

An experimental study on mortar plaster incorporating banana leaf ash as partial replacement for cement and coconut Shell as partial replacement for fine aggregates for sufficient compressive strength and enhanced water resistance in Baguio city

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Abstract

This study investigated the use of Banana Leaf Ash (BLA) and Coconut Shell (CS) as sustainable partial replacements for cement and fine aggregates in Type N mortar plaster. Performance was evaluated through compressive strength testing (ASTM C109) and water absorption analysis (ASTM C1403) at curing intervals of 7, 14, and 28 days. Experimental results revealed that combined replacement levels of 5%, 10%, and 15% failed to meet the mandatory 5.2 MPa required strength. While individual BLA replacements at 5% and 10% yielded strengths of 12.3114 MPa and 11.2416 MPa, and 5% CS achieved 6.9838 MPa, the compositional compatibility between materials proved incompatible at higher concentrations. To refine the mix, exponential regression and a 0.84 safety factor identified an ideal 3% combined replacement. This refined mix achieved a 28-day strength of 8.9168 MPa and a low 28-day water absorption rate of 2.66%. In contrast, the 15% replacement resulted in total early-stage failure with 0 MPa at 7 and 14 days and a significant 28-day water absorption of 5.80%. The study concludes that while increasing coconut shell content significantly compromises compressive strength and moisture resistance due to its porous and fibrous nature, BLA functions effectively with a pozzolanic property that facilitates secondary hydration reactions. When maintained at the 3% ideal replacement level, the mixture achieves the necessary structural requirements for Type N mortar. These results validate a sustainable framework for utilizing locally sourced agricultural by-products in high-altitude, high-rainfall environments, offering an eco-friendly alternative for housing construction in the Baguio City region.

Keywords: banana leaf ash, coconut shell, mortar plaster, compressive strength, water resistance, partial replacement, humid, high-rainfall, moisture

Introduction

The construction industry serves as a fundamental pillar for global infrastructure development, particularly in rapidly urbanizing regions. Within this sector, mortar plays a vital economic role due to its versatility and affordability in masonry and finishing works. However, the production of cement, the primary binder in conventional mortar, results in substantial carbon dioxide emissions. As stated by Welle (2022) [11], these industrial processes account for approximately 8% of global greenhouse gas output. Consequently, cement production is widely recognized as a leading contributor to the significant carbon footprint of the construction industry. In response to these pressing environmental challenges, green construction has emerged as a sustainable approach to mitigate ecological impacts. This movement prioritizes the use of ecological materials, methodologies that prioritize energy efficiency, and waste reduction. Current research indicates that partially replacing cement and aggregates with locally available agricultural waste can conserve natural resources, reduce construction costs, and potentially enhance structural durability. Therefore, utilizing these alternatives presents a viable strategy for modern construction (Alsharari, 2025) [2].

Beyond environmental concerns, conventional masonry faces severe structural challenges in specific climatic conditions, such as the mountainous environment of Baguio City. Frequent rainfall, high humidity, and constant temperature fluctuations make building components in this region highly susceptible to moisture accumulation. This excessive moisture often leads to microcracking, reduced mechanical strength, and the premature deterioration of mortar, which in turn drives up maintenance costs over the extended lifespan of the structure (Yari et al., 2025) [12]. While current construction practices often rely on chemical admixtures to improve resistance to water, many of these commercial waterproofing agents are expensive and imported. This

reliance limits their accessibility for moderately sized projects in developing regions like the Philippines, necessitating the development of durable mortar mixtures using accessible local resources.

To address both environmental and local durability issues, researchers have turned to agricultural byproducts such as Banana Leaf Ash (BLA) and Coconut Shell (CS). BLA is particularly noted for its high silica and alumina content, which facilitates pozzolanic reactivity and strength development. Furthermore, studies have demonstrated that BLA can refine pore structures, thereby increasing material density and improving extended durability (Tavares et al., 2022) [10]. Similarly, crushed coconut shells have been investigated as an effective replacement for fine aggregates. While low replacement levels maintain sufficient structural strength, higher concentrations can increase porosity. Although BLA and CS have been explored individually, there remains a significant lack of research on their combined effects. Specifically, the synergistic potential of these materials has not been comprehensively evaluated for mortar applied in humid, temperate climates, revealing a critical knowledge gap in sustainable building practices.

