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**Review Article**

# Structural performance of concrete reinforced with banana and orange peel fibers - a review

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## ABSTRACT

In recent years, there has been a surge in interest in developing novel materials for sustainable building construction made from renewable resources. Using natural fibers in concrete reinforcement, as opposed to agricultural waste, has significant environmental benefits in reducing the environmental repercussions of the continuous dumping and land filling of massive amounts of agricultural waste in overburdened landfill sites. Banana peel fiber (BPF) and orange peel fiber (OPF) are common agro-wastes with a long history of use in concrete as an additive or a cement substitute. However, their efficiency and performance in terms of reinforcement must be assessed. Based on recent findings, the characteristics, fresh and hardened state structural performance of BPF and OPF as composite materials in sustainable concrete manufacturing are reviewed in this study. For quality concrete reinforcing, it was discovered that OPF and BPF have good surface areas and low specific gravity. For quality concrete reinforcing, it was discovered that OPF and BPF have good surface areas and low specific gravity. BPF and OPF, on the other hand, have significant pozzolanic binding properties of up to 97.3%. This allows them to act as binders and supplement the high strength yielding in concrete. Furthermore, using BPF in concrete enhanced workability, consistency, compressive and tensile strengths, and setting times by 21.1%, 48.64%, 46%, 52.5%, and 47.37%, respectively, whereas the use of OPF raised concrete density by 5.34%. This indicated that both BPF and OPF had much potential for producing high-quality concrete. Using BPF and OPF to reinforce concrete and composites against flexural deflection, heat transmission, and modulus of elasticity significantly increase concrete strength in terms of cracking, deflection, creep, and shrinkage. The inclusion of orange and banana peels in concrete was found to improve the structural qualities of the concrete significantly; thus, they can be employed as supplementary materials in manufacturing concrete. Finally, this study identifies new approaches for achieving the much-anticipated biodegradability and sustainability of natural fiber-reinforced composites for use in various concrete reinforcing applications.

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## 1. INTRODUCTION

Concrete is a composite material generally produced from coarse and fine aggregates, cement, and water proportionally with or without admixture [1, 2]. Concrete is considered a globally acceptable construction material because of its low production cost, global availability for use, setting times, hardening, and strength generation rate that can be achieved at ambient temperature. Some structures were constructed using concrete materials such as bridges and roads, parking structures, buildings, pavements, poles, and fences [3]. Concrete is the second most used material globally; from his estimation, the rate at which an individual yearly consumes concrete globally is up to 3 tonnes. Comparing this to other construction materials such as clay, metals, and wood, the number of concrete materials used for structural construction in building industries was twice that of other construction materials Gopal [4–6]. Almost 19,000 concrete bathtubs are produced every second globally, both in engineering firms and construction industries. It was recorded that up to sixteen million cubic meters of concrete were used for constructing three Gorges dams in China. It was also recorded that up to 4.2 billion cubic meters (about 10 billion tonnes) of concrete were produced globally in a year [7].

As the world population is increasing, the concrete production and construction rate is also increasing, especially in China and Asia. The estimation conducted by the global concrete and cement association showed that up to 4.65 billion tonnes of cement were produced yearly, and about ten billion tonnes of concrete were produced in the construction industries globally in a year. It was also recorded that about one billion meters of cubic water were used for concrete production around the globe yearly [8]. Presented in Table 1 is the rate of cement production in the twelve selected countries of the world from 2010 to 2020. China is considered the largest producer of cement around the globe. Because the amount of concrete produced by concrete industries in China is 2.2 billion metric tonnes greater than that of concrete produced in the other countries of the world in 2020. India is the next country to China in the production of a large quantity of concrete. It was estimated that about 340 million metric tonnes of concrete were produced in India in the year 2020 [9].

Consequent to the generation of cement in China, about 823 million metric tonnes of carbon dioxide were emitted, causing atmospheric pollution [10]. Up to 5.8% of greenhouse gases were emitted from the use of cement for concrete production. Supposed cement is a country, it would have been referred to as a third of the largest carbon dioxide emitter in the world. Among the large concrete-producing countries in the world, the United States and China were generating about 2.8 billion tonnes of concrete than other countries like India, Russia, and the UK, this has been causing their high rate of releasing carbon dioxide into the atmosphere, affecting the ozone layers [11, 12]. The United States, India, and China were observed to have emitted higher percentages of $CO_2$ into the atmosphere from the year 1990 to 2019 than the other selected countries as presented in Figure 1.

**Table 1.** Categories of Artificial and Natural wastes generation in the globe [78, 79]

| Categories of global wastes generation | Types of wastes generated |
|---|---|
| Synthetic | Polyamide (nylon), Polyethylene (fibre, mesh, strip), Polypropylene (Crimpled fibre fibrillated fibre, monofilament fibre, mesh, pulp, tape) |
| Metallic | Aluminum (foil, rod), Copper (wire), Steel (rod wire), Galvanized steel |
| Natural | Bhabar, Human hair, coconut (shell), oil palm fibers, Cotton, hemp, pineapple peel, orange peel, banana peel, mango peel |

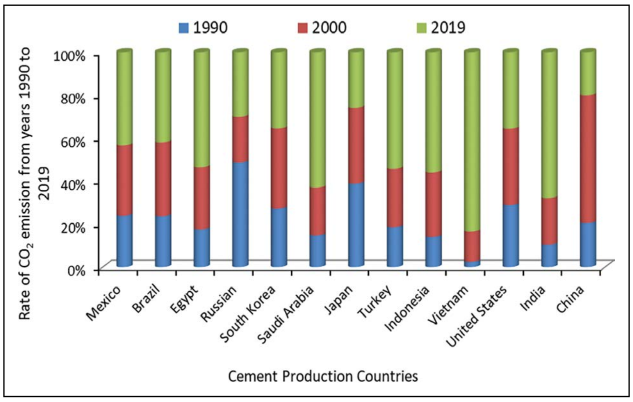


**Figure 1**. Rate of carbon dioxide emissions from cement manufacturing companies [10].

In the construction industry, producing environmentally friendly cement has played a vital part in reducing carbon dioxide emissions from cement production, which is a prerequisite for climatic changes near factory locations around the world. The use of new kiln clinker technology for cement production has reduced the average $CO_2$ emission from the clinker to about 840 kg, which is also expected to be reduced to about 400 kg for the production of one tonne of cement. For instance, the types of cement produced in Spanish cement factories reduced the rate of emitting carbon dioxide by 21%, with a target for cement production from 2010 to 2050. Following the target, the sectors will be able to attain 550 kg of $CO_2$ emission suggested for one tonne of cement produced if the manufactured cement from the companies were made with low emission of $CO_2$ and good cement aggregate intensity is used for the production of concrete and mortar come the year 2050. The burden placed on the environment by the generation and consumption of this large quantity of cement has resulted in an increased quest and interest in more sustainable and green composite materials as suitable replacements for cement in building industries [13, 14].

It was observed that, the rates of global generation of agricultural wastes such as banana and orange peels, especially in the developing nations these days were very high. In a recent report, it was observed that many researchers have been applying agricultural wastes as admixtures in concrete for its sustainability. The effectiveness of these wastes (banana and orange peels) in concrete need evaluation, most especially on concrete structural properties. Thus, this study provides a comprehensive review of the significant properties of concrete structure, its durability characteristics, and structural performance at the application of banana and orange peel fibers as admixtures or aggregates in concrete. It also focuses on evaluating the critical concrete mechanical properties such as compressive strength, tensile strength, flexural strength, density and microstructure, and durability properties such as slump, workability, setting time, and consistency with banana and orange peel fibers. Furthermore, the significant effect of the physical and chemical properties of bananas and oranges - peels on concrete structural enhancement were evaluated. Also, the potential for enhancement of concrete properties with the inclusion of agricultural wastes like banana and orange peels is intensively reviewed in this study. The aim is to determine the level of structural enhancement made by applying the wastes (peels) from banana and orange fruits to concrete in order to improve its structural properties. This evaluation is based on discovery of gaps yet to cover by research scholars, and to recommend them for appropriate improvement. The aim was achieved through the following objectives: (i) to evaluate the physical and chemical sustainable properties of banana and orange peels for concrete structural enhancement (ii) to evaluate the level of structural efficiency of using agricultural wastes (banana and orange peels) to improve the concrete fresh properties (iii) To determine the level of reinforcement contribution made by using agro-wastes (banana and orange peels) to improve the concrete mechanical properties (iv) To evaluate the level of durability capacity of concrete reinforced with banana and orange peels using the reliable experimental data from researchers, and (v) to discover some properties of concrete yet to be efficiently reinforced with the application of banana and orange peel – fibres for its sustainability.These areas, where reinforcement of concrete was not covered were explored for future development. The present study will spotlight new ideas toward realizing the much-anticipated biodegradability and sustainability of these natural fiber-reinforced composites for wide applications in concrete reinforcement.

