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Green Concrete Innovation: Incorporation of Banana Peel Ash for Special Concrete

Subash Thanappan [a, *], Dimitrios A Karras [b], Aiman Al-Odaini [a]

[a] Lincoln University College, Wisma Lincoln, No. 12-18, Jalan SS 6/12, 47301 Petaling Jaya, Selangor Darul Ehsan, Malaysia
[b] National and Kapodistrian University of Athens (NKUA), 30 Panepistimiou Street, Athens, Postal Code 10679, Greece
* Corresponding Author Email: pdf.Subash@lincoln.edu.my

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Abstract: The production of biogenic organic wastes is in huge concentration due to the increase in urbanization in the capital of Ghana. Additionally, the landfill operation becomes a challenging task for the municipal authorities due to the limited capacity of landfill site. As Accra is the largest banana production sectors in Africa, the lack of managing the banana peels by municipal authorities have locally contribute to the release of VOC's and in turn, leads to health-related issues. The potential utilization of Ghanaian-produced banana peels in this manner remains an unexplored area within current research. Although a variety of agricultural waste products have been the subject of considerable research (such as rice husk ash), banana peel ash has received comparatively little scientific attention. To address this knowledge gap, the present study sought to assess how incorporating banana peel ash (BPA) as a partial cement substitute influences both the early-stage and mature properties of C-25 concrete. Hence, this article focusses a pitfall on recycling of banana peel ash (BPA) that can hamper for producing an effective C-25 concrete. Banana Peels are converted into ashes to make use of it for producing the special eco-friendly concretes. Banana peel ashes (BPA's) are added as admixtures in different proportions (0%, 5%, 10% 15%, 20% and 25% based on the mass of Ordinary Portland Cement) and the special C-25 concrete specimens are tested on fineness of blended materials and compressive strength to ascertain the suitability of banana peel ashes for special concrete.

Keywords: Absorption capacity, Banana Peel Ashes, C-25 Concrete, Compressive strength, Eutrophication, Loss of Ignition Method, Respiratory Ailments, Water Displacement Method, Workability.

1. Introduction

Ghana, located in West Africa, is classified as a middle low-income country facing innumerable prosecutions in solid waste management. More than 60% of the solid wastes in Ghana are organic in nature [1]. The concurrent rise in population, urbanization, industrialization, and agricultural activities has led to an increased generation of organic waste, making waste management one of the foremost challenges all over the world including Asia, Europe and Africa [2- 4]. The production of leachate from Agro-wastes are creating environmental nuisance in term of handling and managing in the landfill site near Accra. The detrimental effects of improper waste disposal have particularly impacted the city of Accra, contributing to a rise in disease prevalence. Recycling of Ago-wastes for value added techniques is a new trend towards sustainability [5 - 9]. Sustainable building materials produced from the suitable organic waste items is the best way of reducing pollution level and to protect the natural resources against depletion [10 - 12]. The adoption of sustainable building materials is a pivotal role for the construction industries for their rigid viability. Different kinds of agricultural waste, like rice husk ash, sugarcane bagasse ash, banana or plantain peel ash and bamboo leaf ash, have been found to be useful in making eco-friendly building materials [12, 13]. According to pioneer researches, most of the organic materials result with good engineering performances [14, 15].

The use of sugarcane bagasse ash as a filler makes concrete stronger in different ways, like being able to hold more strength, resist breaking when bent, and handle splitting forces [16]. Most of the pioneer researches declared that half of the cement used could be replaced with Sugarcane Bagasse Ash (SCBA) [17]. Its application for concrete is assured due to the presence of amorphous silica [18]. In focus with the reduction of carbon foot-print, the application of SCBA would be the most appropriate substitute for concrete. So, using SCBA in concrete can create a sustainable construction material that is also less expensive. Compared to regular concrete, concrete with SCBA requires less water to reach the same level of workability because of the smooth, glass-like surface of SCBA. As more SCBA is used in place of cement, the amount of water needed also goes down [18 - 20]. The sustainability of concrete rely upon the SiO2 percentage in the materials used for concrete [21- 26]. The presence of Iron powder (Fe_2O_3) and Aluminum oxides (Al2O3) improves compressive strength for concrete [27]. Calcium chloride (CaO) is an alkaline mineral and its presence in excess would affect the setting time and workability of concrete [28], [29]. The presence of MgO in the ingredients can help compensating against shrinkage and controls the cracks on concrete. The presence of Magnesium oxide (MgO) react as an expansive agent to compensate the temperature cracking in concrete [30]. The percentage of SO_3 in most of the organic materials varies 0.1 to 0.3 % which satisfies with the European standard (of maximum 3.5%) [31]. the dosage of potassium oxide (K_2O) lead to sustain the compressive strength of concrete [32].