Addressing this gap, the primary objective of this study was to evaluate the mechanical properties and water resistance of Type N mortar by incorporating BLA and CS as partial replacements for cement and fine aggregates. The research aimed to determine the most effective replacement percentages by testing levels of 5%, 10%, and 15% to identify an optimized mix design. By analyzing the compressive strength and permeability of the modified mortar, the study sought to ensure compliance with established structural standards for masonry while specifically addressing durability concerns in environments prone to excessive moisture. Furthermore, this project intended to establish an affordable construction material that aligns with the United Nations Sustainable Development Goals, specifically targeting industry innovation and responsible production.

The scope of the investigation was geographically limited to the climatic conditions of Baguio City and focused on the structural and physical evaluation of a 1:3 mortar ratio over a controlled curing period of 28 days. Due to constraints such as a limited academic semester, a fixed thesis defense schedule, and budget limitations, the study relied on available university laboratory resources and manual testing rather than advanced analytical software. Consequently, the research was restricted to mechanical assessments of compressive strength and water absorption. The study excluded extended durability tests such as resistance to sulfate attack, fire, or seismic loading, as well as the evaluation of other mortar types or structural concrete applications. Despite these practical and temporal delimitations, this study provides a vital foundational analysis of these specific mixtures without the ethical complications of human or animal testing.

Materials and Methods

Research Design

This study employed an experimental quantitative research design to evaluate the effectiveness of Banana Leaf Ash (BLA) and Coconut Shell (CS) as partial replacement materials for cement and fine aggregates in Type N mortar plaster. The study investigated the effects of varying replacement levels on the compressive strength and water absorption properties of mortar specimens after 7, 14, and 28 days of curing. The quantitative approach enabled precise measurement and statistical analysis, providing an objective assessment of the relationships between variables (Rana et al., 2021) [9]. Furthermore, the experimental approach enabled direct comparison between the control mixture and modified mortar mixtures containing agricultural waste materials.

Materials

The materials used in this study included Type I Ordinary Portland Cement (OPC), fine aggregates, potable water, banana (*Musa acuminata x balbisiana* (ABB Group)) leaves, and coconut (*Cocos nucifera*) shells. Banana leaves were collected from Laoac, Pangasinan, Philippines, while coconut shells were obtained from Urdaneta City Public Market, Pangasinan.

The banana leaves were sun-dried for at least seven days before incinerated under a controlled high temperature to produce ash. The resulting ash was pulverized and sieved through a No. 200 sieve to obtain fine Banana Leaf Ash (BLA). Coconut shells were also sun-dried, manually crushed, and sieved using No. 4 and No. 200 sieves in accordance with ASTM C136 (ASTM, 2025) [4] to achieve the desired particle size distribution. All processed materials were stored in airtight containers prior to use.

Mix Proportioning

Mortar mixtures were prepared using a Type N mortar proportion of 1:3 (cement:fine aggregate) (Fajardo, 2000) [8]. A base water-cement ratio of 0.40 was initially adopted; however, adjustments in water content were made in accordance with ASTM C270 (ASTM, 2026) [6] to achieve suitable workability requirements, considering the influence of Banana Leaf Ash (BLA) and Coconut Shell (CS) on the consistency of the mortar mixtures. Banana Leaf Ash (BLA) was used as a partial replacement for cement by weight, while Coconut Shell (CS) was used as a partial replacement for fine aggregates by weight.

The initial experimental program consisted of combined BLA–CS replacement levels of 5%, 10%, and 15%, together with a control mixture, adapted from the study of Banting et al. (2023) [7]. Preliminary evaluation of the initial combined mixtures indicated that the compressive strength values did not meet the minimum 5.2 MPa requirement for Type N mortar plaster (Fajardo, 2000) [8] and exhibited inconsistent durability performance relative to the control mixture. To further determine the factors affecting the behavior of the combined mixtures, supplementary trial batches containing individual BLA-only and CS-only replacements were prepared for exploratory evaluation.

A predicted ideal replacement level was subsequently estimated using exponential regression analysis based on the compressive strength and durability results obtained from the 5%, 10%, and 15% combined replacement mixtures. The regression model indicated that a lower replacement level of approximately 3% may yield improved mortar performance while maintaining the sustainability benefits of the agricultural waste materials. Consequently, an additional 3% BLA–CS mortar mixture was prepared and experimentally validated.

Specimen Preparation and Curing

The mortar mixtures were manually mixed using shovels and a mixing board. Dry materials were first blended thoroughly before gradually adding water to achieve uniform consistency. The prepared mortar was cast into 2 in. (50 mm) cube molds coated with form release oil.

An initial total of 72 cube specimens was prepared for the control mixture and the combined BLA–CS replacement mixtures at 5%, 10%, and 15% replacement levels. Following the preliminary evaluation of the initial combined mixtures, additional supplementary specimens were prepared for the regression-derived 3% BLA–CS mixture and for the individual BLA-only and CS-only replacement mixtures. Including the supplementary batches, a total of 126 cube specimens was prepared and tested in the study.

