Journal of Mines, Metals and Fuels, *73(9): 2841-2849; 2025. DOI: 10.18311/jmmf/2025/49686*

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: *www.informaticsjournals.co.in/index.php/jmmf*

Analysis of Biogenic Materials for Self-Compacting Concrete

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Abstract

Notably, the ineffective Biogenic organic waste management is largely due to the limited landfill capacity at Tema town in Ghana, in turn, results with health issues, such as respiratory complications, dermatological irritation, and the increased transmission of infectious diseases. This is mostly due to the release of noxious gases, pathogens, and pollutants, including Methane, Carbon dioxide, and Volatile organic compounds (VOCs) and Particulate matters into the environment. Recycling organic waste is particularly important for public health as it reduces the threat of infection and therefore, this article focuses on recycling of a Bio- organic element for the generation of C-25 self-compacting concrete (SCC). In this research, both fresh and hardened features of concrete and really appropriate allowable alternative fraction of Banana Peel Powder Ash (BPPA) replacing cement had determined for C-25 concrete. Workability of SCC samples was tested by means of T500 slump flow, L-box, and V-Funnel test methods. The outcome of these characteristics of concrete in this investigation form a foundation for proportioning of powerful SCC combinations relevant for further utilization in the building industries. In addition, it plays a key role in minimizing overall environmental issues and reduces intake of cement for making SCC by means of employing Banana Peel Powder Ash (BPPA) as a supplementary ingredient. To achieve the specific goal of this study, six mixes of SCC samples had been investigated. In this case, quantities of satisfactory quantity of fine aggregates and coarse aggregates are kept constant whereas, Cement and Banana Peel Powder Ash (BPPA) amount varies with the fraction of substitute. The optimum advocated constraint of Banana Peel Powder Ash (BPPA) replacing cement to supply suited energy for SCC is 15% accomplishing its 28th day compressive reliability of 26.03Mpa.

Major findings: *The experiments revealed that the applications of banana peels in the form of ashes are appropriate for making self-compacting concretes. The study finds that replacing 15% of cement with BPPA maintains comparable strength and workability for concrete.*

Keywords: *Banana Peel Powder Ash (BPPA), Bio-Aerosols, Dermatological Irritation, Respiratory Complications, Self-Compacting Concrete, Skin Rashes, Vector-Borne Diseases*

1.0 Introduction

The negative impacts on public health are a major issue due to the generation of high rates of biogenic organic waste. The management of these wastes is becoming one of the most important challenges, especially in low- and middle-income countries Ghana today. The detrimental impact of improper waste disposal has significantly affected the city of Accra in Ghana, particularly in terms of the rising incidence of diseases[1]. The pervasive challenges associated

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with organic waste primarily stem from inadequate strategic planning, poor governance, limited resources, insufficient coordination, and ineffective management. In the rapidly growing city of Accra, the most pressing issue is the ineffective collection and disposal of solid waste. Key contributors to this waste include residential neighbourhoods, commercial districts, industrial zones, pilgrimage sites, agricultural lands, and marketplaces[2].

Concerns regarding waste management in Accra predominantly centre on urban areas, as opposed to rural regions. The urban sectors of Accra produce a wide variety of waste (Figure 1), with the main categories being domestic solid waste, industrial waste, and construction debris. Although there are a few designated dumpsites for waste disposal, a significant portion of this waste is improperly discarded in drains, streams, and open spaces. Waste management practices include open dumping, open burning, controlled burning, and disposal at designated sites. The growing population in Accra is exacerbating a sanitation crisis, primarily due to the overwhelming challenges of managing both municipal solid and liquid waste[3].

The pollution levels in water bodies such as the Lafa basin, Korle Lagoon, Densu River, and Glefe-Gbegbe Lagoon in Accra are alarmingly high, largely due to the presence of pathogenic bacteria resulting from the influx of organic volatile waste into these water sources[4-6].

The process of producing organic manure through composting is significantly hindered by the salinity of the soil[7]. Elevated sodium levels in water bodies can lead to sodium toxicity, increased osmotic stress, and reduced cell plasmolysis, which in turn disrupts anaerobic processes and renders the water unsuitable for sensitive crops such as rice, wheat, beans, sorghum, and various other agricultural products[8].