Welded Tuff is a type of rock formed from volcanic materials like ash or dust that were pushed out during a volcanic eruption. It is very common type of rock material available in Grater Wonji lake base near Ambo, Ethiopia. It can be used instead of cement in building projects to get the best binding effect. The rock has a lot of tiny spaces inside, which helps to reduce the temperature when it freezes and also makes it a good insulator [33]. Similarly, the prior treatment of Elephant Grass Ash (EGA) shown improvement on the SiO_2 content [34] and in turn, improvement over the ability of thermal insulation in concrete even up to 65.5% [35]. Using Bermuda Grass Ash (BGA) in concrete greatly affects the concrete as the increment in BGA from 0% to 20% considerably decreases the slump of the fresh concrete due to higher porosity [36].

Rice husk ash (RHA) has also proven to be an effective cement substitute that enhances concrete strength and durability while providing resistance to aggressive environmental conditions. The fine particles of RHA helps to bring a substantial development on compressive strength and Tensile strength. On the contrary, the increase in porosity weakens the concrete [37], [38]. Without compromising the strength, RHA produces lighter weight concrete which is good enough to reduce the structural weight [39].

The socio-economic development of many countries like Ethiopia, India, Indonesia, Brazil, Vietnam, Colombia, and Uganda, rely on the coffee production [40] and its by-product (CHA) shows a favorable pozzolanic action and watertightness when applied in appropriate proportions [41]. The generation of straw waste from Teff in Ethiopia, Eritrea, and Somalia is in excess [42], [43] and its moisture content varies from 7.4 -9.2% aligns better on the ideal range of 6–10% required for the production of concrete [44], [45]. The similar compatibility results with vetiver grass ash with an average moisture content of 7.63% [46].

The representative porosity of Banana Peel Ash (BPA) is contributing the pozzolanic possessions and when it is incorporated into concrete, its absorbent structure readily takes up water from the mixture [47], [48]. This absorption diminishes the quantity of free water essential for the concrete's lubrication, resulting in a more rigid and less pliable mix. Hence, the addition of Banana peel ash as well as Plantain peel ash improves the setting time and in turn the strength of concrete [47], [48]. Concrete made with banana fiber and banana leaf ash could be really useful for making strong, rigid pavements [48]. The sum of SiO_2, Al_2O_3 and Fe_2O_3 requirement is minimum of 50% and this condition satisfies with BPA. Additionally, the moisture content of Banana peels are higher than 90% both in William type and Maghrabi type bananas as shown in Ref. [25]. Cement can be replaced with Coconut Shell Ash (CSA) to reach an average compressive strength of 25 MPa, which helps reduce the environmental impact by more than 15% in terms of global warming potential [49].

The overall literatures shows that the implementation of bio-based organic materials marks a transformative opening in the construction industry and becomes a practical alternative to conventional materials. Although banana and plantain cultivation are concentrated in Asia and Africa, their peels are frequently discarded as waste. Especially, in Ghana, the banana cultivations and in turn, releasing huge quantities of banana peel wastes. Managing the substantial by-products of banana processing poses both environmental and logistical difficulties. While earlier studies have examined various agricultural residues as potential construction materials, comprehensive research on the application of banana peel ash (BPA) in concrete remains limited. Although the fibrous properties of banana peels show the new-fangled path to make use of it for the concrete technology, the lack of their usage for making concrete infers this study to present a novel tactic for the invention of special concrete. This particular research gap motivates to investigate the suitability of Banana peel ash (BPA) to improve the mechanical properties of concrete.

The agricultural waste products are more helpful for the performance and sustainability of C-25 concrete [50]. Although most of the developed countries make use of chemical admixtures and other supplementary products for concrete technology, it is relatively low in Ghana due to limited awareness and accessibility [50]. The pozzolanic responsiveness of BPA is mainly due to the presence of silica content and thus, fits to sustainable infrastructure [51], 52].

With the primary goal of refining the mechanical properties of C- 25 concrete, the current study explores the incorporation of Banana Peel Ash (BPA) as a partial replacement. The performance differences are checked through the comparative assessment between the conventional and special concretes. A systematic analysis over the experimental outcomes against a control sample is accomplished to check the degree of improvement gained through the integration of BPA.

The specific aims guiding this study are:

i) To thoroughly evaluate the various mechanical and durability characteristics of C-25 concrete when BPA is incorporated as an admixture at different, incrementally varied percentages.

ii) To definitively determine and comparatively analyze the comprehensive efficacy of Banana Peel Powder Ash (BPA) as an enhancing additive in C-25 concrete, contrasting its overall performance directly with that of conventionally produced C-25 concrete.

2. Methodology – Collection of Baseline Information

The percentage of organic matter present in banana peels is thoroughly examined by following the standard procedure of Loss on ignition method, [53 - 55]. The loss of ignition method shows that 91.50% of organic matters present in banana peels and this extreme high level of organic matter are highly risky if the management is poor. The high level of organic matter in banana peels is justified in the prior research which is equivalent to the current finding in the study [56]. The decomposition process of very high level organic matters found in the study is a major threat for polluting the ground water, damaging the water bodies etc. [57] and also promoting the health hazards to the human being [58]. Hence, the focus on zero waste processing technique of utilization of banana peel ashes for the production of concrete is made in this study [59]. A sufficient amount of banana peels is collected completely dried traditionally in a normal temperature (Figure 1) as suggested by [60].