The number of specimens prepared for each mixture was based on the required curing periods and testing procedures. For each curing period (7, 14, and 28 days), three specimens were allocated for compressive strength testing and another three specimens for water absorption testing. Consequently, six specimens were prepared per mixture for each curing period to ensure consistency and reliability of the experimental results. All specimens were demolded after 24 hours and submerged in water until the designated curing period prior to testing.

Testing Procedures

Compressive Strength Test

Compressive strength testing was conducted in accordance with ASTM C109 (ASTM, 2025) [3] using a Universal Testing Machine (UTM). After each curing period, the specimens were surface-dried and subjected to compressive loading until failure. The compressive strength was calculated by dividing the maximum load by the cross-sectional area of the specimen.

Water Absorption Test

Water absorption testing was performed following ASTM C1403 (ASTM, 2022) [5]. After the designated curing period, specimens were immersed in water for 24 hours, weighed, oven-dried for at least 8 hours, and reweighed to determine water absorption characteristics.

Statistical Analysis

Descriptive statistical tools including mean, standard deviation, and coefficient of variation were used to summarize the experimental results. The Shapiro–Wilk test was conducted to assess data normality. One-way Analysis of Variance (ANOVA) was used to determine significant differences among the control and experimental mixtures at a 0.05 level of significance. When significant differences were identified, Tukey’s Honestly Significant Difference (HSD) test was applied as a post-hoc analysis.

Results and Discussion

The initial phase of the experimental study focused on the performance of mortar incorporating combined replacements of Banana Leaf Ash (BLA) and Coconut Shell (CS). These initial mixtures were subjected to compressive and water absorption testing to establish a baseline for their structural viability and their resistance to moisture penetration.

Table 1. Water Cement Ratio Summary

Designation	Cement, g	Water, g	W/C RATIO
0% Controlled Sample	1140	650	0.57
5% Replacement (BLA and CS)	1080	1060	0.99
10% Replacement (BLA and CS)	1020	1210	1.19
15% Replacement (BLA and CS)	970	1380	1.43
5% Replacement (BLA) and 0% (CS)	1080	680	0.63
10% Replacement (BLA) and 0% (CS)	1020	750	0.74
15% Replacement (BLA) and 0% (CS)	970	830	0.86
0% (BLA) and 5% Replacement (CS)	1160	860	0.74
0% (BLA) and 10% Replacement (CS)	1180	1060	0.88
0% (BLA) and 15% Replacement (CS)	1200	1170	0.99
3% Replacement (BLA and CS)	1110	730	0.66

The study examines water–cement (w/c) ratios in mortar plaster mixes. An initial baseline w/c ratio of 0.40 was adjusted per ASTM C270 for workability. The control mix showed the lowest ratio at 0.57, while increasing alternative material replacements raised water demand. For Banana Leaf Ash (BLA) as a cement replacement, w/c ratios increased from 0.63 to 0.86 with 5% to 15% replacements, indicating higher water absorption. Crushed Coconut Shell (CS) mixes had even higher ratios, reaching 0.99 at 15% replacement due to their rough texture. Combined BLA and CS mixes showed the highest demand with ratios of 0.99, 1.19, and 1.43 for 5%, 10%, and 15% replacements, respectively. The 15% mix required 1380 g of water, highlighting that both materials together significantly increase water requirements for mortar workability.

Compressive Strength

Table 2. Compressive Strength Data for Combined Replacement Mixtures

Designation	7-Day Strength (MPa)	14-Day Strength (MPa)	28-Day Strength (MPa)
Control (100% Conventional)	5.6376	6.2472	9.6689

Designation	7-Day Strength (MPa)	14-Day Strength (MPa)	28-Day Strength (MPa)
5% Combined Replacement	1.9218	2.6856	3.9495
10% Combined Replacement	0.5354	0.9841	1.8062
15% Combined Replacement	0.0000	0.0000	0.5824

The data presented in the preliminary tables represents the first experimental mixtures tested, which utilized high-percentage combined replacements. These trials yielded results that failed to satisfy the requisite structural performance standards, manifesting a systematic trend of strength degradation directly proportional to the increase in replacement volume. Notably, the 15% replacement group exhibited a total absence of compressive resistance during the 7 and 14-day intervals, signifying a profound disruption of the cementitious matrix. This catastrophic loss of integrity at 5%, 10%, and 15% levels mandated a cessation of these specific ratios and a shift toward mathematical optimization.