## 2. LITERATURE REVIEW

The surge in waste generation rate has been a global threat to environmental sustainability. The World Bank report has estimated that about 2.01 billion tons of waste were generated in 2016, and it is projected to have a 70% increase (3.01 billion tons) by 2050, owing to the growing population and urbanization. This amount to 0.74 kg of waste generation by one person in a day; however, this waste is poorly managed, especially in developing countries. About 90% of the wastes generated from low-income nations of the globe are burned, incessantly dumped, or disposed of irregularly. This consequently impacts the environment negatively, resulting in diseases, climatic changes, and urban violence, especially in developing nations where these wastes are mainly generated [15–17]. Currently, waste disposal cost is high; a method of using them should be developed. Thus, sustainable recycling and reuse of this waste in suitable applications is a sustainable approach to managing this waste. This has led to the inclusion of generated wastes in concrete materials to improve their structural properties. Most of wastes generated global were from industrial and environmental products which were classified as artificial (synthetic, metallic) and natural waste – products. The series of products from these waste categories were commonly used for concrete reinforcement to improve its sustainability and durability were presented as shown in Table 1.

As shown in Table 1, most of the wastes generated from the industrial products ((synthetic and metallic) are too expensive to be afforded because of their cost of treatment for the suitability of concrete reinforcement. Researchers have discovered that, the use of wastes from agricultural products is the best alternative to substitute for the high cost of synthetic and metallic fibres for better sustainability of concrete structure. As reviewed, several research works have been conducted on the use of natural fibres (wastes), most expecially on oil palm fibers, Cotton, hemp, pineapple peel, mango peel, orange peel, and banana peel. The effect of orange, and banana peels have to be properly evaluated so as to encourage the more use of it the construction industries for more structural stability.

Banana is a fruit from the herbaceous plant of Musa species produced in several firmness, colors, and sizes. It has a curved and elongated shape. Its cover can be in deferent colors such as brown (ripe one), purple, red, yellow and green. It is rich in starch and soft in the flesh [18–20]. Plantains were the sorts of bananas used for cooking in several parts of the world. Musa paradisiaca, Musa balbisiana, and Musa acuminata are the scientific names for it. Australia is one of the essential banana-growing countries in the world. Although bananas are grown in up to 135 countries worldwide, Papua New Guinea is dominated by them due to their value for ornamental plants, banana beer and wine, and fiber manufacture [21–27]. Figure 2 shows the image of bananas with their different cover colors. At the same time,

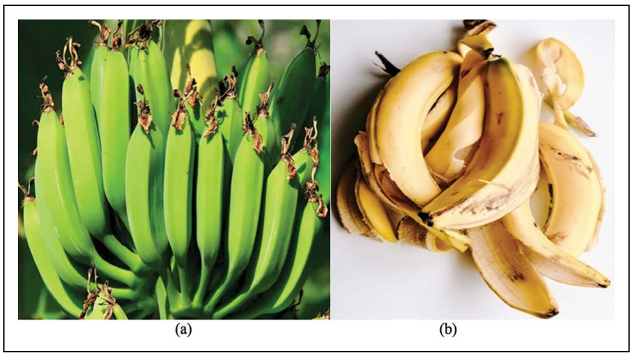


**Figure 2**. The image of bananas with their different colors **(a)** Banana fruits with green and yellow colors **(b)** Yellow bananas' peels scaled [24]

orange is a fruit from the citrus species. Sinensis citrus orange is known as sweet orange. Other oranges are referred to as Citrus aurantium, especially bitter orange, which originated from an area surrounded by Myanmar, Northeast India, and Southern China [28–30]. Orange trees are the most cultivated fruit trees around the globe. They have grown adequately in subtropical and tropical climates. Orange fruit can be eaten fresh after peeling its cover. Juice can also be squeezed from it. About 70% of sweet citrus oranges were produced globally in 2012 [31]. In Brazil only, about 22% of 79 million tonnes of citrus oranges were produced globally in 2019. With this estimation, Brazil is the highest producer of oranges in the world. China and India are next to Brazil in high orange production [27, 31]. Figure 3, 4 show the picture of fresh oranges, squeezed oranges, peeled oranges, and processed orange peels in different sizes.

Based on the available statistics from the United Nations, the global production of bananas was estimated at 115.74 million metric tonnes in 2018. Banana fruits generate about 30–40% peels, an equivalent of about 34.72–46.29 million metric tonnes of peels produced from bananas in 2018, which is a significant burden to the environment [33, 34]. According to Sasha [35], up to 60% of biomass from banana produce in the world is left as waste after harvest. Likewise, juice fruit markets and manufactory industries were generating many waste peels from bananas that can be used to produce other materials instead of allowing them to waste away [36]. Without proper treatment, banana peels will become an environmental problem and lead to a high rate of GHGs emissions. The peel waste from citrus is the highest volume of waste generated from the citrus fruit industries. As estimated, orange peels occupy about 20% of global oranges production. In 2011, estimation showed that up to 15.10 Mt of peels from oranges were produced globally [37]. According to Grohmann [38], about 50–60% of generated wastes around the globe were from the orange fruit. Wastes like segment membrane, peel, and seed. These wastes range from 15 to 25 million tonnes annually [39].

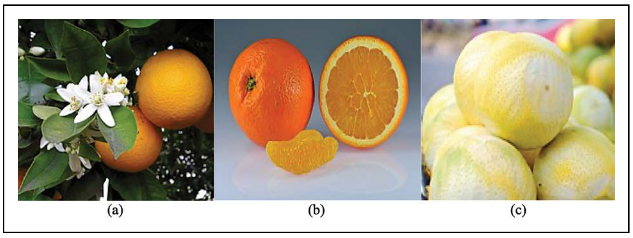


**Figure 3**. **(a)** Bloss oranges **(b)** Half segment of a whole orange **(c)** Peeled oranges [28].

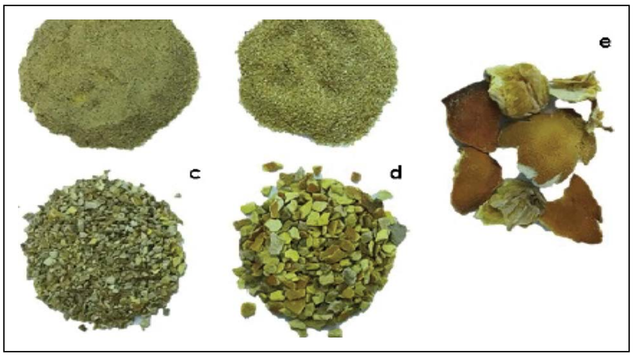


**Figure 4**. Oranges' peels were processed into different particles after oven-dried at hamper temperature [32].

The principal constituent of fruit weight mass is the citrus peel. It occupies up to 44% of waste mass-generated in the world. In 2016, up to 50–60% of global citrus produced 124 million tonnes were eaten raw after cover peeling. Also, about 40 to 50% of these amounts were for industrial purposes [40, 41]. In up to 135 countries, where the production of banana fruits was in large quantities, the skin peels of bananas were collected in urge quantities from government agricultural farms, where the plantation of banana fruits many. Also, banana peels could be serene in bulky at a famous dumping hill in a country, waste disposing locations that belong to banana juice production firms, huge plantain production sites, and global agricultural research centers. As reviewed, mainly all the wastes collected from the dumping locations were treated with chemicals to remove gems and impurities, after which they were sun-dried and oven-dried before turning them into ashes or used as a pure admixture in concrete [23, 42]. Likewise, the peels from citrus fruits were mainly collected from different waste dumping locations, especially from orange production farms around the globe [75].

The review observed that the most significant percentage of orange peels could be composed of juice processing factories in developing countries where agriculture is the primary occupation for economic sustainability. From the other observation, the most significant quantities of citrus peeled skins could be obtained from pastries, hotels, and restaurants waste dumping locations [76]. There is an upsurge in the generation rate of agro-wastes such as banana and orange peels worldwide. Thus, recycling and reusing

**Table 2.** Mechanical and physical properties of Nendran and Dwarf Scavendish banana (Peels) [42, 70]

| Properties | Value | |
|---|---|---|
| | Nendran peels | Dwarf Scavendish peels |
| Average pulp's moisture content (%) | 153.39 | 264.17 |
| Average peel's moisture content (%) | 516.41 | 666.28 |
| Average pulp to peel ratios | 2.32 | 1.39 |
| Peel's thickness (mm) | 2.95 | 3.65 |
| Max. diameter of a banana fruit without peel (mm) | 37.08 | 23.34 |
| Average pulp's specific gravity | 1.110 | 0.993 |
| Max. effective length of banana pulp (mm) | 194.5 | 137.0 |
| Max. effective width of banana pulp (mm) | 50.0 | 66.5 |
| Max. load requirement to cut cross-section of pulp (N) | 28.2 | 22.4 |
| Maximum energy ($J/m^2$) | 724.46 | 686.81 |

them as composite materials in building materials is a sustainable approach to managing waste and its attendant environmental consequences. Applying these agricultural wastes as admixtures in structural concrete has recently gained traction. However, to further enhance its performance in concrete manufacturing, it is essential to evaluate its properties and structural performance.

### 2.1. Mechanical, Chemical, and Physical Properties of Banana Peels

Investigation of the relevant properties of banana peels is critical to evaluating their binding effect and performance in concrete reinforcement. This section examines the banana peels' physical, mechanical and chemical properties. The literature is replete with intensive studies on banana peels' mechanical and physical properties. Kachru et al. [42] and Soltani et al. [69] indicated that the mechanical and physical properties of two different varieties of banana peels, namely Nendran and Dwarf Scavendish, were investigated, as presented in Table 2. As revealed in the table, the average moisture content of Nendran banana peels is 516.41%, which is less than that of Dwarf Scavendish banana peels, which are 66.28%. This implies that peels from the Nendran banana specie have a higher potential for reinforcement of concrete's structural properties than peels from Dwarf Scavendish species of banana. Similarly, the thickness of Dwarf Scavendish banana peels which is 3.65 mm each, had a better quality than that of Nendran banana peels (2.95 mm each).