The secondary products resulting from organic waste primarily stem from alterations in their properties. If not adequately managed, these by-products, known as biodrops, can contain essential nutrients such as various organic compounds, nitrates, phosphates, and occasionally heavy metals, primarily produced through osmotic processes[9]. This mismanagement can lead to significant environmental issues, including Eutrophication, alterations in pH levels, and potential health hazards when contaminated water is utilised for drinking or irrigation purposes. Inadequate disposal of organic waste severely compromises groundwater quality[10].

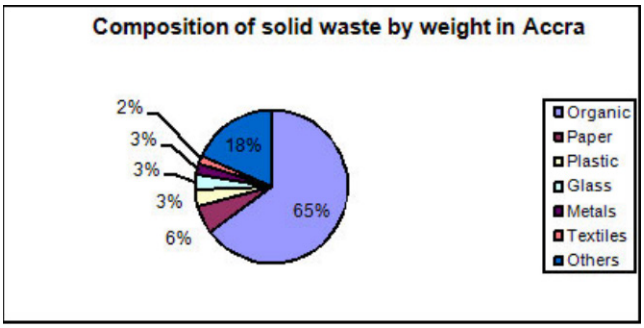


Figure 1. Composition of solid waste by weight in Accra, Ghana. Source: Accra Municipality

2.0 Impacts of Organic Wastes on Human Health

Mathemoglobinemia (commonly referred to as Blue Baby Disease): It is highlighted that decomposable waste, such as banana peels, contributes to elevated nitrate levels, increased Biochemical Oxygen Demand (BOD), and potential bacterial contamination when continuously discarded, particularly when leachate infiltrates the water table. Excessive nitrate concentrations (greater than 45 ppm) in groundwater pose risks to infants less than four years of age, leading to Methemoglobinemia (Blue Baby Disease)[11].

Gastrointestinal and Dermatological Diseases: The presence of organic waste significantly affects the longevity of water by depleting dissolved oxygen levels necessary for decomposition. Eutrophication results in algal blooms that disrupt aquatic ecosystems, adversely affecting fish and other organisms. Consequently, this pollution poses serious health risks due to the consumption of contaminated drinking water[12,13].

Asthma and Byssinosis: It is declared that the impact of organic dust on asthma has been extensively studied, yielding varying outcomes. Organic dust is an intricate mixture of dust and tiny particles of organic origin. Organic dust exposures are linked to the development of chronic bronchitis, chronic obstructive pulmonary disease, asthma, asthma-like syndrome, byssinosis, hypersensitivity pneumonitis, and idiopathic pulmonary fibrosis[14,15].

Allergic symptoms: Volatile Organic Compounds (VOCs) are significant and prevalent air pollutants that can lead to a notable increase in respiratory diseases. Exposure to VOCs is associated with a heightened risk

of developing asthma in children. Additionally, VOC exposure is connected to various negative health effects, including irritation of the respiratory tract, atopic dermatitis, wheezing, inflammation of the airways, allergic reactions, reduced lung function, nocturnal breathlessness, and asthma[16,17].

Hypernatremia: An excessive intake of sodium, or sodium toxicity, primarily results in elevated blood pressure (hypertension), which raises the risk of cardiovascular diseases, strokes, and kidney complications. In severe instances, this condition can lead to hypernatremia, which may result in seizures, coma, and even death[18].

Cholera, Typhoid, Hepatitis, Giardiasis, and Arsenicosis: Liquid waste travels through refuse to the ground and seeps beneath the surface until it reaches the groundwater or enters the groundwater system via gravity. Contaminants from leachate first affect the unsaturated zone before infiltrating the saturated zone of the groundwater table. Consequently, groundwater contamination due to the infiltration of water from landfills poses significant environmental challenges and concerns[19].

Respiratory Problems: A study conducted by Sasha Alzate Acevedo and colleagues in 2021 highlighted that banana peels represent a significant portion of waste generated in markets. In an 18.14 kg box of bananas, approximately 60% is pulp and 40% is peel, with an additional 7.25 kg of sheath. The peels are rich in carbon-based organic compounds, including cellulose (7.6%), hemicellulose (6.4%), pectin (10%), and lignin (6%)[20]. If not disposed of properly, these wastes can emit unpleasant odours due to natural decomposition and release gases that contribute to the greenhouse effect. Prolonged exposure to these conditions can adversely affect various organs, particularly the respiratory, cardiovascular, central nervous, immune, digestive, and reproductive systems[21].

Research by Cheng L. Zhang and colleagues in 2021 demonstrated that VOC emissions from fruit residues, such as banana peels, particularly during aerobic decomposition, pose significant concerns for community health[22].

