CHEMICAL ENGINEERING TRANSACTIONS

VOL. 106, 2023

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Jeng Shiun Lim, Nor Alafiza Yunus, Peck Loo Kiew, Hon Huin Chin

ISBN 979-12-81206-05-2; **ISSN** 2283-9216

DOI: 10.3303/CET23106073

Banana and Orange Peel Powder as Partial Cement Replacement Materials. A Comparative Analysis on its Individual Influence on the Physicomechanical Properties of Cement

Shannen Lyka S. Cruz[a,*], Francheska Edelle Lein G. Pamintuan[a], Ronan B. Villanueva[a], Jonathan C. Muñoz[a], Gil G. Cruz[b]

[a]Department of Civil Engineering, College of Engineering and Architecture, Bataan Peninsula State University, Capitol Compound, Tenejero, Balanga, Bataan, Philippines 2100
[b]Research and Innovation Center for Climate Change and Sustainability, Bataan Peninsula State University, Capitol Compound, Tenejero, Balanga, Bataan, Philippines 2100
slscruz@bpsu.edu.ph

This experimental study investigates the impact of banana peel powder (BPP) and orange peel powder (OPP) as partial replacements on cement's physicomechanical properties. The testing of dried and powdered fruit peels is conducted in accordance with the standards ASTM C150 and ASTM C109. BPP exhibits strong pozzolanic binding characteristics, enhancing compressive strength when used at replacement percentages of 4 %, 6 %, and 8 %. Conversely, the addition of OPP to cement negatively affects compressive strength, falling below the required standard. These findings demonstrate the potential of BPP in producing high-quality cement while suggesting that OPP may not be suitable as a direct substitute in its current form. Utilizing banana peels in cement improves its structural properties, offering a sustainable and cost-effective solution for various construction applications.

1. Introduction

Cement is a vital component of concrete used in buildings and civil engineering structures worldwide. Its cohesive properties make it an essential binding substance in concrete production. However, the continuous production of cement raises environmental concerns due to its significant contribution to carbon dioxide emissions. The global demand for concrete has risen rapidly with the growth of the construction industry, leading to an increase in cement consumption.

In 2021, global cement production is projected to reach 4.4 billion t, a significant rise compared to 1.39 billion t in 1995 (Statista, 2022). Furthermore, the construction sector stands as the primary industry responsible for the greatest consumption of natural resources (Murthi, 2022). It is projected that the consumption of fossil fuels to meet the rising energy demand will increase by 56% by the year 2040 (Fan et al., 2023). Due to the depletion of natural resources and rising CO_2 emissions, the need for sustainability in the construction industry has become crucial. According to a recent study, several researchers have started adding agricultural wastes to cement as admixtures to increase the sustainability of the material.

In the Philippines, roughly 1Mt of fruit side streams (fruit waste) are created in Dole's farms, which equates to around 50,000 40-foot containers (Dole to Repurpose Tons of Fruit Waste - BusinessWorld Online, 2021). Banana peels, which is one of the most abundant fruit waste in the Philippines, possess a high silica dioxide content, along with moderate levels of calcium oxide and potassium oxide, which makes them suitable as a pozzolanic material (Lakhiar et al., 2021). Moreover, because bananas contain natural fibers that could increase cement's durability, several studies have found great potential in utilizing them as an additive in cement. Additionally, bananas contain potassium (K) and sodium (Na) elements, which can improve the strength properties of concrete (Manan et al., 2021).

Paper Received: 14 June 2023; Revised: 5 September 2023; Accepted: 17 September 2023
Please cite this article as: Cruz S.L.S., Pamintuan F.E.L.G., Villanueva R.B., Muñoz J.C., Cruz G.G., 2023, Banana and Orange Peel Powder as Partial Cement Replacement Materials. A Comparative Analysis on its Individual Influence on the Physicomechanical Properties of Cement, Chemical Engineering Transactions, 106, 433-438 DOI:10.3303/CET23106073

Similarly, orange fruit processing creates a substantial amount of waste, the majority of which consists of peels, Therefore, orange peel applications in the building sector are in high possibility. The ash derived from orange peels (OPA) exhibits a high concentration of CaO and SiO2, and when used as a cement substitute, it acts as a strength enhancer (Olubajo et al., 2019).
Furthermore, the majority of previous studies on replacing cement with fruit waste, notably banana and orange peel waste, have concentrated on the structural performance of the resulting concrete. Investigation of cement performance alone is lacking in recent research. In addition, the peel of the majority of fruit waste is incinerated, turning it into ash that can release a considerable amount of carbon dioxide. Additionally, since studies related on the use of banana and orange peel powder were very few, further research is required to determine the physicomechanical properties of cement as an additive or as partial replacement material.
With this in mind, the gaps of the previous studies has influenced the objective of this experimental investigation. This study aims to utilize abundant banana and orange peel waste as a partial replacement for cement, to investigate the chemical composition of banana and orange peel powder: exploring their cement replacement potential and lastly, to investigate the potential use of banana and orange peel waste as a partial cement replacement up to 8% to assess the effect on the physicomechanical characteristics of cement blended with orange peel and banana peel powder. These factors contribute to enhanced cement durability, decreased carbon dioxide emissions, and reduced generation of fruit waste.