Figure 1. Well-dried Banana peels for testing

The clean Banana peels had been exposed to sun to dry and then it turned into reduce into small portions, filled in sacks and transported to Geosystems Consulting Limited at Accra. At the research Centre, the broken dried Banana Peels are burnt with the use of a Furnace at excessive temperature of 500 Degree Celsius, to get the Banana Peel Powder Ashes (BPPA). Additionally, the other ingredients like Dangote Ordinary Portland Cement (OPC) - Dangote Portland Limestone Cement Grade 42.5R from the nearby industries, Aggregates, and Potable water are collected. Sand considered for this study is a Pure River Sand. Quarry stones - Crushed Basaltic Rock (of size 20mm, clean, strong, and sharp, free of clay, loam, dirt, or organic matter) from Ken boat Ltd, Accra. In addition to this, fine and coarse aggregates are tested for the quality control, compatibility assessment and performance evaluation [61], [62]. As shown in Figure 2 and Figure 3, Silt factor, specific gravity, moisture content and water absorption are the main factors for fine aggregates [63].

Figure 2. Test on silt content of fine aggregates

After the initial tests for the ingredients (Figure 2, Figure 3), First mixing method is adopted for mixing of concrete. The preparation process entails a two-stage mixing operation: first, the banana peel ash (BPA) is combined with the cement, and only then are the aggregate and water integrated. Mixing was done for about 5 minutes. Before concrete constituents are combined, they are conditioned to attain a uniform temperature of 20°C. Cement is systematically passed through an 850-µm mesh to eradicate any existing lumps. To counteract the stratification of coarse aggregate, a preparation method is employed: the aggregate is first classified into individual size fractions. The achievement on the optimal grading is ensured through the specific proportions for each batch [64].

In the first phase, the dry blend of the mix of cement, fine aggregate, and banana peel ash (which functions as an admixture) is made by hand until the ingredients are fully intermingled. In the second phase, coarse aggregate is incorporated into the dry blend without adding water until the larger particles are evenly distributed throughout. In the third phase, water is gradually added to the mixture until the desired consistency exists.

Figure 3. Determination of specific gravity of fine aggregates

Table 1. Mixing of ingredients

Mix	Cement Replacement	Cement (kg)	BPA (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Water (liters)
M0	0%	12.0	0.0	18.0	36.0	3.36
M5	5%	11.4	0.6	18.0	36.0	3.36
M10	10%	10.8	1.2	18.0	36.0	3.36
M15	15%	10.2	1.8	18.0	36.0	3.36
M20	20%	9.6	2.4	18.0	36.0	3.36
M25	25%	9.0	3.0	18.0	36.0	3.36

Later, the banana peel ash (BPA) was incorporated at varying percentages of 5%, 10%, 15%, 20% and 25% by mass. After achieving the appropriate mix, concrete specimens of each of 150mm x 150mm x 150mm in size were fabricated, following a curing process for 7 days, 14 days and 28 days for different set of specimens [65, 66]. Table-1 shows BPA replacement levels for concrete. The specimens are tested for fineness, slump value and compressive strength following the standard procedure. GraphPad Prism through ANOVA method was used to analyze the values obtained on compressive strength with varying percentage of BPA.

3. Results and Discussions

3.1 Particle Size of Cement Used

The fineness of cement particles is prime importance to ascertain the mechanical performance during the early stages. The speed up hydration, improving bond formation, and, ultimately, increasing the material's cementitious reactivity, the particles need to finer. The unpretentious value is specified by the strength developed in cement mortar sample even when materials have equal chemical and mineral compositions. An optimum particle size distribution is necessary for confined packing because smaller particles fill the spaces left by bigger grains. This interlinking pattern reduces porosity and creates a compact, long-lasting matrix [66]. The grain size of cement has a direct impact on various physical and chemical parameters, including strength gain, permeability, pace of setting, hydration heat, and water demand [67]. Cement particles are typically 1-50 μm in size, making them suitable for strength and workability in construction. To promote pozzolanic activity and consistent mixing with cement, extra ingredients like banana peel ash (BPA) are crushed to a fine texture (passing through 90-150 μm sieves). As shown in Table 2, the experimental particle size for the cement employed in this investigation nearly matched the requirements described in reference [67].

Table 2. Density, Average Size and Fineness of Cement and BPA

Materials	Density (g/cm^3)	Average size (μm)	Fineness
Cement	3.15	48.34	<10%
BPA	2.17	63.3	<10%

The result of sieve analysis shows the value of fineness modulus as 2.54, and this result outcome satisfies with the IS recommendation, and thus, indicates its appropriateness for high quality concrete [68]. For a 5% BPA-cement blend, the initial setting time was observed to be 45 minutes, while the final setting time was 280 minutes. These values comply with the acceptable limits of 30 to 45 minutes for the initial set and less than 10 hours for the final set ensuring consistent performance [69].

3.2 Test of Workability

Table-3 shows the experimental results of slump tests. The workability test was carried out for five different codes namely M1, M2, M3, M4. M5 and M6. It was observed that the slump is within the limit for 5% BPA. When the BPA replacement percentage increases, the high plasticity nature and non-flowable condition exists due to increase in cementitious tendency. This condition satisfies with the study made over the application of fly ash for concrete as seen in reference [71].

