table 4 Particle Size Distribution for Fine Aggregate

Sieve sizes (mm)	Average weight Retained (g)	Percentage Retained (%)	Cumulative percentage retained (%)	Percentage Passing (%)	Permissible percentage passing as per Bs 12620:200
10	0	0	0	100	100
5.00	14.3	1.43	1.43	98.57	90-100
2.36	24.1	2.41	3.84	96.16	75-100
1.18	129.8	12.98	16.82	83.18	55-90
0.6	313.9	31.39	48.21	51.79	35-59
0.3	221.6	22.16	70.37	29.63	8-30
0.15	253	25.3	95.67	4.33	0-10
0.075	27.1	2.71	98.38	1.62	______
Pan	16.2	1.62	100	0	
FM= 2.36					

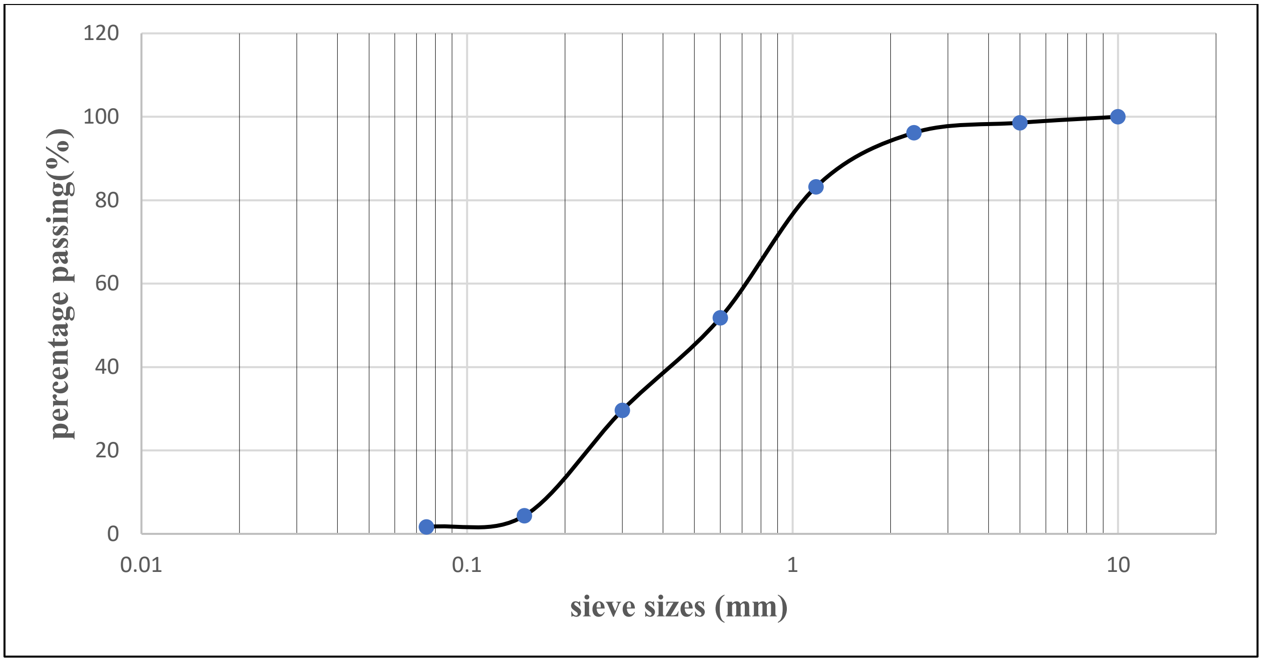


Figure 2 Particle Size Distribution for Fine Aggregate

The results of particle size analysis presented in Table 4, used 1000g of aggregate sample. The maximum percentage of fine aggregate was retained on sieve size 600 µm, followed by sieve size 300 µm, then sieve size 150 µm, then sieve size 1.18 mm. the minimum percentages retained on sieve sizes 5.0 mm, 2.36 mm and 75 µm respectively. The particle size distribution is shown in Figure 2. As per BS EN 12620:200+AI:2008 specification, the fine aggregate falls within zone 2classification, which is good concrete work (Nevile, 2003).