Sequel to this, the peels from Dwarf Scavendish of banana species will improve the concrete reinforcement qualities than that of the concrete reinforced with peels from Nendran specie of banana by 23.7%. However, on the contrary, the maximum diameter and specific gravity of a peel of a banana fruit from Dwarf Scavendish banana species which were 23.34 mm and 0.993, had a good surface characteristic for concrete strength enhancement than the peel of a banana fruit from Nendran banana (37.08 mm and 1.110) due to their low surface properties.

As investigated by Benjamin et al. [43], the chemical composition and properties of banana peels were presented as shown in Table 2. The types of banana peels observed were from Musa sepientum species. Banana peels from Musa sepientum species are rich in calcium and potassium, making them perform better as accurate binders in structural concrete during the geopolymerization process. The combination of potassium (78.10±6.58 mg/g) and calcium (19.20±0.00 mg/g) from Musa Sepientum banana peels, which up to 97.3% (Table 3a), shows that concrete reinforcement with banana peels will pass through smooth geopolymerization. The pozzolanic properties of banana peels observed by Lakhiar et al. [44] and Mohammad et al. [45] are 63.34% and 60.05%, respectively. These values were obtained from the combination of some essential elements such as Silica dioxide ($SiO_2$), Aluminium oxide ($Al_2O_3$), and Iron oxide ($Fe_2O_3$) (Table 3a).

The properties possessed good binding elements for concrete reinforcement up to 63.34% [44] (Table 3b), but less than that of the specified standard for a material to be used as binding material in concrete stated by ASTM C618 [46] for quality concrete production. The use of peels from bananas can be appreciated for standard concrete production when another admixture, like oil palm fiber, is blended with it.

### 2.2. Mechanical, Chemical, and Physical Properties of Orange Peels

Exploring the full benefits of orange fruit peels as composite materials in concrete application and evaluating their structural performance is contingent on proper knowledge of their physical, mechanical, and chemical properties. The properties of orange peels are discussed as follows; the properties of the peels from the sweet species of orange are presented in Table 4.

As indicated in Table 4, the sweet orange's bulk density, which ranges from 0.085 to 2.24, possesses a good surface area for producing lightweight concrete with

**Table 3a.** Mechanical and physical properties of Nendran and Dwarf Scavendish banana (Peels) [42, 70]

| Chemical composition of banana peels | | Chemical properties of banana peels | |
|---|---|---|---|
| **Element** | **Concentration (mg/g)** | **Parameter** | **Concentration** |
| Niobium | 0.02±0.00 | Saponins (mg/g) | 24.00±0.27 |
| Zirconium | 0.02±0.00 | Phytate (mg/g) | 0.28±0.06 |
| Strontium | 0.03±0.01 | Oxalate (mg/g) | 0.51±0.14 |
| Rubidium | 0.21±0.05 | Hydrogen cyanide (mg/g) | 1.33±0.10 |
| Bromine | 0.04±0.00 | Crude fiber (%) | 31.70±0.25 |
| Manganese | 76.20±0.00 | Carbohydrate (%) | 59.00±1.36 |
| Iron | 0.61±0.22 | Crude liquid (%) | 1.70±0.10 |
| Sodium | 24.30±0.12 | Protein (%) | 0.90±0.25 |
| Calcium | 19.20±0.00 | Organic matter (%) | 91.50±0.05 |
| Potassium | 78.10±6.58 | Ash (%) | 8.50±1.52 |
| | | Moisture (%) | 6.70±02.22 |

**Table 3b.** Chemical composition of banana peels [44, 45]

| Chemical composition | CaO | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | MgO | $K_2O$ | C | $SO_3$ | Lol |
|---|---|---|---|---|---|---|---|---|---|
| Banana peels (%) | 8.95 | 55.98 | 2.71 | 4.65 | 1.08 | 17.20 | 1.69 | 2.18 | 5.56 |
| Banana peels (%) | 8.95 | 55.98 | 2.71 | 1.36 | 1.08 | 28.72 | – | 0.10 | – |

**Table 4.** Physical and mechanical properties of peels from sweet oranges [47]

| Properties | Sweet orange | | |
|---|---|---|---|
| | **Minimum** | **Maximum** | **Deviation** |
| Relative density of dried peels ($gcm^{-3}$) | | | 0.4007±0.0023 |
| Bulk density of peels ($gcm^{-3}$) | 0.085 | 2.24 | 0.99±0.38 |
| The volume of peels ($cm^3$) | 12 | 65 | 37.18±13.88 |
| The volume of fruit ($cm^3$) | 64 | 190 | 112.25±31.56 |
| Total volume ($cm^3$) | 85 | 240 | 149.43±39.30 |
| Mass of peel (g) | 73.96 | 55.23 | 32.69±7.90 |
| Mass of fruit (g) | 177.26 | 280.18 | 213.10±22.26 |
| Total mass (g) | 202.72 | 313 | 250.05±27.10 |

high-density quality. Likewise, the average Volume of the peels generated from the sweet orange (38.5 $cm^3$) was up to 30.3% of the average Volume of its fruit. This implies that with 30.3% of peels generated from citrus specie, the structural properties of concrete can be improved using orange peels in concrete production composite. Also, considering the significant rate of wastes (peels) generated from citrus species (especially sweet orange), up to 28.2% mass of lightweight concrete can be substituted with the wastes (peels) from citrus specie. With this, the hygienic condition of our environment can be increased, and there will be excellent availability of construction material, especially for concreting operations [47].

The investigation conducted by Jose et al. [48] determined the chemical composition of orange peels, as shown in Table 5. As presented in Table 5, the orange peel's composition is chemically made up of hemicelluloses, lignin, and cellulose. Among the three, hemicelluloses are the least, with 5.933%, followed by lignin and cellulose, with 19.801% and 69.096% constituent, respectively, as indicated in Table 5. The best component of plant fiber is cellulose, which is a suitable property for concrete structural reinforcement [49]. 69.096% of cellulose from orange peels has excellent potential for concrete reinforcement. All the data in Table 4 showed that orange peels are chemically fit and suitable for concreting operation.

**Table 5.** Analysis of citrus peels' chemical and proximate composition [48]

| Analysis | Composition (% in weight) | Standard deviation |
|---|---|---|
| Hemi-cellulose | 5.433 | 5.433 |
| Cellulose | 69.096 | 9.015 |
| Holocellulose | 78.110 | 4.404 |
| Lignin | 19.801 | 3.595 |
| Extractable hot water | 40.399 | 2.595 |
| Acetone extractable | 6.821 | 0.604 |
| Fixed Carbon | 0.680 | 0.078 |
| Ash | 0.052 | 0.004 |
| Volatiles | 99.261 | 0.074 |
| Moisture | 73.530 | 0.477 |

## 3. RESULTS

### 3.1. Performance of Banana Peels Fiber on Concrete Structural Properties

Several studies have unveiled the significant influence of banana peel fiber on the durability performance, fresh and hardened state properties, and structural characteristics of reinforced concrete. Critical insights into the influence of some banana peels' properties on the reinforced concrete's characteristics, such as workability, water absorption, compressive strength, and flexural strength, are provided.

#### *3.1.1. Workability of Concrete with Fiber from Banana Peels*

The workability of concrete reinforced with banana skill ash (BSA) is presented in Table 6. According to Teh-Sanariah et al. [50], specific volumes of ordinary Portland cement (OPC) were substituted with 1 and 2% of banana skin ash (BSA). In the investigation, it was observed that as the percentages of BSA in concrete were increasing, the slump values of the freshly mixed concrete were decreasing (from 19±1.0 to 15±0.0 mm), which is equivalent to a 21.1% reduction in the workability of the mixed concrete. Including BSA in the concrete led to a reduction in concrete workability by more than 21%. Contrary to the findings of Teh-Sanariah et al. [50], the experimental results of Aliyu et al. [51] investigation show that the replacement of concrete (OPC) with specific percentages of plantain peel ash (PPA) increased the concrete workability. According to the authors, replacing OPC with 5 to 25% (with an increased interval of 5%) of PPA has improved the quality of concrete slump produced. The results of the concrete slump tests fell within the limit of the specification stated for true concrete slumps by [52].

As presented in Figure 5, the increase in the workability of concrete was attached to high slump values. Likewise, the result shows that the inclusion of PPA in concrete aggregate should not exceed 10% to prevent unnecessary constant in concrete fresh–slump values (1 mm). If the PPA inclusion in concrete is beyond 10%, there will be a reduction in concrete moisture during the hydration of cement-concrete, leading to breakage in the hydration process due to moisture loss (Table 7).