3.3 Sieve Analysis for Fine and Coarse Aggregates

The sieve analysis conducted for fine aggregates and coarse aggregates confirmed compliance with ASTM C-33 specifications. Figure 4 and Figure 5 shows a proportionate particle spreading, decisive for accomplishing appropriate stuffing density and considerably reducing the pores.

Table 3. Summary on Workability Test

Code	BPA (%)	Slump value (mm.)	Slump type	ACI 211.1- 91		Remark
				Min.	Max.	
M1	0	50	True slump	20mm.	80mm.	Slump is within the limit [70]
M2	5%	55	True slump	20mm.	80mm.	Slump is within the limit [70]
M3	10%	180	True slump	20mm.	80mm.	Slump is beyond the limit [70]
M4	15%	80	True slump	20mm.	80mm.	Slump is within the limit [70]
M5	20%	170	True slump	20mm.	80mm.	Slump is beyond the limit [70]
M6	25%	40	True slump	20mm.	80mm.	Slump is within the limit [70]

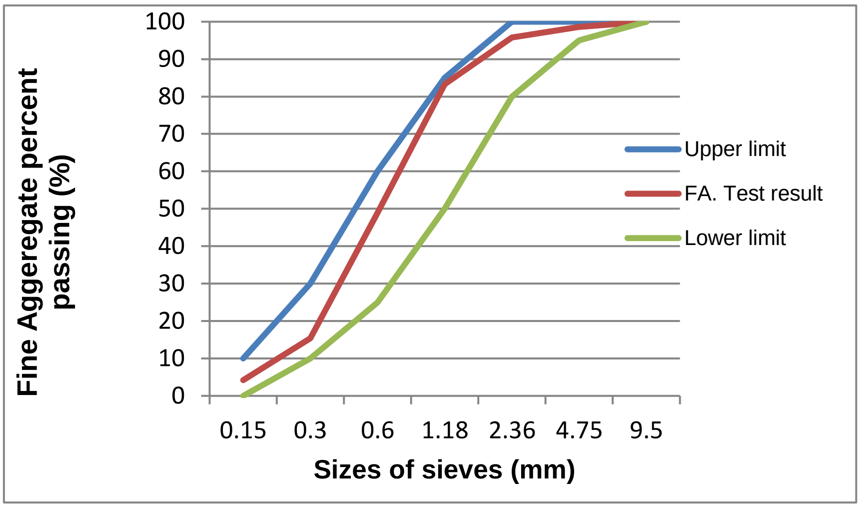


Figure 4. Particle size distribution on fine aggregates

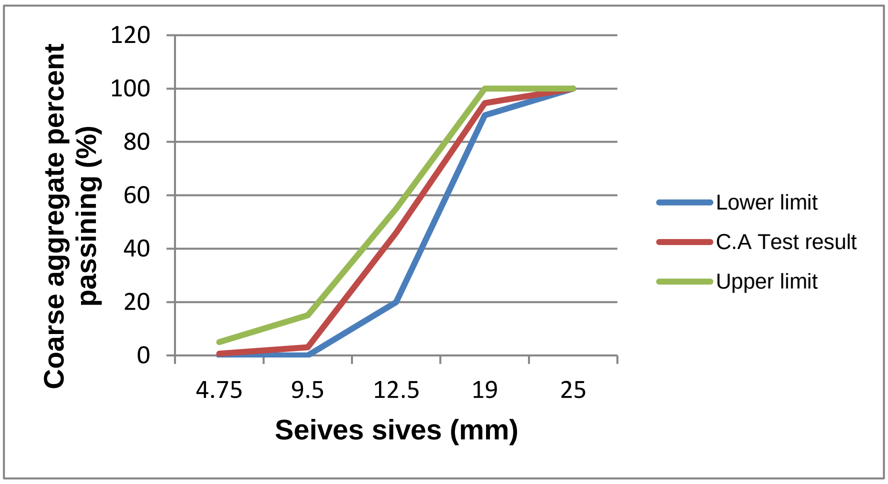


Figure 5. Particle size distribution on coarse aggregates

The workability of concrete is improved due to the systematic grading nature of the controlled aggregates and enhances durability, in general. The value of fineness modulus of fine aggregate and that of the coarse aggregate both are within the standard range of 2.3 to 3.7, thus satisfies the Ghanaian and ASTM C-33 standards and bring into line with results stated in pioneer studies [72].

3.4 Tests on Properties of River Sand

A standard procedure was followed to ascertain the suitability of fine aggregate [73]. In accordance with ASTM C-33, the specific gravity of the sand is ranged between 2.4 and 3.0 [75]. The silt content of 2.5% which is less than 3% satisfies the British code. [74]. Table 4 shows a low moisture content of 0.27%, bulk unit weight in the range of 1560 and 1600 kg/m³, and water absorption capacity of 0.6% indicate a clean and well-graded sand, ensuring upright closeness with the cement paste and abridged the shrinkage [75].