3.4 Physical Assessment of the Coarse Aggregate

The results of tests carried out to establish the physical properties of coarse aggregate. The coarse aggregate has a specific gravity of 2.65, water absorption of 0.81%, moisture content of 1.5% and particle size distribution of coarse aggregate as shown in Table 5.

Table 5 Particle Size Distribution of Coarse Aggregate

Sieve Size (mm)	Average weight retained (g)	Percentage of weight retained (%)	Cumulative weight retained (%)	Percentage passing (%)	Permissible percentage passing as per Bs 8882:1992
20	18.4	1.84	1.84	98.16	100
14	44.6	4.46	6.3	93.7	85-100
10	819.7	81.97	88.27	11.73	0-50
6.3	65.4	6.54	94.81	5.19	0-10
5	41.6	4.16	98.97	1.03	_______
2.3	9.3	0.93	100	0	_______
Pan	0	0	100	0	

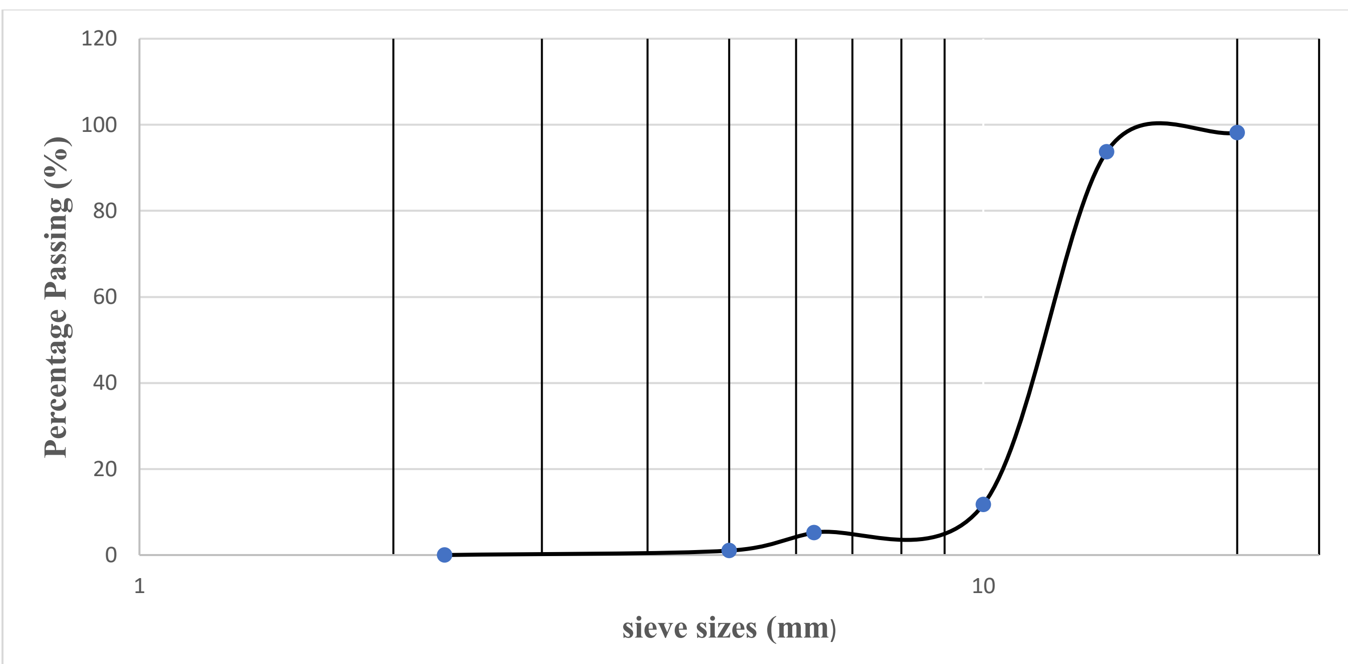


Figure 3 Particle Size Distribution for Coarse Aggregate

The results of particle size analysis are used 1000g of coarse aggregate for the test. The maximum percentage of coarse aggregate was retained on sieve of size 10mm, followed by sieve size 6.3mm, then sieve size 14mm, and then sieve size 5 mm. the least percentage retained was on 2.3 mm and 20 mm respectively. As per BS EN 12620:2002+AI:2008 specification, the coarse aggregate classifies as 14 mm single size.

3.5 Results for Compressive Strength of HPC

Compressive strength tests were conducted at 7,14 and 28 days. Table 4.6 presents the results obtained for different GBPA replacement levels.

Table 6 Results of Compressive Strength

Run	7days of strength	14days of strength	28days of strength
Control	37.06	44.185	55.87
1	25.79	33.59	48.51
2	26.13	31.15	39.34
3	23.62	27.10	30.45
4	21.36	24.80	28.314