**Table 6.** Percentage of BSA, slump, and type of slump formed with concrete reinforced with BSA [50]

| Percentage of BSA (%) | 0 | 1 | 2 |
|---|---|---|---|
| Slump (mm) | >100 | 19±1.0 | 15±0.0 |
| Type of slumps | Collapse | True slump | True slump |

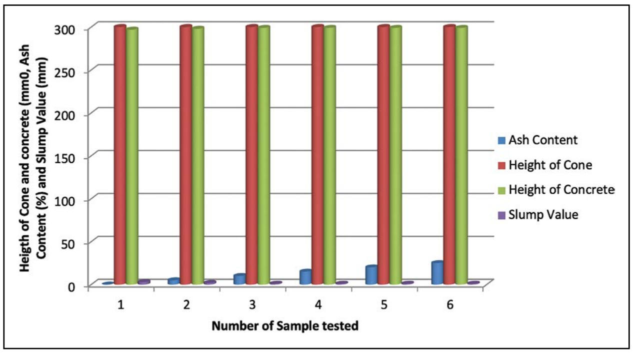


**Figure 5**. Cement – PPA concrete slump test result [51].

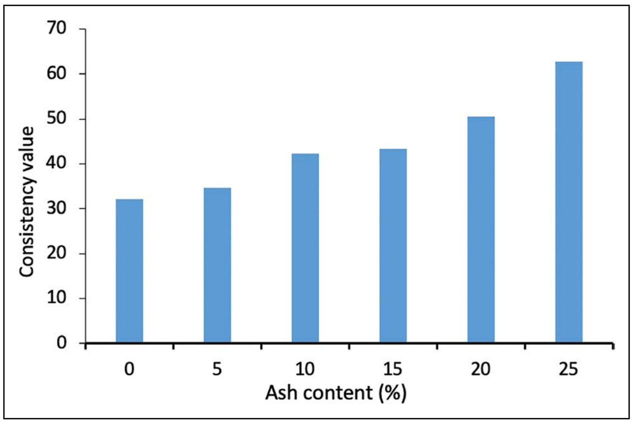


**Figure 6**. Consistency of cement paste at different percentages of PPA included [51].

#### *3.1.2. Consistency of Cement Paste with Banana Peels*

The consistency of the paste's PPA investigated by Aliyu et al. [51] is presented as shown in Figure 6. The consistency value of the cement paste with PPA showed a gradual increment up to 48.64% more than that of the paste with OPC (Table 7). As shown in Figure 5, the values of paste consistency observed were within the specified limit stated by BSEN-196-3 [53]. At the inclusion of treated banana fiber in the cement paste for the modification of cement mortar composite performance, Banjo [54] observed that the cement mortar reinforced with banana fiber developed

**Table 7.** Concrete temperature transmission and its time reduction with banana peel fibre [60]

| Concrete grade | Temperature transmission/days | | | | | Time reduction/days | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 7 | 14 | 21 | 28 | 1 | 7 | 14 | 21 | 28 |
| M20(plain) | 3.34 | 2.14 | 1.91 | 1.82 | 1.37 | 49.18 | 44.15 | 41.54 | 39.16 | 34.13 |
| M20 (with BPP) | 2.89 | 1.62 | 1.51 | 1.64 | 1.20 | 48.29 | 43.11 | 39.45 | 37.06 | 33.29 |
| M30 (plain) | 3.56 | 2.32 | 2.13 | 1.89 | 1.39 | 51.49 | 45.22 | 43.08 | 41.08 | 38.48 |
| M30 (with BPP) | 3.29 | 2.21 | 1.88 | 1.73 | 1.17 | 50.23 | 43.17 | 42.09 | 39.32 | 37.04 |

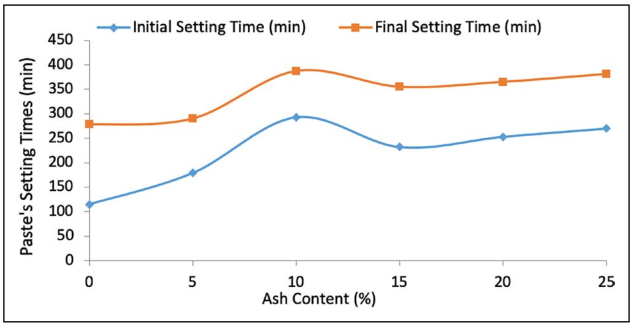


**Figure 7**. Final and initial setting time of cement paste with PPA [51].

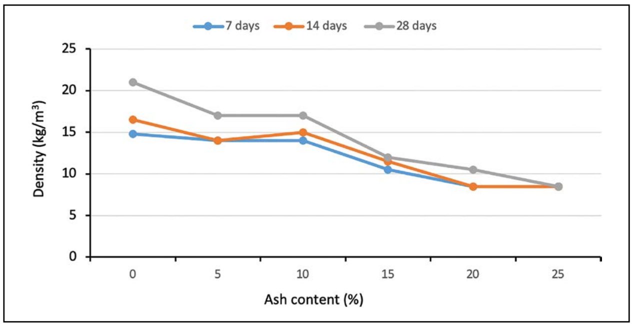


**Figure 8**. Density of concrete reinforced with plantain peels ash (PPA) [51].

optimum consistency, especially with the addition of 1.5% of banana fiber. It was concluded that including banana fiber in concrete will enrich its paste consistency.

### *3.1.3. Setting Time of Cement Paste with Banana Peel Fiber*

In construction settings, the concrete setting time is defined as when the water is mixed with cement to form a paste, and this paste can be molded into any form until it loses its plasticity and begins to harden [55]. The time when a paste formed from the mixture of water and cement begins to gain hardening is referred to as concrete's initial setting time. While the time when a paste formed from the mixture of cement and water has sufficiently hardened in a way that an impression can be made on it by a 1mm needle but would not if a 5mm needle is impressed on it is referred to as concrete's final setting time [56, 71–74]. As conducted in the experiment, the setting times of cement pastes reinforced with banana peel ashes are presented in Figure 7. As presented in Figure 7, the increase in the percentage of PPA included in the concrete cement paste led to an increase in the initial setting time of the paste.

Contrary to this, the initial setting time decreased when the percentage of PPA included in the paste was beyond 10% until a 15% constituent of PPA in the paste was reached. The time of the paste setting at the initial stage later rose when 20% and 25% of PPA were added to the paste. The final setting of the concrete paste followed the same pattern as its initial one.

The paste setting time was increased up to 5%, including PPA in the mix. Likewise, the decrease in the setting time also took place with the inclusion of 10% and 15% of PPA in the paste. With the inclusion of 20% and 25% of PPA in concrete paste, the final setting time of the paste increased from 355min to 365 and 381mins respectively [51]. Including PPA in concrete paste improved the structural properties of the concrete paste.

### *3.1.4. Density of Concrete Reinforced with Banana Peel Fiber*

The density of concrete reinforced by substituting some proportion of cement with plantain peel ash (PPA) is presented as shown in Figure 8. The increase in the percentage of PPA present in cement – PPA concrete has contributed to the decrease in the densities of concrete produced, especially at its $14^{th}$ and $28^{th}$ days of curing. It was observed that concrete with 10% of PPA has a higher density value than that concrete without PPA. The substitution of some percentage of sand aggregate with 1.0, 0.75, 0.5, and 0.25% of plantain fiber has decreased the density of the concrete produced. The data presented by the author shows that the average concrete density of the specimens with 0% of plantain fiber which ranges from 2167–2190 kg/m$^3$, was less than that of concrete with 0.25 to 1.0% of plantain fiber which is within the range of 2051 to 2066 kg/m$^3$. The average concrete weight density reduction was 65.2%. This implies that the addition of plantain fiber to concrete could yield the production of light weight concrete. With this, the weight of materials used for structural concrete construction can be reduced, thus improving the concrete's flexibility properties [51, 57].