Table 3. Isolated Performance Evaluation of Banana Leaf Ash (BLA) Replacements

BLA Replacement Level	7-Day Strength (MPa)	14-Day Strength (MPa)	28-Day Strength (MPa)
5% BLA	6.6514	8.5495	12.3114
10% BLA	6.6876	8.2774	11.2416
15% BLA	5.0202	6.1862	9.3211

Table 4. Isolated Performance Evaluation of Coconut Shell (CS) Replacements

CS Replacement Level	7-Day Strength (MPa)	14-Day Strength (MPa)	28-Day Strength (MPa)
5% CS	5.2662	4.8499	6.9838
10% CS	3.7938	1.7604	2.1752
15% CS	3.1204	1.3202	3.0180

The experimental data showed that the Banana Leaf Ash (BLA) emerged as the superior replacement, demonstrating a consistent capacity to maintain and enhance compressive strength across all curing stages. The highest recorded strength of 12.3114 MPa at the 28th day period suggested that the high silica content inherent in banana leaf ash facilitates a pozzolanic reaction, interacting with calcium hydroxide to produce additional calcium silicate hydrate (C-S-H) gels, which densify the concrete matrix over time.

Conversely, Crushed Coconut Shells (CS) were identified as the least effective material in this study. The strength of CS-integrated specimens declined sharply as replacement levels increased, reaching a critical low of 1.3202 MPa at the 14-day mark for the 15% replacement level. This indicates a fundamental lack of structural bonding between the organic aggregate and the cement paste, likely exacerbated by the smooth surface texture and organic composition of the shells.

The failure of the Combined Material Replacement, particularly at the 10% and 15% thresholds, is attributed to the deleterious physical and mechanical characteristics introduced by the coconut shells. While BLA contributes to the filling of microscopic pores, the inclusion of coconut shells introduces excessive macroporosity and significantly reduces the specimen's unit density. The data shows that the compressive force dropped significantly in the high-percentage CS samples, meaning the shells prevented the concrete from sticking together into a solid block.

In the combined mixture, the coconut shells serve as structural discontinuities or zones of weakness within the matrix. The organic nature of the shells may also lead to the absorption of mixing water, which hinders the

proper hydration of the surrounding cementitious material. Consequently, even with the pozzolanic benefits provided by the Banana Leaf Ash, the internal instability and loss of density caused by the coconut shells predominate.

Table 5. *Compressive Performance of the Mathematically Derived 3% Optimal Level*

Designation	7-Day Strength (MPa)	14-Day Strength (MPa)	28-Day Strength (MPa)
3% Optimal Replacement	5.3410	6.5287	8.9168

This specific substitution level is the only combined replacement that successfully reached the minimum compressive strength required for mortar plaster. It demonstrated that lowering the concentration of replacement allowed the mixture to meet structural standards while maintaining the necessary internal bond.

Table 6. *Comprehensive Data Summary*

Designation	7-Day Strength (MPa)	14-Day Strength (MPa)	28-Day Strength (MPa)
Control (100% Conventional)	5.6376	6.2472	9.6689
3% Combined Replacement	5.341	6.5287	8.9168
5% Combined Replacement	1.9218	2.6856	3.9495
10% Combined Replacement	0.5354	0.9841	1.8062
15% Combined Replacement	0	0	0.5824
5% Banana Leaf Ash (BLA)	6.6514	8.5495	12.3114
10 % Banana Leaf Ash (BLA)	6.6876	8.2774	11.2416
15% Banana Leaf Ash (BLA)	5.0202	6.1862	9.3211
5% Crushed Coconut Shells (CS)	5.2662	4.8499	6.9838
10% Crushed Coconut Shells (CS)	3.7938	1.7604	2.1752
15% Crushed Coconut Shells (CS)	3.1204	1.3202	3.018