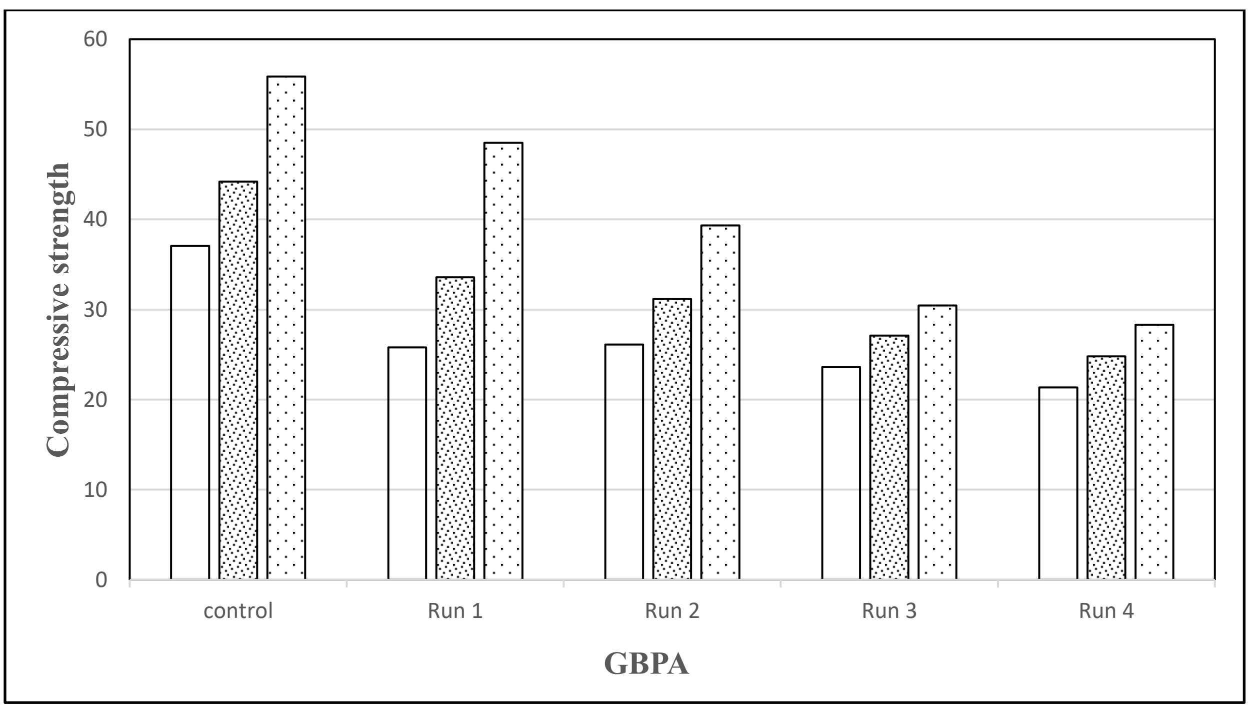


Figure 4 Graphical Representation for compressive strength

The results indicate a gradual decrease in compressive strength as the proportion of Green Banana Peel Ash (GBPA) increases. The control mixture demonstrated the greatest strength throughout all curing periods, reaching 37.06 MPa after 7days, 44.1 MPa after 14days, and 55.87 MPa at 28days. In contrast, mixtures containing GBPA exhibited a reduction in strength, with Run 1 (5%GBPA) measuring 25.79 MPa after 7days, 33.59 MPa at 14days, and 48.51MPa at 28days, suggesting that a low level of GBPA substitution still permitted a satisfactory retention of strength. At increased levels of GBPA replacement, the reduction in strength becomes more pronounced. Run 2 (10%GBPA) showed values of 26.13 MPa, 31.15 MPa, and 39.34 MPa, respectively. This indicates that despite some pozzolanic activity, the dilution effect from the lower cement content hindered strength gains. Beyond the 10% GBPA mark, the drop in strength was even more significant, with Run 3 (15% GBPA) falling to 23.62 MPa at 7days, 27.1 MPa at 14days, and 30.45 MPa at 28days. The most considerable strength decline was seen in Run 4 (20% GBPA), which only measured 21.36 MPa at 7days, 24.80 MPa at 14days, and 28.314 MPa at 28days, reinforcing the idea that excessive GBPA replacement compromises the integrity of the cement matrix.

These findings of GBPA exhibited some pozzolanic properties, it could not offset the dilution effect caused by the lower cement content. Even with a 5% replacement of GBPA, the strength decreased, indicating that GBPA is unsuitable for high-performance concrete without further modifications. Additional enhancements, such as increasing the fineness of GBPA, optimizing the dosage of superplasticizers, or blending it with other cementitious materials, might be required to improve performance. A research conducted by (Ali, 2022) investigated the impact of substituting cement with plantain peel ash at different proportions (0%, 5%, 10%, 15%, 20%, and 25%). The findings revealed a decline in compressive strength as the level of replacement rose, indicating that increased amounts of plantain peel ash negatively influence the strength of concrete.

3.6 Results of Splitting Tensile Strength of HPC

Splitting tensile strength tests were conducted at 7,14 and 28 days. Table 7 presents the results obtained for different GBPA replacement levels.

Table 7 Splitting Tensile Strength Results

Run	7days of Strength	14days of Strength	28days of Strength
control	2.26	2.61	4.64
1	1.988	2.27	3.96
2	1.74	2.17	3.58