Anju Anilkumar and associates (2015) found that groundwater samples indicated that leachate from accumulated organic waste plays a crucial role in local groundwater contamination. The levels of nitrates (88 mg/L) and Total Dissolved Solids (TDS) (726 mg/L) in the groundwater are concerning and should be carefully evaluated before being used for drinking. Additionally, groundwater near municipal solid waste dumping sites was found to be contaminated with faecal E. coli (8 kbe/100 ml), rendering it unsuitable for consumption[23].

Transforming banana peels, a type of biogenic organic waste, into usable materials should be considered as an alternative disposal method, as this approach can help reduce greenhouse gas emissions[24,25].

3.0 Methodology for the Recycling of Biogenic Organic Waste: Utilising Banana Peels as an Eco-Friendly Alternative to Enhance Public Health.

Promoting public health can be achieved through the implementation of effective waste management technologies, particularly in the recycling of biogenic organic materials. Landfill guidelines for organic wastes like banana peels should prioritise reducing the volume of waste going to landfills through recycling. For Ghana, the Environmental Protection Agency (EPA) also recommends techniques like recycling, while banana peels can be disposed of in landfills.

Self-Compacting Concrete (SCC) is a specialised type of concrete that flows uniformly into formwork without segregation or bleeding. It offers superior finishes, simplifies placement, allows thinner concrete sections, eliminates the need for vibration, and creates a safer working environment. The numerous benefits of SCC, such as faster production times, reduced space requirements for thinner sections, enhanced durability, and compatibility with dense reinforcement, have led to its increasing popularity in civil engineering projects[26]. SCC represents a modern concrete technology that has been developed over the last three decades[27,28]. This type of concrete is composed of standard cement, supplementary materials (including fly ash and GGBS), fine and coarse aggregates, and high-quality plasticisers[29].

Considering this, the current research aims to incorporate Banana Peels in the form of ash as a partial replacement for cement. An experimental study was conducted to assess the impact of adding Banana Peel Powder Ash (BPPA) on the fresh and hardened properties of self-compacting concrete, including its filling capacity, passing ability, and compressive strength[30].

4.0 Methodology

4.1 Collection of Baseline Information about Organic Wastes in Ghana

The secondary data regarding the generation of organic waste was gathered through literature reviews, databases, and direct interviews conducted with various organisations in Accra, Ghana. This data encompasses information from the Accra Metropolitan Assembly (AMA) Waste Management Department, the FAOSTAT database—an internally approved database in Ghana; Ghana's Fourth Inventory Report (2019); the West African Plantain and Banana Database; the Department of Agriculture in Accra; as well as the Bureau of Statistics and Ministry of Agriculture websites. Additionally, it includes the Manual for the Preparation of District Waste Management Plans in Ghana (2002) and the Ghana Landfill Guidelines from July 2002.

Banana peels were sourced from the Kasoa fruit market in Accra and subjected to initial treatments. After thorough washing with deionised potable water, the banana peels were cut into small pieces and heated in an oven at 100°C. The well-heated dry samples were then ignited using a traditional method (as illustrated in Figure 2) to produce Banana Peel Powder Ash (BPPA) in powdered form (as shown in Figure 3).

The properties of both coarse and fine aggregates were assessed by standard laboratory procedures. The coarse aggregate of 20mm size was used for the study as per the Ghana guidelines. The cement, aggregates, and water were combined based on weight, while the water was measured by volume. All specimens were cast under consistent room temperature conditions[31]. The substitution of cement with BPPA was conducted based on weight[32]. The moisture content of the fine aggregate was adjusted to ensure optimal performance.



Figure 2. Traditional heating process of Oven-dried Banana peels.



Figure 3. Banana Peel Powder Ash (BPPA) (EGA).

This experimental study involved the creation of six distinct mixtures, each with different proportions of ash substituting cement at levels of 0%, 5%, 10%, 15%, 20%, and 25%. The research focuses on the development of Self-Compacting Concrete (SCC) by replacing cement with Banana Peel Powder Ash (BPPA) at these six varying percentages, while also utilising a high-range water-reducing admixture. The properties evaluated for each mixture included workability, stability index, and compressive strength[33].

Once the material proportions were determined, the aggregates, cement, and BPPA were mixed dry for one minute. Following this, water was added, and the mixture was thoroughly blended for an additional two minutes using a mixing machine. After the concrete was prepared, its workability and fresh unit weight were measured using L-box, V-funnel, slump cone, and weight balance methods (Figure 4). A V-funnel test was conducted to ascertain the ease of flow of the concrete. The specimens were then carefully placed on a stable, flat surface within pre-made moulds measuring 150mm x 150mm x 150mm to form compressive cubes.