Table 4. Overall Properties of Fine Aggregates

No.	Test Description		Test Results
1	Silt content		2.5%
2	Moisture Content		0.27%
3	Bulk Unit Weight	Loss	1560 kg/m³
		Compacted	1600 kg/m³
4	Absorption Capacity		0.6%
5	Fineness Modulus		2.54%
6	Specific Gravity	Bulk	2.7
		Bulk (SSD)	2.74
		Apparent	2.76

3.5 Test Results on Coarse Aggregate

Table-5 shows the overall properties of coarse aggregates.

Table 5. Overall Properties of Coarse Aggregates

No.	Test Description		Test Results
1	Maximum Size		20mm
2	Moisture Content		0.89%
3	Unit Weight	Loss	1560 kg/m³
		Compacted	1747 kg/m³
4	Absorption Capacity		1.25%
5	Specific Gravity	Bulk	2.7
		Bulk (SSD)	2.79
		Apparent	2.85

The results over the physical tests on coarse aggregates are reported in Table 6 and Table 7 are within ASTM C-33 standards. A minor adjustment is required over the higher absorption rate during mixing and the overall properties confirm the suitability of the aggregate for structural concrete [76].

3.6 Concentration of Banana Peel Components

Under dry condition, the overall concentration in mg per 100 gm peel for various components are listed in Table-7.

The reduction in overall weight of the concrete is achieved due to lower density of BPA. Furthermore, the specific gravity of 2.16 g/cm³ and average particle size of 63.5 µm of BPA authorize its fitness as a partial cement replacement.

3.7 Fineness of Combined Cement - BPA Blends

As shown in Table-8, the finess requirement is highly satisfied as the proportion of residue retained was below 10% in each code [78]. No substantial changes occurred due to the inclusion of BPA and thus fits on pozzolanic tendency. This prevailing nature of the blend is promoting the bonding and hydration, conducive to the overall strength of the concrete.

3.8 Compressive Strength of BPA-Modified Concrete

It is prime importance to evaluate the compressive load-bearing capacity of blended concrete [79] and measured at curing intervals of 7, 14, and 28 days, is systematically presented in Table-9 and Figure 6. The result outcome highlights the required strength of 25 Mpa in 7 days is resulted with 5% BPA addition.

The variations in compressive strength are examined by the statistical analysis using ANOVA and GraphPad Prism (Version 8.0) across different BPA concentrations [80, 81], as shown in Figure 7.

Graphical prism (version 8) was used to show BPA variants as shown in Figures 7 and 8.

The standard deviation of 1.756 to 3.200 corresponding to 0% BPA, indicates the highest variability. More consistent and predictable behavior is seen with 5% BPA as the standard deviation narrowed between 0.9326 and 0.9416. On the trail with 10% BPA, the variability slightly increased while the irregular dispersion was found with 15% BPA. The analysis confirmed that the addition of 5% to 15% of BPA is good enough to achieve the stability as the excessive replacement reduces workability and result with the less cohesive nature [82-85].

Table 6. Mix Proportioning of C-25 concrete (SCC)

Item unit	Ingredients			
	Cement	Fine aggregate	Coarse aggregate	Water
kg/m^3	409	942.36	886.32	211.26
Ratio	1	2.3	2.17	0.52
Per one bag cement	50 kg	115.14 kg	106.09kg	25.8 kg
Per 1mix. (0.0304)	12.43 kg	28.65 kg	26.9kg	6.42 kg

Table 7. Concentration of components of Banana Peels in Dry Condition

Components	Concentration in mg per 100 gm Peel in Dry condition
Calcium	0.36
Starch	0.79
Phosphorous	0.25
Lipids	1.20
Zinc	0.19
Crude Protein	4.55
Raw Fiber	11.85

Source: (James Darmey *et al.,* 2023),[77]

Table 8. Proportion of Blending of Banana Peel Ash and Cement

S. No	Code	Proportion by volume W_1		Weight of blended cement retained on no.200 sieve (gm) W_2	Fineness (F) in % $F=\frac{W2}{W1}*100$
		Cement (%)	BPA (%)		
1	BPA 0	100	0	1.2	1.2
2	BPA 5	95	5	1.75	1.75
3	BPA 10	90	10	3.1	3.1
4	BPA 15	85	15	4.25	4.25
5	BPA 20	80	20	6.5	6.5
6	BPA 25	75	25	8.25	8.25

Table 9. Average Compressive Strength using BPA

BPA (%)	7 days Average Compressive strength (Mpa)	14days Average Compressive strength (Mpa)	28 days Average Compressive strength (Mpa)
0	28.77	32.04	35.24
5	25.37	28.79	30.27
10	23.91	26.60	28.37
15	21.56	24.13	25.53
20	18.59	20.07	22.69
25	13.77	16.19	17.19