3	1.40	1.98	3.33
4	1.26	1.90	3.11

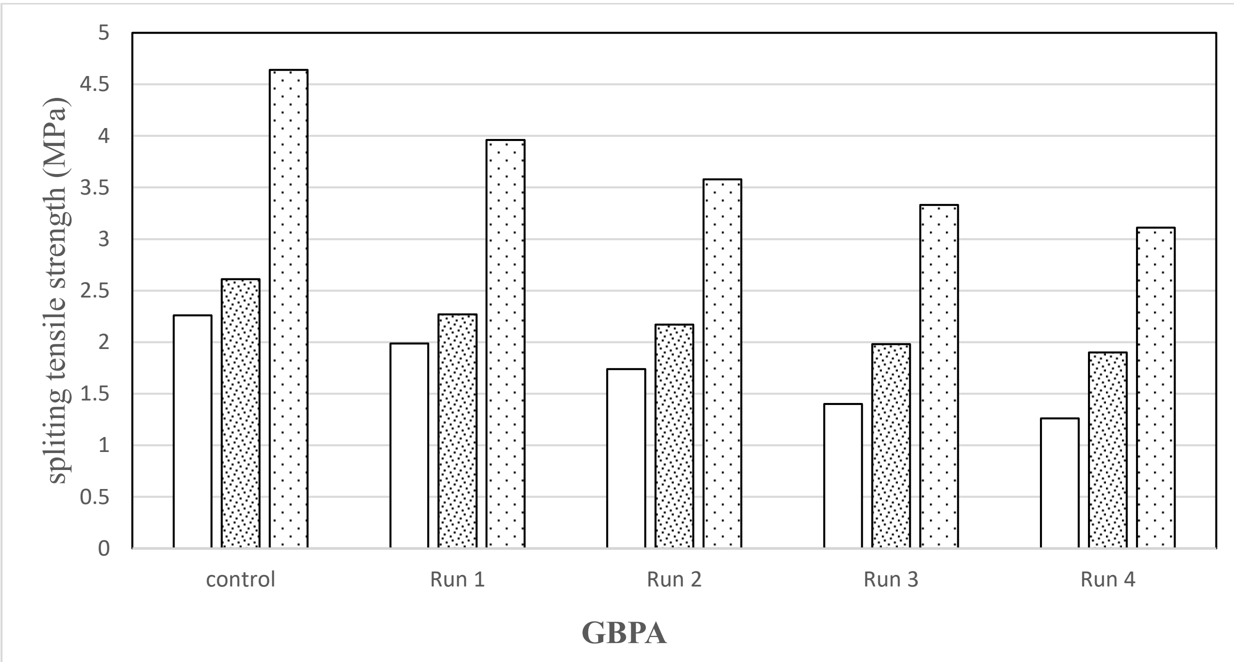


Figure 5 Shows Graphical Representation of Splitting Tensile Strength

The results indicate the percentage of Green Banana Peel Ash (GBPA) replacement rises; the splitting tensile strength findings show a progressive loss in strength. With values of 2.26MPa at 7days, 2.61 MPa at 14days, and 4.64 MPa at 28days, the control mix showed the maximum tensile strength at all curing ages, proving the better bonding and cohesion of regular Portland cement (OPC) in HPC. The tensile strength progressively decreased as the GBPA content rose. A little GBPA replacement had moderate impact on tensile strength, as seen by Run 1 (5% GBPA), which reported 1.988 MPa at 7days, 2.27 MPa at 14 days, and 3.96 MPa at 28days. Strengths at 7, 14, and 28 days respectively, Once GBPA replacement reached 10% the decline becomes more substantial. At 7,14, and 28days, run 2 (10% GBPA) showed values of 1.74 MPa, 2.17 MPa, and 3.58 MPa, demonstrating that too much cement replacement weakens the concrete matrix and decreases aggregate cohesiveness. while Run 3 (15% GBPA) produced even lower values of 1.40 MPa, 1.98 MPa, and 3.33 MPa. Run 4 (20% GBPA) had the lowest tensile strength, measuring just 1.26 MPa, at 7days, 1.90 MPa at 14 days, and 3.11 MPa at 28days. This indicates that HPC's resistance to tensile pressure is diminished by excessive replacement. The decrease is explained by the reduced calcium silicate hydrate (CSH) production, which is essential for the development of tensile strength, and GBPA's worse binding capacity in comparison to cement. The results indicate that while Higher replacements result in a more noticeable loss in performance, GBPA can be utilized in HPC up to an ideal limit of 5% without appreciably reducing tensile strength. Fiber reinforcing, more pozzolanic materials, or improved GBPA processing (such finer griding) might all be used to increase tensile strength at greater GBPA levels. The mixtures with a 5% replacement of plantain peel ash demonstrated similar performance to those made with ordinary Portland cement, while specimens with a 20% replacement showed significant microcracking and a reduction in the strength of the interfacial transition zone. Our SEM analysis indicated inadequate bonding between the ash particles and the cement matrix at the higher replacement level (Usman et al. (2018)).