After a period of 24 hours, the specimens were extracted from the moulds and subsequently placed in a curing tank for durations of 7, 14, and 28 days at the laboratory's ambient temperature. During the preparation of the concrete, it underwent six distinct batches (phases), with each phase containing nine cubes that incorporated specific percentages of cement replacement with BPPA.



Figure 4. L-box test.



Figure 5. Slump flow test.

The compressive strengths for all replacement percentages were assessed at 7, 14, and 28 days.

5.0 Results and Discussion

The test results on the properties of coarse aggregate and fine aggregate are tabulated as shown in Table 1.

The proportions of fine and coarse aggregates remained constant across all replacement percentages, with fine aggregate weighing 942.36 kg/m^3 and coarse aggregate weighing 886.32 kg/m^3. To mitigate segregation issues, the minimum powder content in Self-Compacting Concrete (SCC)[34] should range from 380 kg/m^3 to 600 kg/m^3. Consequently, this study adopted a powder content of 409 kg/m^3. As detailed in Table 2, 8.18 litres of high-range water-reducing admixture were incorporated into the mixture, with the maximum water content permissible in this study being 211.26 kg/m^3. To overcome the effect of the water–cement ratio, the amount of water is kept constant as shown in Table 2.

Table 1. Properties of aggregates

Properties of coarse aggregate	
Nominal Maximum size	20mm
Fineness Modulus	**3.50%**
Unit weight	1,747kg/m^3
Specific gravity	2.79
Absorption	1.25%
Free moisture content	0.89%
Properties of fine aggregate	
Fineness Modulus	**2.54%**
Unit weight	1600 kg/m^3
Specific gravity	2.74
Absorption	0.6%
Free moisture content	0.27%
Sand Silt Content	2.5%

5.1 Workability and Flowability of SCC

Table 3 and Figure 6 illustrate that as the percentage of BPPA replacing cement increases, the flowability of the concrete diminishes, and the time required to achieve a 500mm diameter increases[35]. Therefore, this study identifies the optimal acceptable BPPA replacement for cement, in terms of slump flow and V-funnel tests, to be up to 15%. The corresponding T500 slump flow, h2/h1 ratio, and V-funnel times are recorded as 4.33 seconds, 0.83 seconds, and 14.01 seconds, respectively. Thus, the acceptable range of up to 15% is deemed appropriate[36]. They strongly advised that the replacement rate should not exceed 20%. Furthermore, Hongzhang noted that excessive cement replacement could adversely affect the concrete's strength[37]. Therefore, a 15% replacement of cement with BPPA is considered acceptable.

5.2 Compressive Strength of SCC

The experiment indicates that the compressive strength of concrete with a 0% control mix surpasses that of all other samples where cement was substituted with Ash at various percentages. Consequently, the compressive strength of concrete with a 25% replacement of cement by Banana Peel Powder Ash (BPPA) was identified

Table 2. Mix proportioning

Mix. No.	% of replacement.	Cement (kg/m³)	BPPA (kg/m³)	Fine aggregate (kg/m³)	Coarse aggregate (kg/m³)	Water (kg/m³)	Super Plasticizer (kg/m³)
SCC1	0	409	0	942.36	886.32	211.26	8.18
SCC2	5	397.82	11.18	942.36	886.32	211.26	8.18
SCC3	10	386.64	22.36	942.36	886.32	211.26	8.18
SCC4	15	375.46	33.54	942.36	886.32	211.26	8.18
SCC5	20	364.28	44.72	942.36	886.32	211.26	8.18
SCC6	25	353.1	55.9	942.36	886.32	211.26	8.18

Table 3. Workability of varying mixes

Mix. no.	Replaced BPPA (%)	T500 (sec)	V-Funnel (sec)	L-Box (h_2/h_1)	Slump flow (mm)
SCC1	0	1.97	9.16	0.92	630
SCC2	5	2.51	10.7	0.89	600
SCC3	10	3.10	12.5	0.86	580
SCC4	15	4.33	14.01	0.8	550
SCC5	20	6.95	16.95	0.55	505
SCC6	25	8.46	18.87	0.3	480