2. Methods

2.1 Material Selection and Preparation

Owing to the significant and escalating volume of discarded banana peel waste that accumulates on a global scale, coupled with its discernible potential as a valuable pozzolanic substance, the decision was made to ingeniously incorporate banana peels as a strategic fractional substitute for conventional cement within the confines of this meticulously designed experiment. In a parallel manner, the prevailing surplus of discarded citrus peels, conspicuously widespread across diverse geographical regions, presented itself as an eminently viable contender for repurposing as an innovative cement augmenting agent. Notably, the finely powdered or ash-derived manifestation of orange peels presents an inherent array of pozzolanic attributes that, when harnessed, exhibit a palpable efficacy in the realm of cementitious production processes.
The meticulously acquired specimens of banana and orange peels, intentionally selected at the peak of their ripeness to encapsulate their optimal chemical composition, were conscientiously sourced from a diverse array of purveyors specializing in banana-based delicacies, in addition to being procured from reputable supermarket establishments that consistently stock a comprehensive array of fresh produce.
In order to create a consistent and reliable benchmark for the purpose of comparison, the choice was made to employ Ordinary Portland cement, with a specific focus on the widely recognized and frequently employed RapidSet brand; this particular brand stood out as the prevailing and extensively accessible variant of cement found within local hardware stores throughout the Philippines. With meticulous deliberation encompassing an array of potential methodologies, the decision was ultimately reached to opt for the sun-drying technique for the specimens' desiccation process. Furthermore, as a means of ensuring homogeneity in composition and texture, the raw materials underwent a transformation into a finely powdered state utilizing the capabilities of a food processor.

2.2 Moisture Content

The moisture content of the sample specimens was determined by subjecting them to sun-drying at an average temperature of 34.73°C. After 7 d of sun-drying for banana peel and 14 d for orange peel, the weight of the samples remained unchanged, indicating that they had reached a state where they could be powdered. The following equation (Eq. (1)) illustrates the formula of determining the moisture content of banana and orange peels. To obtain the moisture content, subtract the final sample weight (W_f) from the initial weight (W_i)and then divide this difference by the initial weight.

$$\left(\frac{W_i - W_f}{W_i}\right)(100)\ \% \tag{1}$$

As indicated in Table 1, the initial and final weights of banana and orange peels are presented alongside their corresponding moisture contents.

Table 1: Moisture Content

Type of Sample	Initial Weight (grams)	Final Weight	Moisture Content
Banana Peels	1000	175	82.50 %
Orange Peels	1250	300	76 %

2.3 Testing Procedures

The experimental investigation involved six specimens with varying percentages of cement and fruit waste replacement, along with pure ordinary Portland cement, banana peel powder, and orange peel powder. Based on the study by Usman et al. (2018), three percentages of cement substitution (4 %, 6 %, and 8 %) were utilized, as these percentages had shown improvement in the physicomechanical properties of cement. However, the mentioned study used fruit waste ash instead of powder. The change in cement replacement percentages directly affected the compressive strength, fineness, and specific gravity of the specimens.
All specimens had to pass through sieve number 200, which was the standard for cement. Pure specimens underwent chemical testing, while specimens with cement substitution underwent physical testing following ASTM C150 and ASTM C109 standards. ASTM C150, are part of chemical testing and are used to determine the composition of the cement phase. While, ASTM C109 provides a means of determining the compressive strength of hydraulic cement and other mortars and results may be used to determine compliance with specifications.

3. Results and Discussion

Specimens were prepared according to ASTM C109 for physical analysis and ASTM C150 for chemical analysis. These specimens underwent tests for compressive strength, fineness, and specific gravity to evaluate their properties and adherence to ASTM standards. The experimental inquiry includes six specimens with varying percentages of cement and fruit waste replacement, as well as pure ordinary Portland cement, banana peel powder, and orange peel powder. Usman et al. (2018) indicated that cement substitution percentages of 4 %, 6 %, and 8 % improved the physicomechanical properties of cement, although their study used fruit waste ash instead of powder. Changes in cement replacement percentages directly impact compressive strength, fineness, and specific gravity. All specimens must pass sieve number 200, the standard for cement. Pure specimens undergo chemical testing, while specimens with cement substitution undergo physical testing according to ASTM C150 and ASTM C109 standards.