4.5.4 Relationship Between Compressive and Splitting Tensile Strengths

In concrete technology, two key mechanical properties that characterize the performance of concrete under various loading scenarios are compressive strength and splitting tensile strength (Usman et al. (2018)). Compressive strength assesses how well concrete can endure axial loads without failing, whereas splitting tensile strength looks at its ability to resist indirect tensile stresses. Given that concrete typically has high strength in compression but low strength in tension., it is essential to grasp the relationship between two strengths for effective structural design and material optimization. As shown in Figure 6

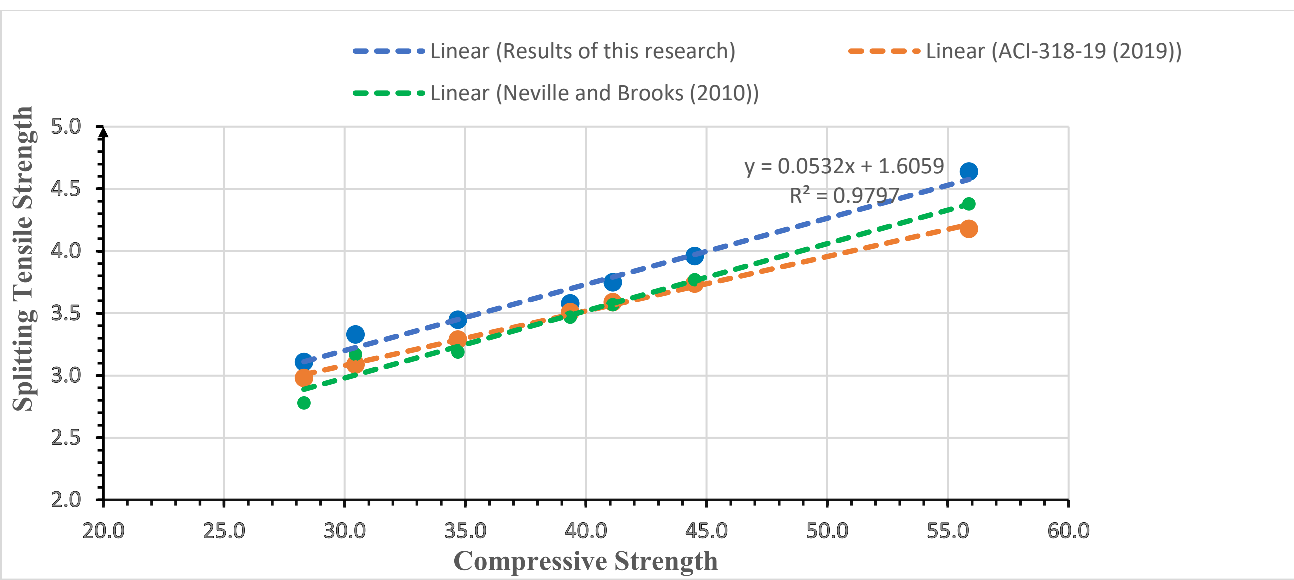


Figure 6 Relationship between compressive and splitting tensile strengths

The connection between compressive strength and splitting tensile strength depicted in the graph is consistent with results from multiple studies. As noted by Neville and Books (2010), splitting tensile strength usually shows a correlation with compressive strength, with tensile strength commonly falling between 8% and 15% of the compressive strength. This pattern is apparent in the current findings, where the linear regression analysis, which has an R^2 value of 0.9797, indicates a robust relationship.

Additionally, ACI 318-19 (2019) provides empirical formulas to estimate tensile strength from compressive strength, often leading to conservative predictions. Similar to the present study, research by Rafat Siddique (2012) and Chindaprasirt *et al.* (2007) observed deviations from ACI estimates when supplementary cementitious materials (SCMs) like fly ash or pozzolanic materials were used. The enhanced pozzolanic reaction, which forms additional calcium silicate hydrate (C-S-H), improves the tensile strength by reducing micro-cracks and enhancing the interfacial bond.