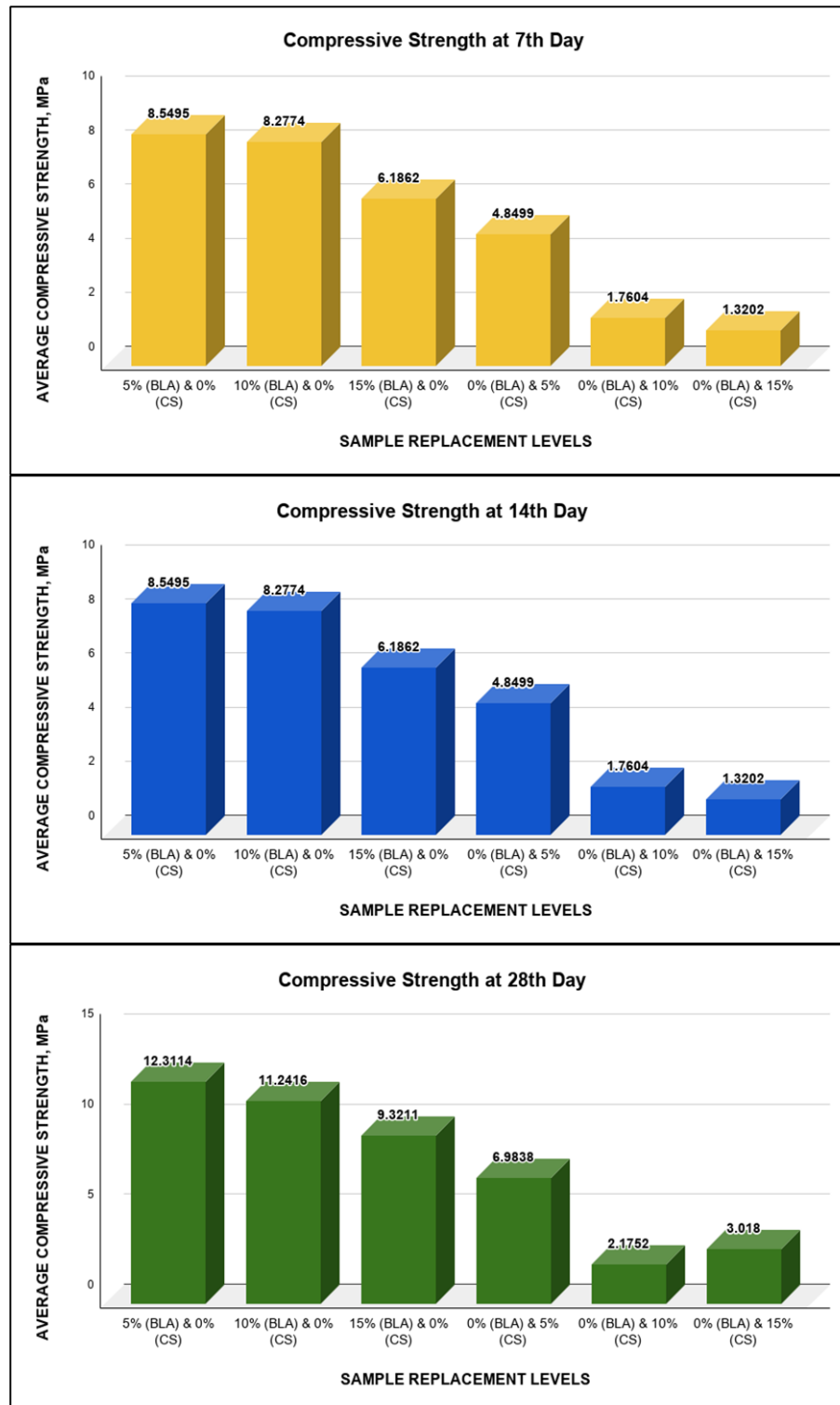


Figure 1. Summary of Compressive Strength of Individual Mix at different Curing Periods. 7-Day Compressive Strength (a), 14-Day Compressive Strength (b), 28-Day Compressive Strength (c).

The experimental results highlighted a significant contrast in how these two materials influence the mortar plaster. Banana Leaf Ash acted as a reinforcing agent. Its fine particulate nature likely created a denser microstructure that improved the capacity of the plaster.

In contrast, the data identified the crushed coconut shells as the primary cause of mechanical instability. The separate 10% coconut shell mixture showed a sharp decline to 2.1752 MPa, proving that the shells create internal weak points. Their organic texture prevents a strong bond with the cement paste, resulting in a brittle

material that cannot resist high pressure. This confirmed that while the ash served as a performance-enhancing replacement, the shell fragments lead to structural failure when the replacement percentage is too high.