3.1 Chemical Analysis of OPC, BPP, and OPP

Analyzing the chemical characteristics of powdered banana and orange peels plays a crucial role in understanding their binding capabilities and other pertinent properties that demonstrate their effectiveness as cement. This section investigates the chemical properties of banana peel powder (BPP), orange peel powder (OPP), and ordinary Portland cement (OPC) to compare their chemical compositions.
Table 2 shows that banana peel powder (BPP) possesses chemical properties that make it suitable as a partial replacement material for cement. The thorough analysis reveals a significant similarity in composition between banana peel powder (BPP) and ordinary Portland cement (OPC), indicating the potential viability of BPP as a suitable replacement in cement-related applications. However, a detailed examination of orange peel powder (OPP) raises concerns as its quantitative attributes surpass established thresholds. This prompts careful consideration of how it could affect the durability of cement materials, potentially leading to unfavorable outcomes that require cautious evaluation.

Table 2: Chemical Analysis of OPC, BPP, and OPP ASTM-C150

	Standard (Max.)	OPC	BPP	OPP
Magnesium oxide (MgO), %	6	2.43	2.49	7.25
Loss on Ignition, %	3	1.56	1.35	4.52
Insoluble Residue, %	0.75	0.51	0.45	1.88
Sulfur trioxide (SO_3), %	3	2.56	2.04	4.41

3.2 Compressive Strength Test

Figure 1 shows the compressive strength test results for the cement cube specimens, which adhere to the dimensions specified in the ASTM C109 standard. The test outcomes meet the mixture requirements outlined in the study. According to DPWH-BRS guidelines, concrete with a design strength of 3,500 psi at 28 d should reach a minimum of 71 % of its design strength, equivalent to 2,495 psi, at 7 d.

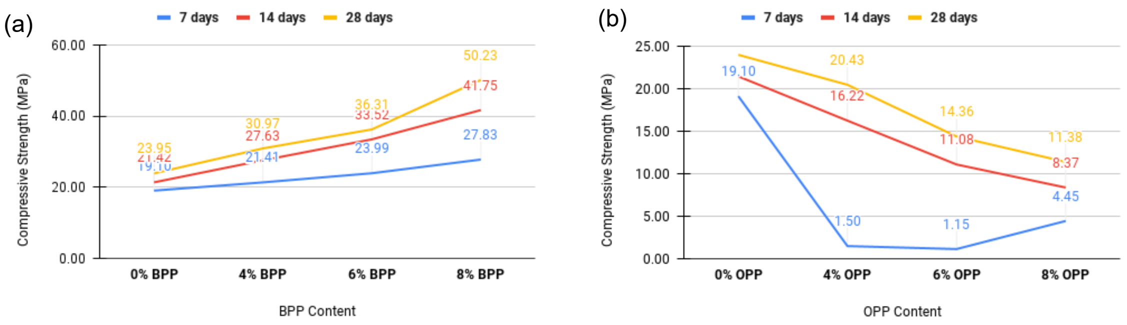

Figure 1: Line Graph of the Compressive Strength Test (a) with BPP, and (b) with OPP replacements

The results obtained clearly demonstrate that BPP possesses significant potential as a material for partially replacing cement. The findings at Figure 1(a) clearly indicate that as the percentage of BPP increases within the range of 4 % to 8 %, the compression strength exhibits a noticeable rise. When the normal OPC was tested for compressive strength, it achieved a maximum value of merely 23.95 MPa after 28 d of curing. Meanwhile, by incorporating 8 % BPP content, the compression strength remarkably increased to 50.23 MPa, representing a highly significant improvement.

In contrast to Figure 1(a), Figure 1(b) reveals a distinctive trend in the comparative analysis. This detailed examination highlights the complex interplay between two additives: orange peel powder (OPP) and banana peel powder (BPP), and their impact on cement performance. The empirical data diverges significantly from previous findings, emphasizing the distinct effect of incorporating orange peel powder. Notably, the inclusion of orange peel powder within the cement matrix results in a significant reduction in strength parameters, evident from the presented data. This shift in mechanical behavior, observed through systematic analysis, prompts a thoughtful consideration of the intricate dynamics governing the interaction between cementitious materials and botanical additives.