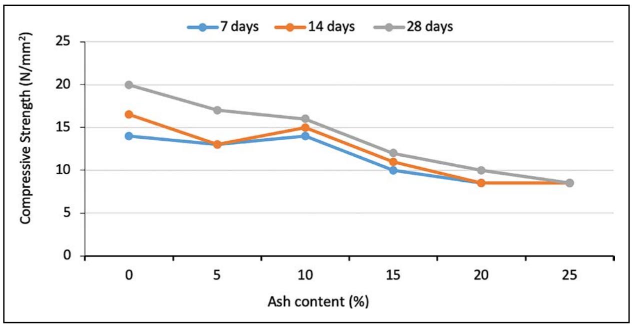


**Figure 9a**. Concrete compressive strength with specific percentages of PPA [51].

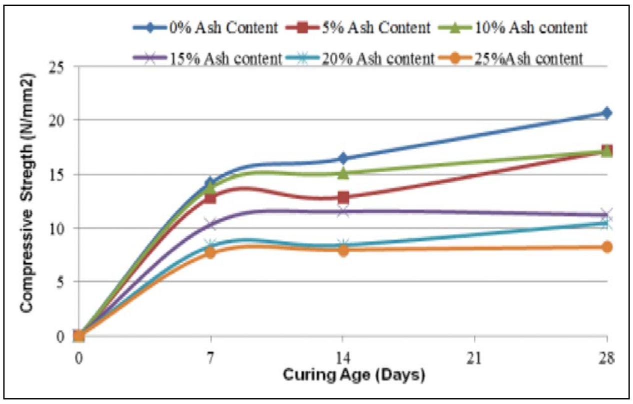


**Figure 9b**. Cement-PPA concrete compressive strength [51].

### *3.1.5. Compressive Strength of Concrete Reinforced with Banana Peel Fiber*

The concrete compressive strength is an essential property needed by a concrete structure to carry its intending loads [58]. High compressive strength of concrete with banana skin powder (BSP) was recorded in the experiment carried out by Mohamed et al [45]. According to the authors, the replacement of certain concrete sand aggregate with BSP has caused the increment in concrete compressive strength from 18.9 to 27.6 MPa which was about 46%. With this output, it was deduced that BSP has the great potential for concrete reinforcement and it will be useful in concrete industries in terms of replacing some aggregate to lengthen the existed construction materials. Though, the use of plantain peel ash (PPA) as a supplement of cement in concrete does not have positive effect towards the reinforcement of concrete compressive strength like that of BSP used as aggregate substitutes in concrete. According to Aliyu et al [51], the inclusion of plantain peel ash (PPA) as cement substitute has contributed to the formation of low concrete compressive strength which is bad for construction purposes. As shown in figure 9(a), all the compressive strengths of concrete with PPA observed were less to that of concrete with 0% of PPA at 7, 14 and 28 days of curing in water. This implies that, the application of PPA in concrete as a cement supplement material could reduced the concrete strength unlike when the banana peel powder (BPP) is applied as aggregate substitute in concrete which really increase the strength of concrete at compressive zone. According to these findings, it is advisable to make use of banana peels as aggregate supplement in concrete or as concrete additive than to use them as cement substitute in order to increase the concrete compressive strength greatly.

From another perspective, the cement – PPA concrete compressive strength was appreciated by increasing its curing ages presented in Figure 9b. It could be deduced from Figure 9b that fiber from PPA could function as binder or pozzolan in replacement of structural concrete. Its curing age is prolonged till 28, 180, and beyond. Likewise, the findings of Gangadhar et al. [59] also support the latest strength increment of concrete reinforced with banana fiber. According to the authors, the compressive strength of concrete with banana fiber increased up to 4% inclusion of the fiber. This grade 30 concrete with banana fiber performed excellently in loading than the ordinary concrete. Also, concrete began to increase in its compressive strength at 21 curing days when M20 grade was used together with banana peel powder for its production. At the same time, its strength increment with grade M30 was appreciated from 14 days of curing [60].

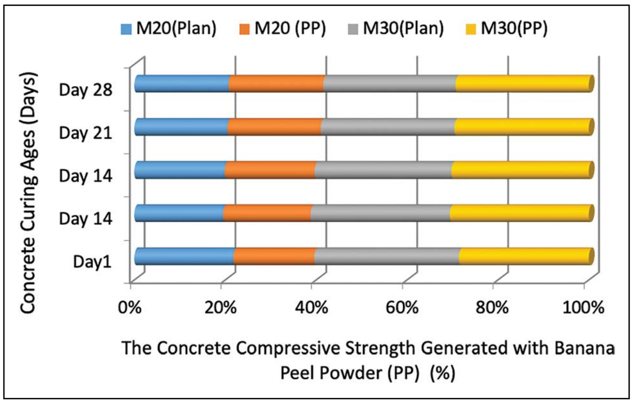


**Figure 10**. Concrete compressive strength with banana peel powder and its curing ages [60].

With the findings presented in Figure 10, it could be observed that the compressive strength of the concrete reinforced with banana peel fiber will increase strength if the high grades of concrete cement are used and cured for long days. The higher the curing days of concrete with banana peel fiber, the better the strength [60].

### *3.1.6. Tensile Strength of Concrete with Banana Peel Fiber*

Concrete tensile strength is defined as concrete's ability to resist breaking or cracking when suggested to tension. This strength is usually within the range of 300–700 psi, equivalent to 2–5 MPa. Averagely, the tensile strength of standard concrete is about 10% of its compressive strength [61]. The result of incorporating some percentage of banana fiber in a concrete mix of grade 30 was indicated by Gan-

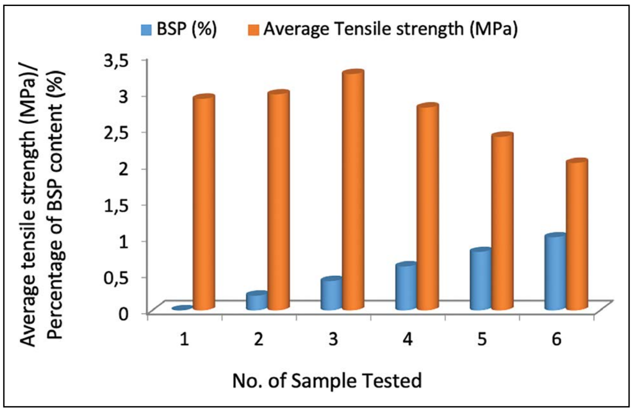


**Figure 11**. Average tensile properties of concrete with banana skin powder [62].

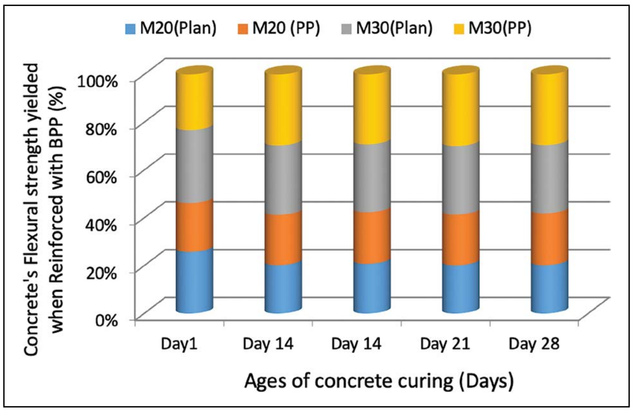


**Figure 12**. Flexural strength of concrete reinforced with BPP versus curing ages [60].

gadhar et al. [59]. It proved that banana fiber has a greater resistance capacity against cracking during tension. As conducted by the authors, the strengths of the concrete specimens cast with banana fiber were far greater than that of concrete with Ordinary Portland Cement (OPC). Also, replacing some sand aggregate percentages with banana peel powder (BPP) has increased the concrete tensile strength against cracking from 1.54 MPa to 3.24 MPa. This increment was about 52.5%. Thus, BPP can double the strength of concrete against cracks [45]. The findings of Humphrey [57] also support the above report. According to the author, as the concrete's curing ages with banana fiber increased, the concrete tensile strength was also increasing rapidly. The three best strengths yielded were 1.58, 1.6, and

1.65 MPa at the inclusion of 0.25, 0.5, and 1.0% of banana fiber. These values are 12.1% more than the control's (1.45 MPa). When reinforced with banana fiber, the concrete's tensile capacity can be increased by 12%. The result of the investigation conducted by Muhammad [62] also complied with previous results of the scholars presented earlier. As shown in Figure 11, including banana skin powder (BSP) in concrete has contributed to the high increase in the concrete's tensile strength. The highest tensile strength was recorded at the inclusion of 0.4% of BSP in concrete (3.24 MPa), which is 10.5% greater than the tensile strength of standard concrete (2.90MPa). With these reinforcement achievements of using BSP in concrete, it was clearly shown that BSP is a great potential material for controlling cracks in concrete which is one of the significant problems in construction industries nowadays.

#### *3.1.7. Flexural Strength of Concrete with Banana Peel Fiber*

As presented in Figure 12, the flexural strength of concrete with banana peel powder (BPP) was significantly increased in both concrete produced with grades M20 and M30 compared with that of control. According to Gadgidhalli et al. [60], the bending resistance capacity of grade M20 concrete reinforced with BPP was 85.2% greater than

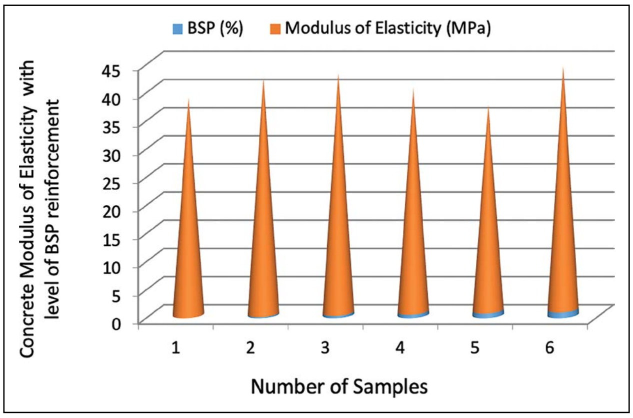


**Figure 13**. Concrete modulus of elasticity with the level of BSP reinforcement [62].

that of plain concrete. Likewise, the tensile strength of M30 grade concrete was increased by 87.1% over its control specimen. This implied that BPP is a tremendous potential material for concrete reinforcement against bending. Mohamad et al. [45] also confirmed that banana skin powder (BSP) has excellent potential for concrete flexural strength increment up to 1.0% inclusion of BSP compared with control.