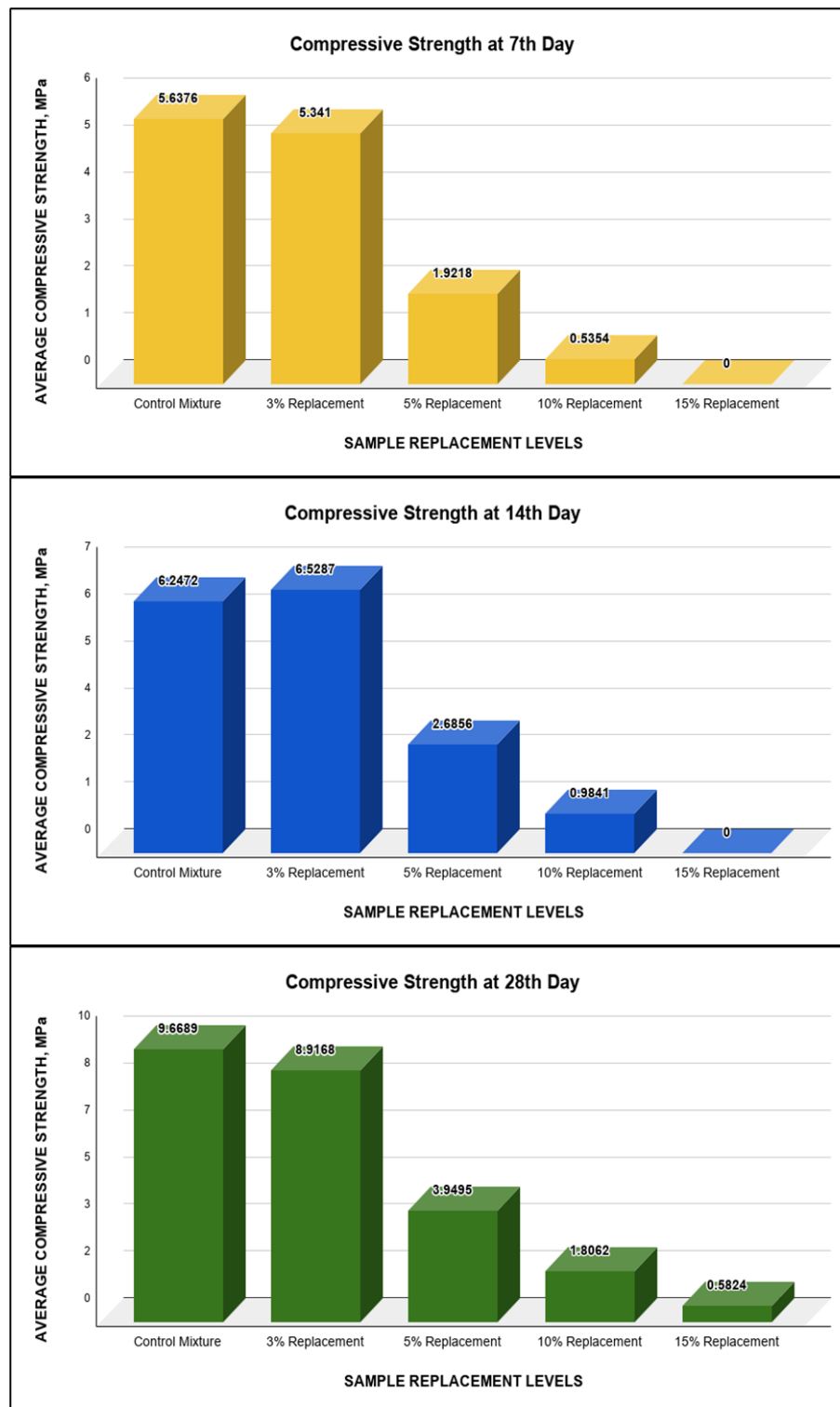


Figure 2. Summary of Compressive Strength of Combined Mix at different Curing Periods. 7-Day Compressive Strength (a), 14-Day Compressive Strength (b), 28-Day Compressive Strength (c).

Based on the data, the analysis identified a 3% replacement level as the mathematically optimal threshold for maintaining structural integrity near the control baseline. The results distinguished Banana Leaf Ash (BLA) as a high-performing replacement that enhances compressive strength, while identifying Coconut Shell (CS) as the detrimental component responsible for the precipitous decline in the mortar's capacity.

The results represented the most effective balance between material substitution and capacity performance, proving that a lower replacement level of 3% allowed for a proper chemical hydration process and a stable internal bond. This substitution level is the only combined replacement in the study that successfully reached the minimum compressive strength required for mortar plaster. The steady growth in strength across the 7, 14, and 28-day periods confirmed that the mixture remains structurally viable and meets the necessary standards for practical application.

Water Absorption

Table 7. *Water Absorption Data for Combined Replacement Mixtures*

Designation	7-Day Water Absorption (%)	14-Day Water Absorption (%)	28-Day Water Absorption (%)
Control (100% Conventional)	4.1	3.44	3.09
5% Combined Replacement	4.8	4.2	3.35
10% Combined Replacement	5.52	4.82	4.33
15% Combined Replacement	7.61	6.43	5.8

The control and 5% combined replacement mixtures exhibited values within the acceptable 5% limit, the 10% replacement exceeded this threshold at early curing, and the 15% replacement consistently surpassed the limit across all curing periods, indicating excessive permeability. This trend suggested that higher levels of substitution adversely affect the integrity and compactness of the mortar matrix. Accordingly, these findings necessitated the discontinuation of higher-percentage mixtures and justified the transition toward optimized, lower-percentage formulations to achieve enhanced water resistance and overall material performance.