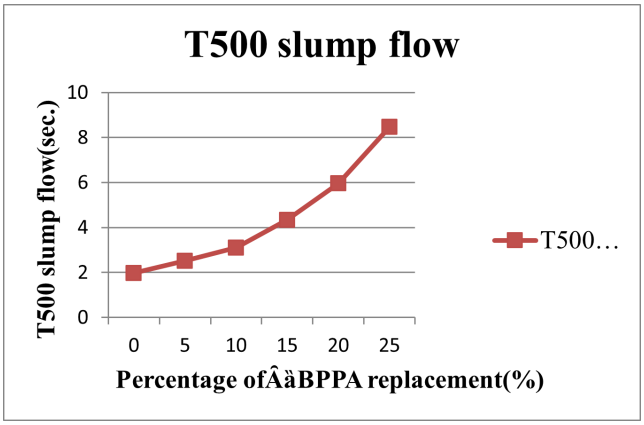


Figure 6. Slump Flow Graph of the mix at different EGA replacement percentages.

as the lowest. Furthermore, the compressive strength of concrete diminishes as the amount of BPPA in the mixture increases[38-42].

For a comprehensive analysis, as illustrated in Table 4 and Figure 7, the compressive strength of concrete declines from 35.24 MPa to 17.19 MPa on the 28th day as the replacement percentage rises from 0% to 25%. The investigation concluded that the optimal ash-to-cement ratio for mixtures containing a high-range water-reducing chemical admixture to achieve adequate strength is 15%. Thus, at a 15% replacement of BPPA, the compressive strength of concrete on the 28th day reached 26.03 MPa.

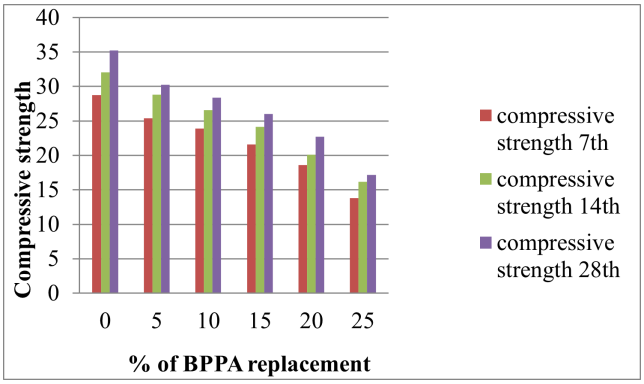


Figure 7. A flow chart showing variation in compressive strength.

Table 4. Test results on compressive strength (MPa)

BPPA Replacement (%)		0% BPPA	5% BPPA	10% BPPA	15% BPPA	20% BPPA	25% BPPA
Compressive strength (MPa)	7th	28.77	25.37	23.91	21.56	18.59	13.77
	14th	32.04	28.79	26.6	24.13	20.07	16.19
	28th	35.24	30.27	28.37	26.03	22.69	17.19

Table 5. Raw material input for one cubic meter of self-compacting concrete

Mix Code	BPPA0	BPPA5	BPPA10	BPPA15	BPPA20	BPPA25
OPC (kg/m^3)	409	397.82	386.64	375.46	364.28	353.1
BPPA (kg/m^3)	0	11.18	22.36	33.54	44.72	55.9
Saving of materials (%)	0	2.73	5.47	8.2	10.9	13.5

5.3 Reduction in CO_2 Emission

The production of one ton of Portland cement releases approximately one ton of carbon dioxide into the atmosphere. The cement industry accounts for about 5% of global carbon dioxide emissions[43]. As shown in Table 5, the 15% replacement led to a 15.08% reduction in raw material usage, which corresponds to roughly 33.54 kg of cement per cubic meter of concrete, compared to the control concrete, which also stands at around 33.54 kg/m^3.

6.0 Conclusion

In this research, a public health initiative was implemented by recycling the biogenic organic waste component. The ideal proportion of Banana Peel Powder Ash (BPPA) as a substitute for cement is determined by its ability to produce a self-flowing, non-segregating SCC mixture that meets the characteristic design requirement of achieving a minimum compressive strength of 25 MPa by the 28th day. The findings indicated that replacing 15% of cement with BPPA results in concrete that maintains comparable strength and workability. Furthermore, it was found that 37% of total CO_2 emissions occur during the fuel consumption phase of cement production. By incorporating BPPA as a partial replacement for Portland cement, the environmental impact of concrete production can be significantly reduced, including the consumption of raw materials and energy, as well as air emissions. The results of this study provide foundational strategies for implementing cost-effective, practical, and straightforward technologies aimed at achieving zero waste, thereby addressing health-related issues and promoting a greener environment.

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