Furthermore, studies by Gopalakrishnan and Govindarajan (2020) reported that sustainable additives like banana peel ash could strengthen the matrix, contributing to higher tensile strength values than conventional models predict as evident in this research. In this context, the improved tensile strength in the GBPA-modified concrete indicates the material's potential for structural applications, particularly in situations requiring enhanced tensile resistance. Further investigation into long-term performance and durability would provide additional insights into the reliability of these formulations

CONCLUSIONS

The research studied the suitability of using green banana peel ash (GBPA) in replacement of cement in High-performance concrete (HPC). The performance of GBPA in HPC mixtures was assessed in terms of compressive strength, splitting tensile strength. As well as the physical and chemical characteristics of GBPA were thoroughly investigated and described. The influence of GBPA on these properties was analyzed, and its performance was correlated with its chemical composition and pozzolanic activity to establish meaningful relationships between its characteristics and concrete performance. This chapter of 5 also summarizes the key findings of the research objectives and its contribution to knowledge, while recommendations for future work based on the results and conclusion of this study are also presented.

On the basis of the results obtained from this study, the following conclusions were reached after analyzing the laboratory test results. Characterization of green banana peel ash (GBPA) has shown that it possesses some pozzolanic properties which is less than the stander percentage.

Compressive strength results of 5% replacement demonstrated that early-age strength (7 and 14 days) were lower than the control mix, indicating a slower strength gain due to the pozzolanic reaction taking time to develop. However, at 28 days, GBPA-modified HPC exhibited significant strength improvements while it also lower than the target strength at less the 3.2%, with some replacement levels achieving values somehow comparable to the control mix, confirming its long-term strength contribution. The highest compressive strength recorded was 48.51 MPa at 28 days with 5% replacement, which is competitive for structural applications.

Splitting tensile strength followed a similar trend, with initial reductions at 7 and 14 days but improved performance at 28days in each age. The control mix achieved 4.64 MPa at 28 days, while the GBPA-modified mixes showed values ranging from 3.11 MPa to 3.96 MPa, indicating that there was a reduction, the tensile strength remained within acceptable limits for HPC.

5.3 Recommendations

Based on the research findings the following suggestions are put forth to further investigation the potential of Green Banana Peel Ash (GBPA) in High-performance concrete (HPC):

I. Verification of the Optimal GBPA Dosage in Various Mix Designs: Further research should concentrate on verifying this dosage in various HPC mix designs under various cement compositions, aggregate types, and curing conditions in order to guarantee its adaptability for a range of concrete applications, as this study was successful in determining the ideal GBPA replacement level.

II. Long-term durability studies : in order to ascertain the long-term sustainability of GBPA-modified HPC in various structural applications, extensive research on the durability of GBPA-modified HPC under various environmental conditions is needed , including sulfate attack, carbonation resistance, freeze-thaw cycles, and chloride exposure, should be conducted.

III. Evaluation of mechanical properties beyond strength: this research focused on compressive strength and splitting tensile strength, but additional mechanical properties such as modulus of elasticity, shrinkage, creep behavior, and flexural strength should be investigated to assess the full structural performance of GBPA-modified HPC.

IV. Microstructural Analysis and pozzolanic reaction: To gain a better understanding of the reaction mechanisms of GBPA in cementitious systems and how it affects the formation of hydration products like C-S-H, more research should be done using sophisticated characterization techniques like Thermo-Gravimetric Analysis (TGA), Differential Thermal Analysis (DTA), and Scanning Electron Microscopy (SEM).

V. Sustainability and Economic Studies: To ascertain the economic feasibility of GBPA use in sustainable construction, more research should evaluate the cost effectiveness and environmental impact of using it in concrete in comparison to traditional cement and other supplemental cementitious materials.

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Author Contributions

Abdirashid Abdulahi Mohamed and Ahmed Abdirizak Dirie contributed to the conceptualization, methodology, data analysis, interpretation of the result and preparation of the original draft. Dr. Sani Aliyu Abubakar supervised the work. Farhan Adan Nuur, manuscript review,technical support and corrections.