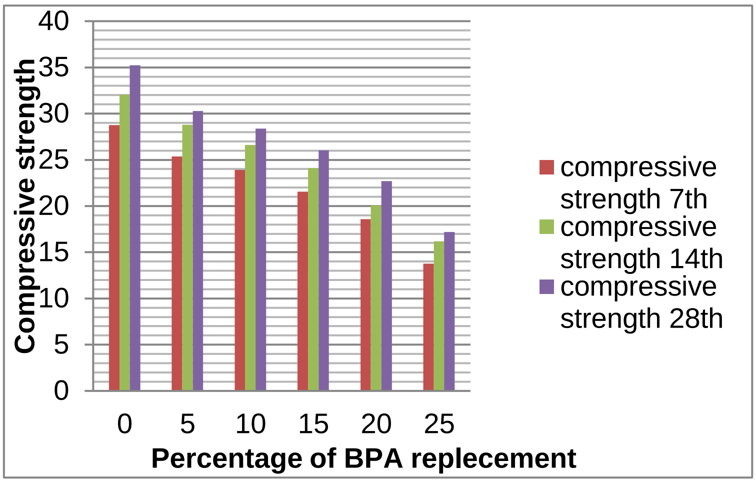


Figure 6. Variations on Compressive strengths corresponding to 7 days, 14 days and 28 days

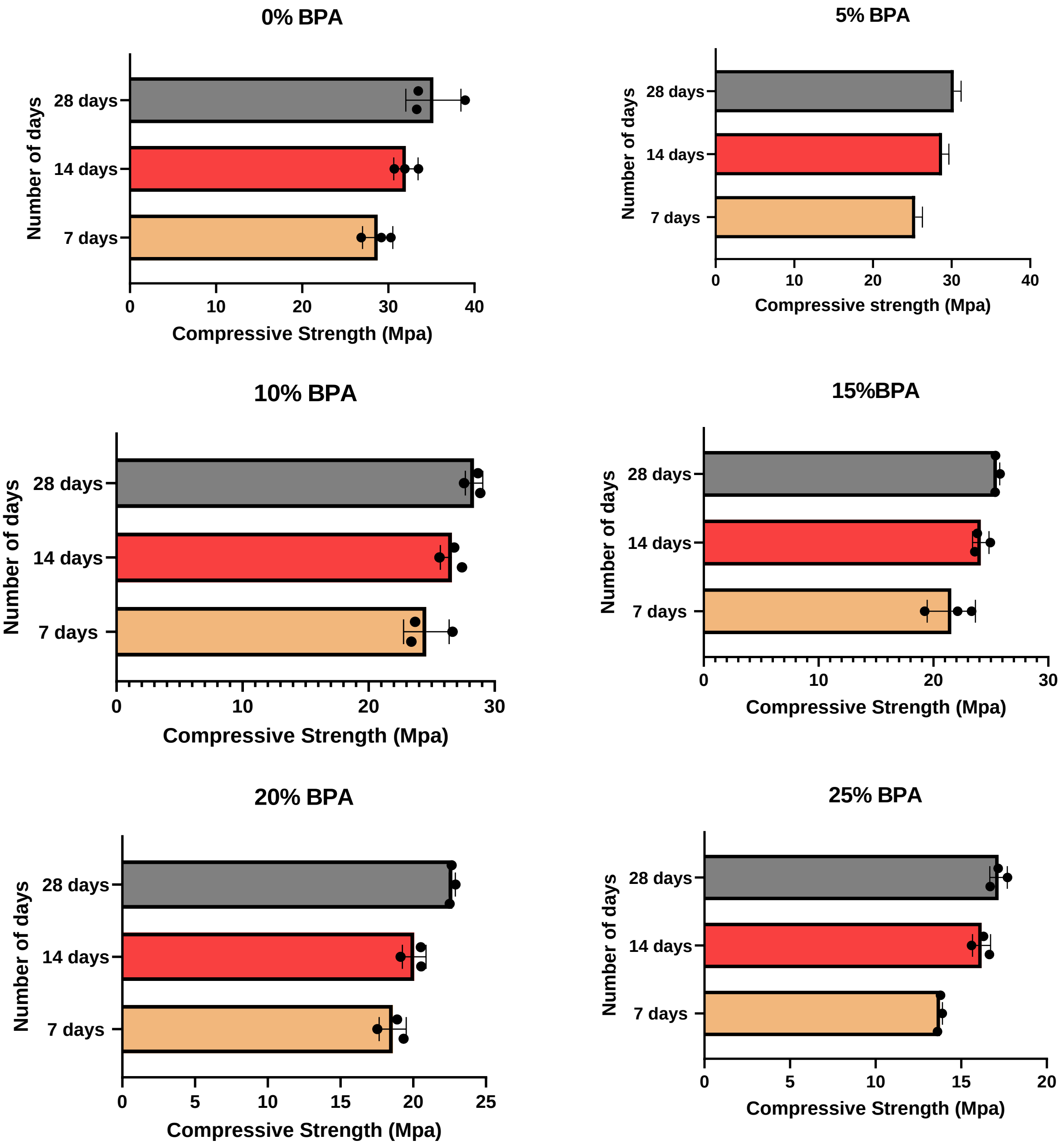
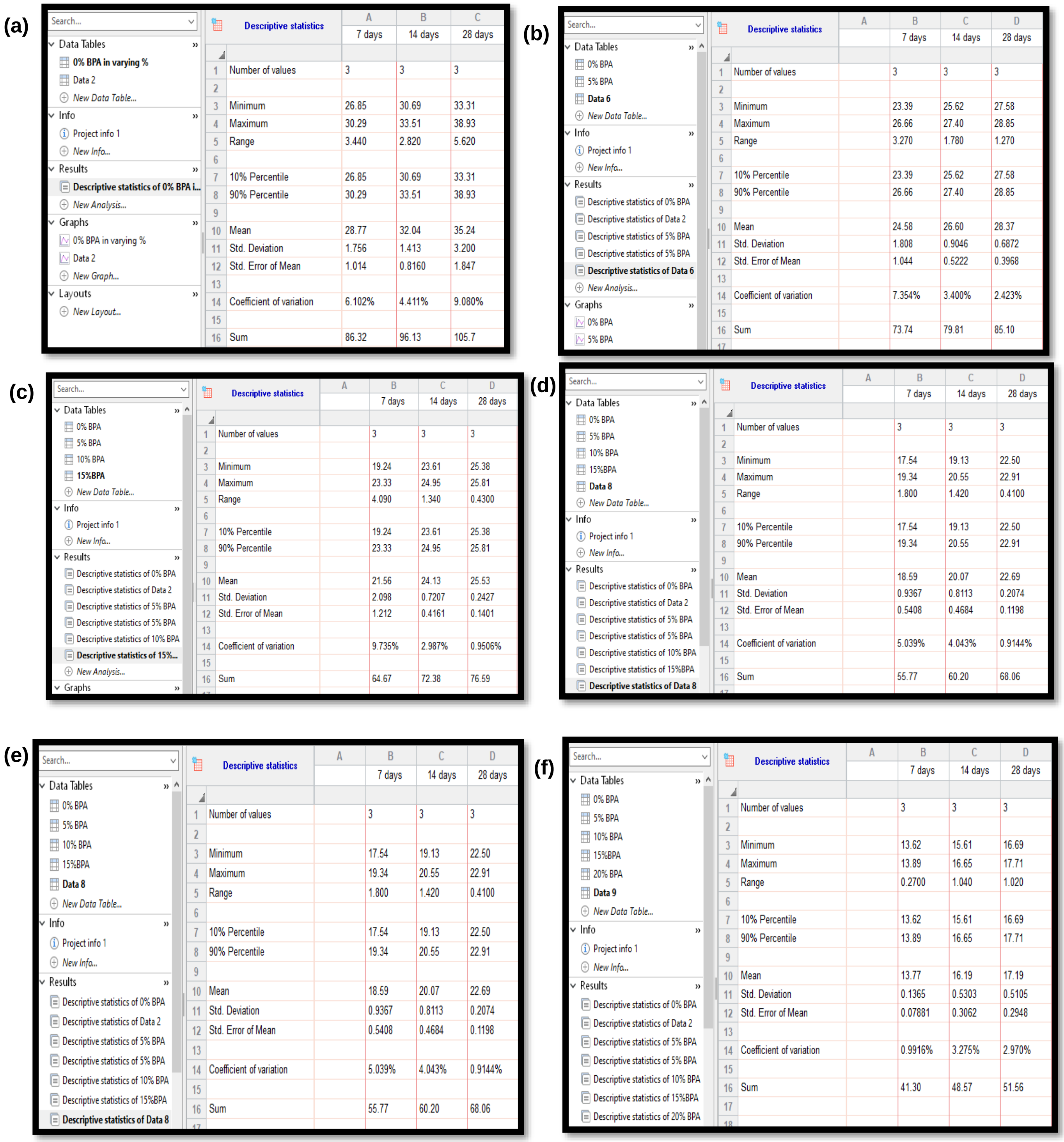