#### *3.1.8. Modulus of Concrete Elasticity with Banana Peel Fiber*

The process of a concrete structure contracting and expanding due to climatic variations is known as concrete elasticity. If the issue is frequent and not adequately addressed, it may result in cracks [49]. As a result, quality design is required to expand cracks of concrete composites or materials to prevent cracks. The result shows that the concrete's expansion and contraction rate was reduced by replacing a certain percentage of sand aggregates with banana skin powder in concrete. This reduction was achievable because some of the developed pores and holes within the concrete might have been blocked by BSP, thus restricting their movement during contraction and expansion. As indicated in Figure

**Table 8.** Optimized model validations [50]

| | Concrete curing ages (day) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 7 days | | | 14 days | | | 28 days | | |
| BSA (%) | 0 | 1 | 2 | 0 | 1 | 2 | 0 | 1 | 2 |
| Experimental | 20.76 | 21.19 | 21.51 | 23.86 | 21.97 | 24.00 | 31.61 | 28.77 | 29.50 |
| Predicted | 19.90 | 21.70 | 27.00 | 23.30 | 25.10 | 30.50 | 32.30 | 34.10 | 39.40 |
| Error percentage (%) | 4.1 | 2.4 | 25.50 | 2.4 | 14.3 | 27.1 | 2.2 | 18.5 | 33.6 |

13, the reduction rate in concrete's elasticity (MOE) was higher than that of concrete with OPC. All the concrete specimens reinforced with 0.2%–1.0% of BSP (with a 0.2% increase interval) showed an increase in concrete stiffening strengths against expansion due to its modulus of elasticity.

#### *3.1.9. Effect of Banana Peel Fiber on Concrete Temperature Transmission*

One of the significant climatic conditions that are usually causing cracks in concrete is the change in concrete temperature. The effect of expansion and contraction of concrete structures in high temperatures can be developed into forming pores, cracks, and holes within the concrete structure. Including peels from banana fiber as concrete's admixture has caused much reduction in its heat transmission and high temperature that could increase the concrete's elasticity. The concrete's strength developed against high temperatures rising was 2.5 to 3.5% greater than regular concrete [63]. However, banana peel powders (BPP) were added to the concrete as an admixture, and the BPP included has increased the strength capacity of concrete significantly against deformation, cracking, and shrinkage, thus, reducing the rate of concrete temperature and time transmissions [60].

As presented in Table 7, the rates of reduction in concrete's temperature's transmission were reduced by 24.3 and 11.7% (Maximum) on the 7$^{th}$ and 14$^{th}$ days of concrete curing of grades M20 and M30, respectively. Likewise, the concrete temperature transmitting time rates were reduced by 5.4 and 4.5% on the 21$^{st}$ and 7$^{th}$ days of curing grades M20 and M30, respectively. Therefore, it was concluded that dried BPP has excellent potential for reduction of exothermal reaction in concrete. Also, the increase in concrete curing age will significantly develop the high resisting capacities of concrete against thermal transmission.

#### *3.1.10. Modeling and Analysis of Concrete's Strength Response Reinforced with Banana Peel Fiber*

The interrelation between banana skin ash (BSA) in concrete, concrete's curing days, and its compressive strength were predicted by Teh-Sabariah et al. [50] during experimental laboratory work. The modeling activity involved Expert design software using the surface response method (SRM) for the central design of concrete composites (CDC). Its statistical prediction involved the use of analysis of variance (ANOVA). It was discovered that adding BSA to concrete composite has excellent potential for concrete strength increment. From the validity of the model result recorded, the optimum BSA adopted by the authors for concrete strength reinforcement was 1.25%. At this optimum (1.25%), from 7 to 28 days of curing concrete, all the concrete compressive strengths were at maximum. As presented in Table 8, the minimum errors observed were 18.5, 14.3, and 2.4% for 28, 14, and 7 days of curing concrete. With the use of Pearson's proximity matrices device, it was observed that there was a correlation between concrete compressive strength and its curing ages (both predicted and experimental). Looking at the validation of the model, it can be applied for the prediction of concrete reinforced with BSA as an admixture in industries.

### 3.2. Performance of Orange Peels Fiber on Concrete Structural Properties

#### *3.2.1. Workability of Concrete Reinforced with Orange Peels Fiber*

As it has been known, concrete workability depends on the materials' quality, the proportion of mixed aggregates, the percentage of water applied to the concrete mixing, and its production methods. If these were not adequately catered for, it could result in segregation, production of tick concrete that cannot flow easily, wet concrete, formation of pores and holes within the concrete, shrinkage, and creeping [49]. Apart from proper production methods, applying admixture in concrete will improve the quality of concrete produced. From the literature review, no proper workability test was conducted on concrete with orange peel fiber.

#### *3.2.2. Consistency of Cement Paste with Orange Peel Fiber*

One of the standard methods of calculating the precise amount of water needed for normal concrete paste formation is the consistency of the paste. Olumide et al. [64] replaced 2.5 to 10.0% of ordinary Portland cement with burnt ashes from orange peels. The replacement of concrete cement aggregate with orange peel ash (OPA) has caused an increase in the water demand rate for the formation of OPA cement to paste from 89.4 to 127.2 mm. The more the increase in the content of OPA in the cement paste, the higher the consistency of OPA- paste (Figure

**Table 9.** The rate of demand for water, settings times, and consistency of OPA – cement pastes [64]

| OPA content (%) | 0.0 | 2.5 | 5.0 | 7.5 | 10.0 |
|---|---|---|---|---|---|
| Water consistency (%) | 28.5 | 29.80 | 34.20 | 38.60 | 42.40 |
| Water demand (mm) | 85.8 | 89.4 | 102.6 | 115.8 | 127.2 |
| Initial setting time (min) | 120 | 126 | 136 | 148 | 152 |
| Final setting time (min) | 148 | 152 | 162 | 198 | 224 |

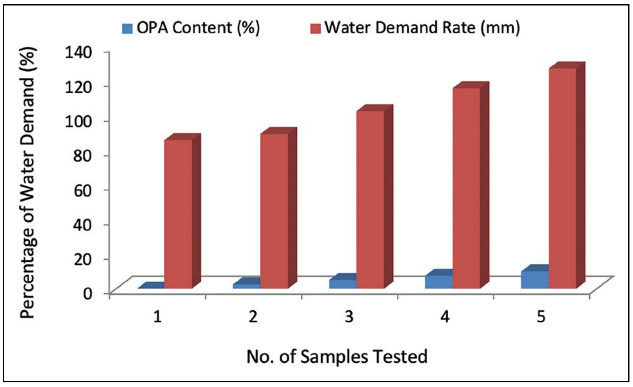


**Figure 14**. Effect of OPA content on the rate of water demanding binary cement blend [64].

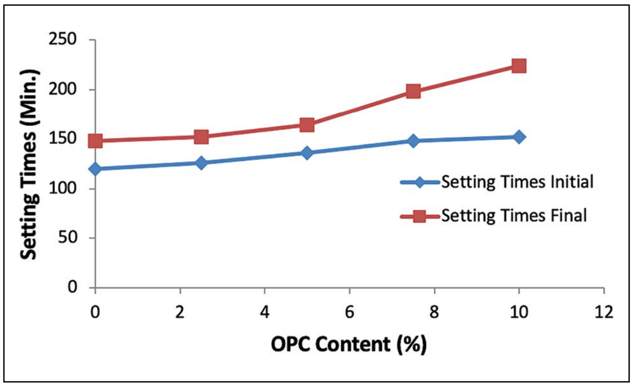


**Figure 15**. Effect of blending some percentages of cement with OPA on concrete setting times [64].

14). The high level of water demand in the OPA-cement paste was attributed to the presence of unburnt carbon in the OPA produced. Hence, a higher water-cement ratio is required to form a consistency of OPA-cement paste.

#### *3.2.3. Setting Time of OPA-Cement Paste*

A setting time of cement paste or concrete is defined as the assigned time needed for the mortar or concrete to change to a plastic state from liquid state, and solid state from plastic state until its surface becomes adequately rigid in withstanding a certain amount of pressure [77]. According to [77], the time at which the cement – paste starts to loss its plasticity is called initial setting time of cement. While the time at which a cement paste has completely loses its plasticity is known as cement final setting time. These times are important for the accurate setting of concrete paste for standard building concrete inner strengths for structural stability. The setting times of concrete with OPA were evaluated, and some of the data were presented in Figure 15 as shown below.

As presented in Figure 15, the increase in Orange Peel Ash (OPA) content of OPA-cement paste has lead to the increase in the both initial and final setting times of concrete pastes by 20.64% and 47.37% than that of paste with Ordinary Portland Cement (OPC). These increments were within the range of including 7.5–10.0% of OPA in the concrete's paste. This might be attributed to the clinker content diminution in the OPA included in the concrete –cement - paste. Since the normal consistence of concrete required high content of water to attain a standard paste' consistence, hence, the higher water cement ratio is required to achieve the consistence of cement paste with OPA (Olumide et al. [64]). Table 9 gives the compressive information on the rate of demanding for water by OPA – Cement pastes, settings times and Consistence of OPA – Cement pastes.

#### *3.2.4. Composite/Concrete Density Reinforced with Orange Peel Fiber*

All construction industries require the use of concrete with high-yielding strength to construct structural members. The suitability of the materials used will determine the weight of the concrete produced against deformations during loading [49]. Applying orange peel fiber in composite or concrete improved the quantity of concrete structural properties. Katla and Chetty [65] and [77] on the reinforcement of epoxy composite with fiber from orange peel indicated that the percentage of orange peel powder (OPP) used ranges from 5–30% with an increased interval of 5%. As observed from the result, the 20, 30, and 10% composite samples showed a high rise in composites' density by 5.34%, 5.07%, and 2.79%, respectively, as presented in Figure 16.