Table 8. *Isolated Performance Evaluation of Banana Leaf Ash (BLA) Replacements*

BLA Replacement Level	7-Day Water Absorption (%)	14-Day Water Absorption (%)	28-Day Water Absorption (%)
5% BLA	3.95	2.62	3.05
10% BLA	3.91	3.43	2.59
15% BLA	4.22	4.74	3.87

Table 9. *Isolated Performance Evaluation of Coconut Shell (CS) Replacements*

CS Replacement Level	7-Day Water Absorption (%)	14-Day Water Absorption (%)	28-Day Water Absorption (%)
5% CS	4.15	4.09	4.39
10% CS	4.99	5.57	6.04
15% CS	5.65	6.83	5.64

The coconut shell specimens showed a trend of increasing permeability unlike the BLA mix, which saw improved resistance over time. This suggested a fundamental lack of dense bonding between the organic aggregate and the cement paste. The naturally porous and fibrous nature of the shells likely introduced interconnected voids, which acted as pathways for water to travel through the plaster. The data showed that water intake rose sharply in samples with higher CS content, meaning the shells prevented the mortar from forming a sufficiently watertight barrier.

Table 10. Water Absorption Performance of the Mathematically Derived 3% Optimal Level

Designation	7-Day Water Absorption (%)	14-Day Water Absorption (%)	28-Day Water Absorption (%)
3% Optimal Replacement	5.56	4.15	2.66

The findings suggested that maintaining a lower percentage of combined replacements is essential in preserving the integrity and durability of the mortar. Hence, the 3% combined replacement is considered the most suitable proportion for achieving improved water resistance while maintaining acceptable material performance.

Table 11. Comprehensive Data Summary

Designation	7-Day Water Absorption (%)	14-Day Water Absorption (%)	28-Day Water Absorption (%)
Control (100% Conventional)	4.1	3.44	3.09
3% Combined Replacement	5.56	4.12	2.66
5% Combined Replacement	4.8	4.2	3.35
10% Combined Replacement	5.52	4.82	4.33
15% Combined Replacement	7.61	6.43	5.8
5% Banana Leaf Ash (BLA)	3.95	2.62	3.05
10 % Banana Leaf Ash (BLA)	3.91	3.43	2.59
15% Banana Leaf Ash (BLA)	4.22	4.74	3.87
5% Crushed Coconut Shells (CS)	4.15	4.09	4.39
10% Crushed Coconut Shells (CS)	4.99	5.57	6.04
15% Crushed Coconut Shells (CS)	5.65	6.83	5.64

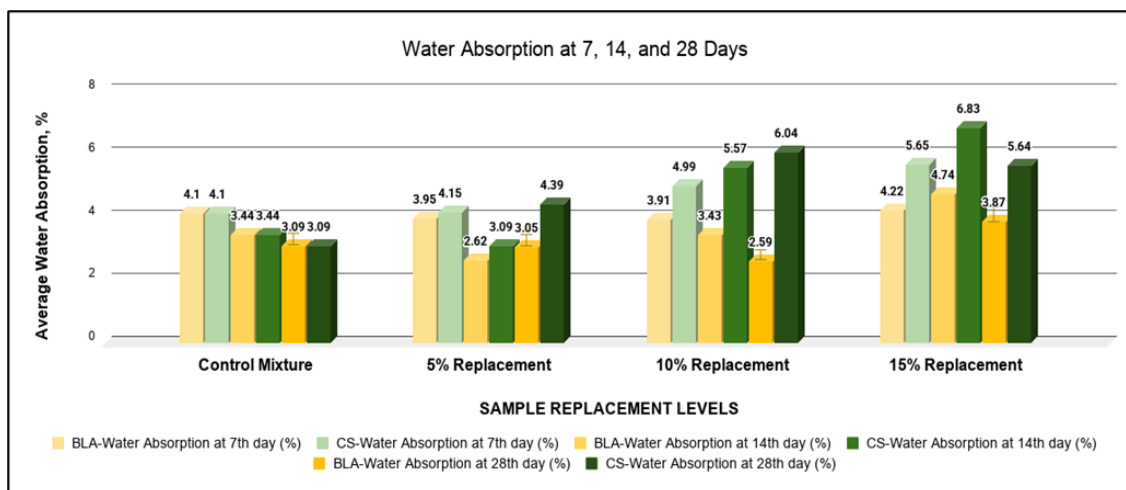


Figure 3. Summary of Water Absorption of Individual Mix

The data identified the crushed coconut shells as the primary factor behind increased hydraulic permeability. The 15% coconut shell replacement showed a substantial rise in water intake, peaking at 5.64%, which indicated that these organic fragments hindered the formation of a dense cement bond. This trend suggested that while the ash served as a performance-enhancing additive, the inclusion of shell fragments introduced internal voids that compromised the material's moisture resistance at higher substitution levels.