Figure 7. Statistical profile on BPA variants using ANOVA method (GraphPad Prism Version 8.0)



(a)

	Descriptive statistics	A 7 days	B 14 days	C 28 days
1	Number of values	3	3	3
2				
3	Minimum	26.85	30.69	33.31
4	Maximum	30.29	33.51	38.93
5	Range	3.440	2.820	5.620
6				
7	10% Percentile	26.85	30.69	33.31
8	90% Percentile	30.29	33.51	38.93
9				
10	Mean	28.77	32.04	35.24
11	Std. Deviation	1.756	1.413	3.200
12	Std. Error of Mean	1.014	0.8160	1.847
13				
14	Coefficient of variation	6.102%	4.411%	9.080%
15				
16	Sum	86.32	96.13	105.7

(b)

	Descriptive statistics	A	B 7 days	C 14 days	D 28 days
1	Number of values		3	3	3
2					
3	Minimum		23.39	25.62	27.58
4	Maximum		26.66	27.40	28.85
5	Range		3.270	1.780	1.270
6					
7	10% Percentile		23.39	25.62	27.58
8	90% Percentile		26.66	27.40	28.85
9					
10	Mean		24.58	26.60	28.37
11	Std. Deviation		1.808	0.9046	0.6872
12	Std. Error of Mean		1.044	0.5222	0.3968
13					
14	Coefficient of variation		7.354%	3.400%	2.423%
15					
16	Sum		73.74	79.81	85.10