From their experimental output, it was observed that an increase in the content of OPP in the composite had caused an increase in the density of the composite. On the contrary, the composite bulk density developed by using certain percentages of dried orange peels (DOP) for the production of building insulating material decreased as the DOP content increased. The decrease rate was from168.63±12 kg/m$^3$ (W75) to 558.46±13 kg/m$^3$ (W100). This is equivalent to about a 16% reduction. Hence, DOP is good for lightweight concrete production [32].

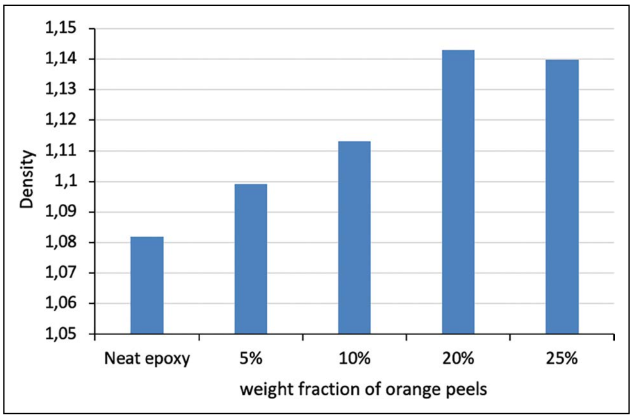


**Figure 16**. Density of epoxy composite reinforced with orange peel fiber [65].

### *3.2.5. Compressive Strength of Concrete Reinforced with Orange Peel Fiber*

Shaymaa and Tamas [66] indicate that orange peel fiber (green inhibitor) was incorporated in concrete material to mitigate its sulfate and chloride attack. According to the authors, the inclusions of inhibitors were by 1 and 3% of the weight of cement. The output of the investigation was presented as shown in Figure 17. From Figure 17. The concrete reinforced with corrosion inhibitor (orange peel extract) was observed to reduce strength by 10.5 and 13% when 1 and 3% of inhibitors were included, respectively. Therefore, to use orange peel in concrete as an inhibitor, proper treatment should be adopted to prevent causing a reduction in concrete strength.

Also, concrete mortar reinforced with orange peel ash (OPA) developed low strength compared to concrete with only OPC (control). The reduction could result from the high demand for water by OPA – paste to attain consistency or diminution because of its clinker content [64] (Fig. 18). It is observed that the mortar's compressive strength was significantly increased from 28.88 to 44.41 MPa, which is equivalent to 80% of strength increment at 28 days of curing. The inclusion of OPA in concrete mortar should not exceed 5% to avoid strength reduction. Besides, the increase in mortar's curing ages from 2 to 60 days has increased mortar compressive strength. Therefore, the concrete reinforced with OPA requires long curing age to develop high strength. Considering the effect of orange peels on composite, the investigation by Mahato et al. [32] showed that blending orange peel with epoxy to form composite has developed maximum hardness (strength) at the point of blending 20% of orange peels with epoxy to form composites.

### *3.2.6. Tensile Properties of Composite/Concrete Reinforced with Orange Peel Fiber*

The reinforcement of epoxy with 20% of orange peel powder (OPP) to form composite has developed high strength against cracking than the other two samples observed together with the control. According to Katla and

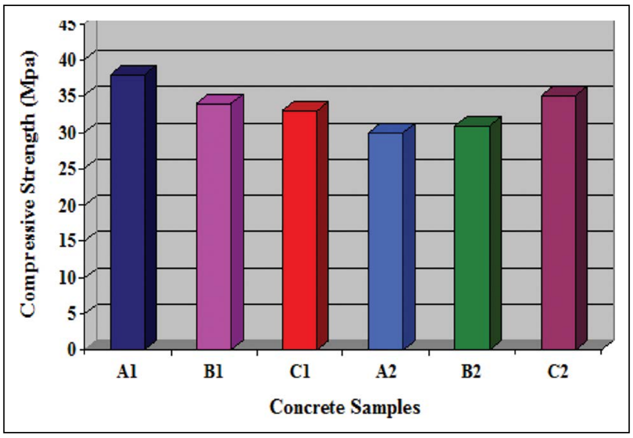


**Figure 17**. Compressive strength of concrete samples after immersion in tap water [66].

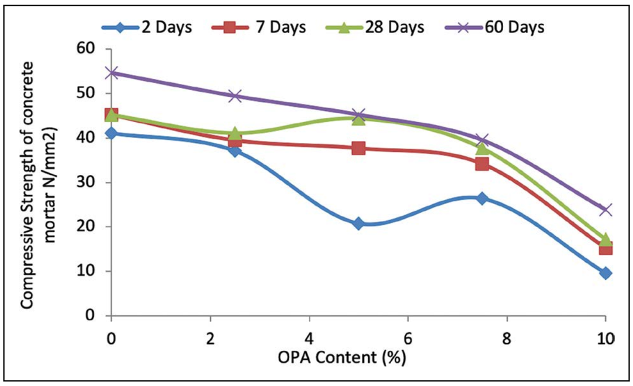


**Figure 18**. Effect of OPA on mortar compressive strength [64].

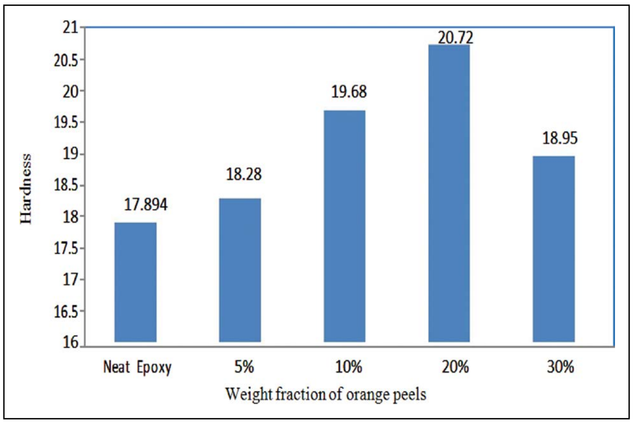


**Figure 19**. Variation of tensile strength with different percentages of orange peels content [65].

Chetty [65], the level of strength increment was about 30.25% more than that of the control, as shown in Figure 19.

This shows that orange peels can increase concrete strength by 30% when applied as an admixture in concrete or composite. Thus, orange peel could be an excellent substitute for concrete aggregate or cement in the concrete industries. Likewise

#### *3.2.7. Concrete/Composite Flexural Strength Reinforced with Orange Peel Fiber*

The investigation conducted by Olumide et al. [64] shows that concrete flexural strength was mostly appreciated when 2.5% of OPA was included in its mix and cured for 60 days, as illustrated in Figure 20. The bending resisting capacity of OPA – concrete declined when its OPA content was increased beyond 2.5%. From another perspective, the increase in curing ages of OPA-concrete mortar leads to an increase in the mortar's strength to withstand bending and deflections during loading. In support of this, an output of blending orange peels as an insulator for building applications shows that orange peels have great potential for concrete and composite improvement [32].

The investigation highlight revealed that the W75 sample developed higher strength to withstand deflection than the other samples tested. The samples from W80 to W100 displayed a high level of deflection when suggested to stress. With critical consideration of the above results, it was observed that applying orange peels in composite or concrete as admixture or as a substitute material for cement will contribute an excellent strength increment to concrete strength against deflection or bending.

#### *3.2.8. Modulus of Elasticity of Composite Reinforced with Orange Peel Fiber*

The composite modulus of elasticity without orange peels (W100) is higher by ten times than that of W75 samples. The performance was associated with the mixed composite's homogeneity and porosity. Also, there might be the reaction of pyrolysis, caramelization, and Maillard of organic components within the compacted aggregates. This implied that, with the inclusion of orange peel fibers in concrete or composite, the pores and holes within the concrete or composite aggregate would have been blocked and acts as fillers in concrete to prevent cracks due to constant elasticity [32].

#### *3.2.9. Effect of Orange Peel Fiber on Concrete Thermal Conductivity*

The strength of an orange peel-reinforced composite against thermal expansion was conducted and observed by Mahato et al. [32]. The samples used were allowed to pass through the thermal conductivity test, and the results were recorded. AW75 sample was observed to show a higher level of thermal conductivity. The mean thermal conductivity of the W100 sample, with 0.66W/mk capacity, is 1.2 times more than that of the W75 sample with 0.77 W/mk capacity [67]. Also, the authors stated that the composite produced with 4 to 12% orange peels could generate high thermal conductivity with the increase in the temperature of the composite. This is in line with the findings of Ochs et al. [68]. Therefore, orange peel is excellent potential for composite and concrete reinforcement.