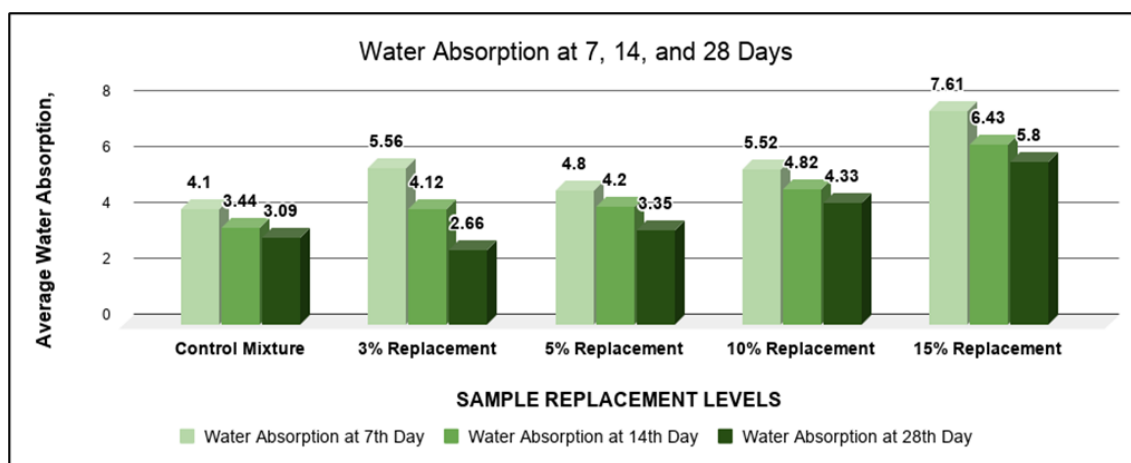


Figure 4. Summary of Water Absorption of Combined Mix

The experimental results identified the 3% combined replacement of Banana Leaf Ash and Crushed Coconut Shells as the optimal threshold for enhancing the specimen's resistance to water penetration. This mixture exhibited lower absorption percentages than the control, hence, it demonstrated that it is the most significant rate of improvement during the curing process, ultimately achieving a water absorption value of 2.66% by the 28th day.

Furthermore, the 3% substitution level stands as the only combined replacement in the study to achieve a lower absorption percentage than the control mixture at the end of the 28-day period. Therefore, this mixture represented the most viable balance between sustainable material replacement and long-term durability, effectively meeting the standards required for moisture-resistant mortar applications.

Conclusion

The implications of these findings are highly relevant to the field of civil engineering and sustainable construction. First, the study demonstrated that agricultural by-products can be effectively utilized in construction materials when properly proportioned, supporting the growing demand for eco-friendly

alternatives in the industry. The incorporation of BLA contributed to improved strength due to its pozzolanic properties, while the controlled use of CS introduced lightweight characteristics without significantly compromising durability when used at low percentages.

Second, the findings are particularly applicable to humid environments such as Barangay Irisan in Baguio City, where high rainfall and moisture exposure are major concerns. The acceptable moisture resistance of the optimized mix suggested that it can withstand such environmental conditions, making it suitable for plastering applications in similar climates. This enhanced the practical relevance of the study and supports its potential for real-world implementation.

Furthermore, the study highlighted important economic and environmental benefits. By partially replacing conventional cement and aggregates with locally available agricultural waste materials, construction costs can be reduced. At the same time, this approach contributed to waste management and environmental sustainability by minimizing agricultural wastes and reducing the carbon footprint associated with cement production.

In conclusion, the study established that while high replacement levels of coconut shell are detrimental due to increased porosity and reduced bonding, a carefully optimized low-percentage combination with banana leaf ash yielded a mortar mix that is both structurally sound and durable. The 3% BLA and 3% CS mixture is therefore recommended as the optimal proportion, as it met the required engineering standards while promoting sustainable and cost-effective construction practices. These findings not only validated the feasibility of using agricultural wastes in mortar plaster but also provided a foundation for future research and potential industry adoption.

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