(c)

	Descriptive statistics	A	B 7 days	C 14 days	D 28 days
1	Number of values		3	3	3
2					
3	Minimum		19.24	23.61	25.38
4	Maximum		23.33	24.95	25.81
5	Range		4.090	1.340	0.4300
6					
7	10% Percentile		19.24	23.61	25.38
8	90% Percentile		23.33	24.95	25.81
9					
10	Mean		21.56	24.13	25.53
11	Std. Deviation		2.098	0.7207	0.2427
12	Std. Error of Mean		1.212	0.4161	0.1401
13					
14	Coefficient of variation		9.735%	2.987%	0.9506%
15					
16	Sum		64.67	72.38	76.59

(d)

	Descriptive statistics	A	B 7 days	C 14 days	D 28 days
1	Number of values		3	3	3
2					
3	Minimum		17.54	19.13	22.50
4	Maximum		19.34	20.55	22.91
5	Range		1.800	1.420	0.4100
6					
7	10% Percentile		17.54	19.13	22.50
8	90% Percentile		19.34	20.55	22.91
9					
10	Mean		18.59	20.07	22.69
11	Std. Deviation		0.9367	0.8113	0.2074
12	Std. Error of Mean		0.5408	0.4684	0.1198
13					
14	Coefficient of variation		5.039%	4.043%	0.9144%
15					
16	Sum		55.77	60.20	68.06

(e)

	Descriptive statistics	A	B 7 days	C 14 days	D 28 days
1	Number of values		3	3	3
2					
3	Minimum		17.54	19.13	22.50
4	Maximum		19.34	20.55	22.91
5	Range		1.800	1.420	0.4100
6					
7	10% Percentile		17.54	19.13	22.50
8	90% Percentile		19.34	20.55	22.91
9					
10	Mean		18.59	20.07	22.69
11	Std. Deviation		0.9367	0.8113	0.2074
12	Std. Error of Mean		0.5408	0.4684	0.1198
13					
14	Coefficient of variation		5.039%	4.043%	0.9144%
15					
16	Sum		55.77	60.20	68.06

(f)

	Descriptive statistics	A	B 7 days	C 14 days	D 28 days
1	Number of values		3	3	3
2					
3	Minimum		13.62	15.61	16.69
4	Maximum		13.89	16.65	17.71
5	Range		0.2700	1.040	1.020
6					
7	10% Percentile		13.62	15.61	16.69
8	90% Percentile		13.89	16.65	17.71
9					
10	Mean		13.77	16.19	17.19
11	Std. Deviation		0.1365	0.5303	0.5105
12	Std. Error of Mean		0.07881	0.3062	0.2948
13					
14	Coefficient of variation		0.9916%	3.275%	2.970%
15					
16	Sum		41.30	48.57	51.56
17					

Figure 8. Statistical analysis on Mean and Standard divisions of BPA variants (GraphPad Prism Version 8.0), (a) Descriptive Statistics – 01, (b) Descriptive Statistics – 02, (c) Descriptive Statistics – 03, (d) Descriptive Statistics – 04, (e) Descriptive Statistics – 05, (f) Descriptive Statistics - 06

4. Limitation of the Study

The research did not focus on Ultrasonic Pulse velocity test to evaluate the structural soundness of special concrete.

5. Conclusions

When BPA is introduced in larger quantities, the compressive strength decreases. This is because a large amount of the cement is replaced, reducing the total cementitious material available for binding. Excessive BPA can also cause larger void spaces in the concrete and reduced workability, jeopardizing its structural integrity. The overall findings show that including BPA into cement formulations progresses setting times, workability, and ultimate strength. Furthermore, BPA's ability to retain a sufficient plasticity index indicates its potential to advance structural resilience and lower the danger of early concrete collapse. As a result, using BPA as a cement alternative within these set limits provides significant environmental benefits. This partial replacement technique directly helps to reduce carbon dioxide (CO_2) emissions, a key greenhouse gas. Beyond CO_2, using BPA in concrete production reduces the demand for virgin raw materials, reduces energy consumption during manufacturing, and, eventually, lowers overall atmospheric pollutant emissions. This technology reduces landfill pressure by transforming banana peels into useable construction additives while also recycling organic leftovers. Locally generated agricultural waste, such as banana peel ash, is a cheaper alternative to more expensive imported resources such as cement, cutting construction costs. Partially substituting cement, a substantial carbon emitter, with banana peel ash (BPA) helps lower the carbon footprint of the construction industry, leading to better building practices.

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Authors Contribution Statement

Subash Thanappan: Conceptualization, Investigation, Methodology, Data collection, Formal analysis, Writing Original Manuscript. Dimitrios A Karras: Validation, Review Writing & Editing. Aiman Al-Odaini: Conceptualization, Visualization, Supervision. All the authors read and approved the final version of the manuscript.

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Competing Interests

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Data Availability

The data supporting the findings of this study can be obtained from the corresponding author upon reasonable request.

Has this article screened for similarity?

Yes

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