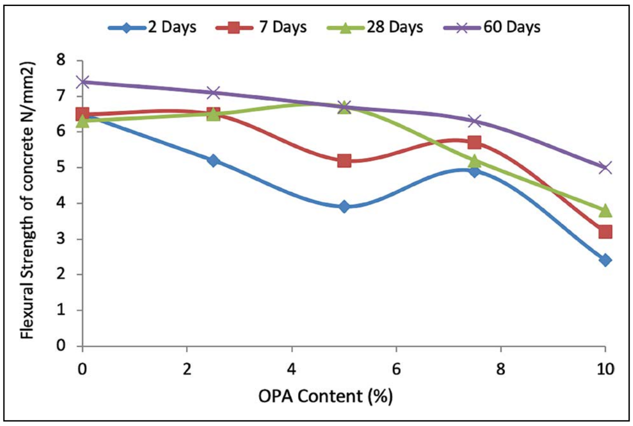


**Figure 20**. Flexural strength of concrete blended OPA [64].

## 4. DISCUSSION

The previous estimation showed that up to 4.2 billion meters and 3 tonnes of cement and concrete were consumed globally in a year [5, 8]. Likewise, the carbon dioxide emission rate from cement production companies globally is very high. China only was emitting about 823 million metric tonnes of carbon dioxide yearly from its cement production companies, causing harm to human health, destroying the ozone layers, and increasing the rate of global warming. Also, the study showed that about 34.72 to 46.29 million metric tonnes of peels were generated from bananas, and up to 15.10Mt of peels were generated from oranges globally [33, 37]. These wastes have become environmental problems, hazardous to humans' health, and have emitted a high volume of carbon dioxides into the atmosphere. With the outcome of this review, the application of treated orange and banana waste peels for cement and concrete production will go a long way in enhancing the rate of cement and concrete production around the globe. It will be a strategic method of eradicating the large Volume of piled wastes from banana and orange peels that have been causing environmental pollution, likewise, as global warming.

Also, their application will serve as a substitute for cement and concrete materials, making the two materials cheaply available for global citizens at affordable prices. Then, many concrete structures could be raised due to the availability and low cost of cement and concrete materials. Furthermore, applying these peels in concrete will prolong the use of non-renewable natural materials (sand, granite), which can be exhausted in years to come if supplementary materials are not provided [38, 67]. The results of the experiments conducted by the scholars show that banana and orange peel fibers were physically fit for concrete reinforcement. As reviewed, both wastes have good surface areas for quality concreting, low specific gravity for stability, and exact lengths and breadths for concrete reinforcement.

The review has shown that the pozzolanic components of banana peels' essential elements: potassium (78.10±6.58 mg/g) and calcium (19.20±0.00 mg/g), are made up of 97.3% of pozzolanic binding properties for quality concrete reinforcement. This percentage (97.3%) is more than that of specified properties of any material used as pozzolan in concrete, as stated by ASTM C618 [46], which is 70%. While orange peels have three important chemical properties that could significantly enhance the quality of concrete produced, that is, hemicelluloses - 5.933%, lignin – 19.801%, and cellulose – 69.096%. These qualities made both orange and banana peels suitable for concrete. The application of banana peels in concrete increased its workability properties by 21.1% [50]. This negates the results of other studies that indicate that banana peels decrease concrete workability. With the critical consideration of these results, it was observed that banana peels have great potential for improving concrete workability, but proper care should be taken on the water-cement ratio used for its production. As observed in the review, the concrete paste with banana and orange peels was discovered to increase by 48.64% more than that of the control. As the percentage of banana peel fiber (BPF) substantially increases, the BPF – the concrete paste will also increase. Likewise, the more the percentage of OPF in concrete, the more the consistency of OPF-cement pastes. So, a high water-cement ratio is required to attain the consistency of BPF and OPF-cement concrete paste. The increase in the percentage of BPF in concrete has brought about an increase in concrete's final and initial setting time.

This time increment was achievable up to 5% of BPF in concrete, while the decrease in concrete setting times occurred within 10 to 15% of including BPF in concrete. Likewise, the addition of OPF to concrete increased OPF – cement concrete setting times by 47.37%. It requires the use of a higher water-cement ratio to control this. Also, to achieve the typical setting of concrete with BPF, a not-too-high water-cement ratio should be adopted. Application of OPF in concrete leads to an increase in concrete density by 5.34%. Therefore, orange peels have great potential for the production of lightweight concrete. The review shows an increase in the concrete compressive strength with the increase in the percentage of banana peels included in the concrete up to 46% than that of the control. This shows that the relationship between the concrete and banana peel fiber is linear. Concrete with BPF should be suspended for long curing days (Up to 180 days) to gain maximum compressive strength. Since applying orange peels in concrete as a green inhibitor was to mitigate the effect of sulfate and chlorine attack in concrete, proper treatment should be applied to OPF before use in concrete as an inhibitor. The BPF-concrete's tensile properties developed maximum strength increment up to 52.5%.

Therefore, banana peels have an excellent potential for concrete strength reinforcement against cracks due to stress on concrete. The study's flexural strength tests show that BPF has contributed about 87.1% to the concrete strength against bending and deflection. So, BPF is suitable for producing concrete for residential house slabs, beams, and columns. The concrete stiffness capacities against expansion due to elasticity were greatly enhanced than that of control with the application of BPF. The concrete elasticity effect in concrete due to stress could be eradicated using BPF. The capacity of BPF-concrete was developed to withstand temperature transmission by 2.5 to 3.5% more than regular concrete [63–65]. It was found that BPF reduced the concrete transmission temperature by 24.3%. The review output deduced that applying BPF in concrete will reduce deformation, crack, and shrinkage. The prediction observed from Expert design model software shows that 1.25% is the optimum for reinforcing concrete with BPF [66–71].

Though, according to the review, the high concrete strength yielding was observed when the processed banana and orange peels were included in concrete, notwithstanding, the proper treatment is required on banana and orange peels biomass in order to prevent them from chemical attack and acidic reaction during the hydration process which can reduce the rate of concrete strength yielding at the formation stage. The production of banana and orange peels" ashes require adequate supervision so as to allow the burning of peels to produce pure ashes (without impurity) for supplementary of concrete pozzolanic materials. Ashes with impurity can reduce the strength, durability, sustainability and stability of concrete, thus, reducing the quality of concrete needed for accurate construction purposes.

## 5. CONCLUSION AND RECOMMENDATIONS

It was observed that banana and orange peels have great potential for concrete reinforcement. The authors suggested that an accurate water-cement ratio should be used to avoid reducing concrete workability. Based on the information provided by this review, using banana peels in concrete requires a higher water-cement ratio to attain stable consistency. To avoid too quick setting and too late setting of concrete with BPF, the author suggested that the medium (not too high) water-cement ratio should be adopted. Also, a higher water-cement ratio should be adopted for OPF-cement concrete to normalize their high setting time. With the observed 46% strength increment on the concrete compressive capacity, BPF is recommended for twice the reinforcement of concrete strength to carry the intending loads. More research work should be done on BPF-concrete compressive strength. Since the researchers on the use of BPF in concrete were very few, more investigation is needed on the concrete compressive strength using banana peels as an admixture or as a material substitute. Also, it was suggested that concrete with BPF should be suspended for long curing days (Up to 180 days) to gain maximum compressive strength.

It was suggested that BPF should be adopted for concrete tensile cracking and deflection control. It was recommended that the use of OPF in concrete should not exceed 2.5% to avoid a decrease in its flexural strength. Authors suggested that banana and orange peels should be incorporated into concrete that will be used to construct residential houses' slabs and for frame beam construction to prevent them from being saved against deflection. Also, the inclusion of OPF in concrete should not exceed 20% to avoid reducing concrete flexural strength. Concrete with orange peels should be allowed to be a cure for long days to improve its strength against deflection. BPF is recommended for thermal reaction reduction in concrete. Also, proper treatment should be applied to OPF before use in concrete as a green inhibitor. It was recommended that software like artificial intelligence model, finite element structural model software, and civil engineering simulation be used to predict the optimum strength of concrete with BPF and OPF for industrial use.

Likewise, this software should be used to show the correlation between concrete compressive strength and its curing age to increase its industrial values. In conclusion, using orange and banana peels in concrete has contributed significantly to enhancing concrete's structural properties; hence, they can be used as supplementary materials for concrete production. More rigorous studies which investigate the OPF-cement concrete consistency are required. More slump and impact factors tests were needed to predict the effect of OPF in concrete. Few research tests were conducted on using banana peel fibers in concrete. More experimental investigations are needed on concrete compressive strength, the accurate water-cement ratio for BPF –cement concrete, and more test is required in the area of concrete elasticity with BPF. Predictability of the critical structural materials of these natural fibers in concrete reinforcement is significant to ensuring accurate building design prior to construction.

This study recommends an intelligent predictive model and process optimization for natural-fibers-based concrete. Owing to the limitations of the classical linear model involving the use of Expert design and Pearson's proximity metrics device for statistical analysis, artificial intelligence model, finite element structural model software, and civil engineering simulation software is recommended to predict the concrete strengths to ascertain the standard and accurate strength prediction of using BPF and OPF in concrete. The use of OPF for tensile reinforcement of concrete properties needs more investigation using a not too high water-cement ratio. The application of OPF for concrete tensile strength reinforcement requires more investigation. The concrete thermal conductivity with orange peel fiber needs quick investigation. Future studies could focus on this to determine the capacity of the OPF against thermal defects.

Further, the application of orange peel to improve the elasticity capacity of concrete due to modulus effects needs to be researched. This will reduce cracks in the concrete due to the modulus of elasticity. Finally, different software applications are needed to accurately predict concrete strength on all its mechanical properties, which requires quick action.

## ETHICS

There are no ethical issues with the publication of this manuscript.

## DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

## FINANCIAL DISCLOSURE

The authors declared that this study has received no financial support.

## PEER-REVIEW

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