Compliance with Ethical Standards

Conflict of Interest

The authors declare no conflict of interest.

Ethical Approval

This study was conducted in accordance with Kampala International University and national ethical guidelines of Uganda.

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Data Availability Statement

All data generated or analyzed during this study are included in this article.

Ethics and Consent to Participate

Not applicable.

Consent to Publish

The authors confirm that this manuscript does not contain personal or sensitive information requires consent for publication

Clinical Trial Declaration

Not applicable.

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APPENDICES

APPENDIX I: PROJECT PHOTOS

APPENDIX II: MIX DESIGN CALCULATIONS

The HPC grade 50 mix design in accordance with IS 10262: 2019 and IS 456: 2000, are presented below:

Step 1: Determine Basic Parameters

Characteristic Compressive Strength (f_{ck}):

Target Strength (f_{ck}) = 50 MPa

Assuming Standard Deviation (S) = 5 MPa (IS-10262-2019, Table-2)

Target Mean Strength (f_{cm}) = f_{ck} + 1.65 * S

f_{cm} = 50 + 1.65 * 5 = 58.25 MPa

Selection of Water-Cement Ratio (W/C Ratio):

W/C ratio = 0.30

Selection of Workability:

Slump = 75-100 mm (high workability)

Selection of Cement Content:

Cement content = 450 kg/m^3

Step 2: Calculate Water Content

For a slump of 75-100 mm, from IS 10262: 2019,

Adjust for the W/C ratio: Water content = 450 kg/m^3 * 0.30 = 135 kg/m^3

Check if this water content provides the required workability; if not, adjust accordingly.

Step 3: Calculate Aggregate Content

Coarse Aggregate Content:

Maximum size of aggregate = 14 mm

For the water-cement ratio of 0.30 and a target slump of 75-100 mm, the volume of coarse aggregate per unit volume of total aggregate = 0.62 (IS 10262: 2019)

Fine Aggregate Content:

Volume of fine aggregate per unit volume of total aggregate = 1 - Volume of coarse aggregate

Step 4: Calculate the Mix Proportion

Calculate the volume of cement:

Volume of cement = Cement content / Specific gravity of cement * 1/1000

Assuming specific gravity of cement = 3.15

Volume of cement = 450 / (3.15 * 1000) = 0.1429 m^3

Calculate the volume of water:

Volume of water = Water content / Specific gravity of water * 1/1000

Volume of water = 135 / (1 * 1000) = 0.135 m^3

Volume of admixtures (if any):

Assuming 2% by weight of cement (superplasticizer)

Volume of admixture = 2/100 * 450 / 1.145 = 0.0079 m^3

Volume of total aggregates = 1 - (Volume of cement + Volume of water + Volume of admixtures):

Volume of total aggregates = 1 - (0.1429 + 0.135 + 0.0079) = 0.7142 m^3

Mass of coarse aggregate:

Volume of coarse aggregate = 0.7142 * 0.62 = 0.4428 m^3

Mass of coarse aggregate = 0.4428 * Specific gravity of coarse aggregate * 1000

specific gravity of coarse aggregate = 2.65

Mass of coarse aggregate = 0.4428 * 2.65 * 1000 = 1213.3 kg

Mass of fine aggregate:

Volume of fine aggregate = 0.7142 * (1 - 0.62) = 0.2714 m^3

Mass of fine aggregate = 0.2714 * Specific gravity of fine aggregate * 1000

specific gravity of fine aggregate = 2.62

Mass of fine aggregate = 0.2714 * 2.62* 1000 = 719.2 kg

Final Mix Proportion

Cement: 450 kg/m^3

Water: 135 kg/m^3

Coarse Aggregate: 1213.3 kg/m^3

Fine Aggregate: 719.2 kg/m^3

Admixture: 9 kg/m^3 (assuming superplasticizer)