3.2.1 Data Analysis

The following tables and graphs present the outcomes of a comparative analysis between ordinary Portland cement and BPP and OPP, along with cement blended with specific quantities of BPP and OPP. The statistical method of Analysis of Variance (ANOVA) was employed to analyze the data. The study is deemed meaningful if the "Adj R-Squared" value is 75% or above.The values of Prob>F in this table indicate that the null hypothesis must be rejected, as they are below 0.01 for the curing periods of 7 d, 14 d, and 28 d. Table 3 reveals that the percentage of BPP in cement has a significant impact on its compressive strength.

Table 3: Analysis of variance table of compressive strength test (BPP)

		DF	Sum of Squares	Mean Square	F Value	Prob>F
7-d Curing days	Model	3	126.18276	42.06092	60.0949	<0.0001
	Error	8	5.59927	0.069991		
	Total	11	131.78202			
14-d Curing days	Model	3	675.34427	225.11476	125.97415	<0.0001
	Error	8	14.29593	1.78699		
	Total	11	689.6402			
28-d Curing days	Model	3	1114.66683	371.555641	233.03058	<0.0001
	Error	8	12.7556	1.59445		
	Total	11	1127.42243			

Based on the Prob>F values in this table, which are below 0.01 for the 7-day, 14-day, and 28-day curing periods, it is evident that the null hypothesis should be rejected. Table 4 provides evidence that the percentage of OPP in cement has a notable influence on its compressive strength.

Table 4: Analysis of variance table of compressive strength test (OPP)

		DF	Sum of Squares	Mean Square	F Value	Prob>F
7-d Curing days	Model	3	649.51603	216.50534	19.80289	4.64E-04
	Error	8	87.46414	10.93302		
	Total	11	736.98017			
14-d Curing days	Model	3	299.95417	99.98472	64.43975	<0.0001
	Error	8	12.4128	1.5516		
	Total	11	312.36697			
28-d Curing days	Model	3	288.87967	96.29322	91.82443	<0.0001
	Error	8	8.838933	1.04867		
	Total	11	297.269			

3.3 Fineness and Specific Gravity of Cement Incorporated with BPP and OPP

The degree of fineness of cement significantly influences the speed of hydration, which in turn affects both the rate of strength gain and the rate of heat evolution. Cement with a finer texture provides a larger surface area for hydration, resulting in accelerated strength development. Meanwhile, the density of a material in relation to water is determined by its specific gravity. In the case of cement, specific gravity is a significant characteristic that relates to both its density and viscosity. It serves as one of the factors used to determine the density of cement.

The following data depicted in Table 5 and 6 showcases the results of specific gravity and fineness in conjunction with BPP and OPP content. Fineness of BPP and OPP show that approximately 91.56 % of the particles were observed to pass through the No. 200 sieve for 4 %, while 93.10 % and 93.88 % passed for 6 % and 8 %, respectively. These findings indicate that the percentage of particles retained on Sieve No. 200 did not surpass the maximum standard limit. However, in the case of orange particles, the results reveal that the fineness of cement with OPP particles exceeds the required standard at 10 %.

Table 5: Fineness and Specific Gravity of Cement with BPP

Sample	Fineness (%Retained on Sieve #200)	Specific Gravity
4 % BPP	8.44	2.63
6 % BPP	6.90	2.72
8 % BPP	6.12	2.93

Table 6: Fineness and Specific Gravity of Cement with OPP

Sample	Fineness (%Retained on Sieve #200)	Specific Gravity
4 % OPP	38.32	2.38
6 % OPP	42.60	2.50
8 % OPP	47.82	2.78

Moreover, as shown in Table 5 and 6, the specific gravity of BPP at 4 %, 6 %, and 8 % was measured as 2.63, 2.72, and 2.93, respectively, and the specific gravity of OPP at 4 %, 6 %, and 8 % was measured to be as 2.38, 2.50, and 2.78, respectively, in the experimental study. If the specific gravity of cement exceeds 3.19, it suggests that the cement has not been adequately ground to meet industry standards. Based on the depiction intables above, it can be inferred that the specific gravity of both BPP and OPP adhered to the standard.

4. Conclusions

The researchers conducted and tested an investigation on the physicomechanical properties of cement with partial replacements of BPP or OPP. The collected data was analyzed and interpreted, leading the researchers to reach several conclusions.

The incorporation of BPP into cement has exhibited a notable enhancement in compressive strength as compared to OPP. This effect is particularly evident as the proportion of BPP used in cement replacement increases, leading to a corresponding rise in compressive strength. Conversely, when the percentage of OPP substitution in cement rises, it results in a reduction in compressive strength.

In a 7 d curing timeframe, cement infused with BPP demonstrates a remarkable enhancement ranging from 12 % to 29 %. This improvement becomes even more substantial after 14 d of curing, with a range of 26 % to 56 %. Impressively, the progress continues, as BPP-infused cement showcases an improvement range of 46 % to

110 % after 28 d of curing. In contrast, utilizing OPP as a replacement for cement negatively impacts compressive strength. However, further analysis reveals that the compressive strength of OPP-infused cement follows an upward trajectory with prolonged curing periods.

The moisture absorption characteristics of BPP, OPP, and the cement itself play a crucial role in the fineness of the cement mixture. OPP exhibits higher moisture absorption, leading to the formation of clumps in OPP-infused cement and a failure to meet the required fineness standard. The specific gravity of cement infused with both BPP and OPP remains within the recommended range. Moreover, as the percentage of cement replacement increases, the specific gravity also shows a corresponding increase.

Moreover, BPP undergoes chemical analysis according to ASTM C150 and aligns well with ordinary Portland cement results, affirming its suitability as a substitute for cement. Conversely, the chemical analysis of OPP exceeds the maximum standard, indicating its unsuitability as a cement replacement.

On the other hand, the research may have successfully accomplished its intended objectives or goals, it remains unfinished. As a result, to further enhance and refine the study additional incorporation of BPP and OPP is necessary. Additionally, in order to evaluate the alternative potential influence on cement, replace the mixed varieties with a particular type of banana/orange and examine its effects. Given that this study solely focuses on cement, it is also advised to conduct additional research on utilizing the cement that has been partially incorporated with BPP and OPP in concrete production, thereby exploring their potential applications. Lastly, it is recommended to perform a comprehensive analysis specifically focused on the water absorption characteristics of both BPP and OPP.

Acknowledgments

We express our gratitude for the financial assistance provided by the Circular Cities Asia and The Regional Project Energy Security and Climate Change Asia-Pacific (RECAP) of the Konrad-Adenauer-Stiftung. The authors would also like to extend their appreciation to the advisers from BPSU Civil Engineering and the Reliance Concrete Testing Consultancy (RCTC), Philippines, for the technical support.

References

Ochave, R. M. D., 2021, Dole to Repurpose Tons of Fruit Waste, BusinessWorld Online <bworldonline.com/corporate/2021/11/29/413737/dole-to-repurpose-tons-of-fruit-waste/> accessed 28.11.2022

Fan, W. K., Tahir, M., Alias, H., 2023, Visible Light Promoted Low Temperature Photothermal CO2 Methanation Over Morphologically Engineered Ni/TiO2 NWs Catalyst, Materials Today: Proceedings <sciencedirect.com/science/article/abs/pii/S2214785323032911> accessed 28.11.2022

Garside, M., 2023, Cement Production Worldwide from 1995 to 2022, Statista <statista.com/statistics/1087115/global-cement-production-volume/> accessed 25.02.2023

Lakhiar, M., Mohamad, N., Abdul Samad, A. A., Muthusamy, K., Azree, M., Goh, W., George, S., 2021, Effect of Banana Skin Powder and Coir Fibre on Properties and Flexural Behaviour of Precast SCC Beam, International Journal of Sustainable Engineering, 14(5), 1–13.

Manan, T. S. B. A., Kamal, N. L. M., Beddu, S., Khan, T., Mohamad, D., Syamsir, A., Itam, Z., Jusoh, H., Basri, N. A. N., Mohtar, W. H. M. W., Isa, M. H., Shafiq, N., Ahmad, A., Rasdi, N. W., 2021, Strength Enhancement of Concrete Using Incinerated Agricultural Waste as Supplementary Cement Materials, Scientific Reports, 11(12722).

Murthi, P., Lavanya V., Poongodi K., 2022, Effect of Eggshell Powder on Structural and Durability Properties of High-Strength Green Concrete for Sustainability: A Critical Review, Materials Today: Proceedings, 68(5), 1311-1318.

Olubajo, O., Osha, O., Abdullahi, B., 2019, Potential of Orange Peel Ash as a Cement Replacement Material, Path of Science, 5(7), 2009–2019.

Statista, 2021, Cement production global 2021 <http://www.statista.com/statistics/1087115/global-cement-production-volume/?fbclid=IwAR2gMGF7Dv2IQIExBAiWjYqUaz_us2bAd6jukCDm3Ch1l6hwm7d1EZ4Hrk> accessed 01.04.2022.

Usman, A., Bala, N., Bashiru, M., 2018, Effect of Plantain Peel Ash (PPA) on the Mechanical Properties of Concrete, Noble International Journal of Scientific Research, 2(3), 11–18.