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Effects Of Coal, Wood, And Crop Ashes on the Compressive Strength and Water Absorption of Eco-Friendly Building Blocks

Cybelle A. Gonzales[1*], Redjie C. Megallos[1,2], Ian Poecholo Ignacio[1,3] and Marlixis Angela R. Cao[1,4]
Cebu City Don Carlos A. Gothong Memorial National High School C. Padilla St., Cebu City, Philippines
[*]*cybelle.gonzales@deped.gov.ph* [2]*redjie.megallos@deped.gov.ph,* [3]*ianpoecholoignacio@gmail.com,*
[4]*marlixisrubacao@gmail.com*

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ABSTRACT

This study explored the use of coal ash, wood ash, and crop ashes as alternative materials in producing eco-friendly building blocks. The research aimed to determine whether these waste materials could serve as sustainable substitutes while maintaining acceptable physical and structural properties. Using a quasi-experimental research design, ash-based bricks were compared with commercially available bricks in terms of dimensions, moisture content, and compressive strength. Findings revealed that the ash-based bricks had dimensions comparable to commercial bricks, indicating that the materials were suitable for brick formation and molding. In terms of moisture content, the ash-based bricks met the acceptable standard range, suggesting good water retention and bonding properties during curing. Statistical analysis also showed a significant difference in moisture content between ash-based and commercial bricks. For compressive strength, the ash-based bricks demonstrated acceptable performance during the drop test; however, variations in strength were observed among the samples, indicating inconsistencies in material composition and curing conditions. Although some ash-based bricks performed well, commercial bricks exhibited more stable and reliable structural performance overall. Despite these limitations, the findings suggest that coal, wood, and crop ashes have potential as sustainable materials for construction applications. Overall, the study highlights the possibility of transforming agricultural and industrial waste into useful construction materials that may help reduce environmental waste while supporting sustainable and low-cost building practices. Further improvement in the production process is recommended to achieve more consistent structural performance and enhance the practical application of ash-based bricks in the construction industry.

Keywords: *ash-based bricks, coal ash, sustainable construction, compressive strength, moisture content*

INTRODUCTION

The Philippines continues to face a persistent housing crisis, particularly among urban poor communities living in informal settlements. Although low-cost housing programs have been implemented to improve living conditions, these initiatives often fall short of providing durable, safe, and sustainable shelter, leaving vulnerable populations at risk (UN-Habitat, 2020). Since 2007, the majority of the global population has been living in urban areas, with the fastest urban growth occurring in developing countries. This trend has led to the rapid expansion of informal settlements and slums, placing immense pressure on cities to provide adequate housing, infrastructure, and essential services (Gehander & Mörnhed, 2020). In this context, there is a critical need for innovative and environmentally responsible construction solutions that are both affordable and sustainable.

One promising approach is the use of renewable resources and agricultural by-products in construction. Biomass—including residues from crops and wood—has emerged as a potential substitute for conventional building materials (Hinojosa et al., 2014; Pachero da Costa et al., 2019). Globally, agricultural activity generates roughly 140 billion metric tons of biomass annually, much of which is burned or discarded, contributing to environmental pollution. Converting these residues into ashes for use as supplementary cementitious materials (SCMs) not only reduces waste but also lowers the environmental footprint of construction projects (Martirena & Monzó, 2018).

Several studies have explored the use of biomass ashes—such as rice straw, sugarcane bagasse, banana leaves, and other crop residues—as partial replacements for Ordinary Portland Cement (OPC). These ashes have been shown to reduce carbon dioxide emissions, conserve energy, and maintain mechanical strength comparable to traditional materials (Thomas et al., 2021; Laskar et al., 2022). Despite these findings, most research has focused on laboratory-based evaluations, with limited attention given to the practical application of biomass ashes in low-cost housing for vulnerable communities.

This study addresses that gap by examining the use of coal, wood, and crop ashes to produce eco-friendly concrete bricks. By repurposing industrial and agricultural waste, the research aims to reduce construction costs, minimize environmental impact, and improve the accessibility of durable housing. Unlike prior studies that emphasize material properties, this work evaluates the real-world performance of ash-based bricks, including their physical characteristics, moisture absorption, and structural strength, compared to conventional commercial bricks.

The goal of the study was to determine whether coal, wood, and crop ashes can serve as viable, sustainable alternatives to traditional construction materials. By combining practical experimentation with environmental considerations, this research offers insights into how biomass-derived materials can help address the housing crisis while promoting eco-friendly construction practices. This study aimed to determine the effects of coal, wood, and crop ashes on the compressive strength and water absorption of eco-friendly building blocks. Specifically, it sought to answer the following questions:

1. What are the physical characteristics of ash-based bricks in terms of:
   1.1 mass,
   1.2 dimensions (length, width, and height), and
   1.3 density,
   and how do these compare with commercial bricks?
2. What is the moisture content of ash-based bricks after a 24-hour absorption period, and does it fall within the standard range of 15–20% of dry weight?
3. Is there a significant difference in the moisture content between ash-based bricks and commercial bricks?
4. How do ash-based bricks perform in terms of compressive strength (using the drop test) compared to commercial bricks?
5. Is there a significant difference in the compressive strength of ash-based bricks and commercial bricks?
6. Based on the findings, how suitable are ash-based bricks in terms of:
   - durability,
   - safety, and
   - potential application in low-cost and sustainable construction?

METHODS

Research Design

A quasi-experimental nonequivalent control group design (NECGD) was employed to examine the effects of coal, wood, and crop ashes on the compressive strength and water absorption of eco-friendly bricks. Ash-based bricks formed the experimental groups, while commercially manufactured bricks served as the control. Both groups underwent standardized testing for compressive strength, density, moisture content, and water absorption, enabling a direct comparison of performance. The NECGD is particularly suitable when random assignment is impractical, such as in construction material research, allowing for reliable evaluation under real-world conditions (Campbell & Stanley, 1963).

Environment

Coal, wood, and crop ashes were collected around San Nicolas de Tolentino Parish, Cebu City. Coal and wood ashes came from local chicken-roasting establishments (Mr. Liempo and Sr. San Pedro), which provide a consistent supply. Crop ashes were sourced from parish grounds, where dried leaves from surrounding trees are frequently burned, offering a sustainable source of raw material. Experiments were conducted at the residence of one of the researchers. The house's ample indoor and outdoor space, proximity to raw material sources, and accessibility to the main road ensured safety and practicality during experimentation. Its closeness to the school allowed researchers to conduct the study conveniently after class hours.

Subjects

The primary subjects were ash-based bricks produced from coal, wood, and crop ashes, with commercially available bricks as the control.

Ash-based bricks were prepared by air-drying, grinding, and sieving the ashes for uniform particle size. Using a fixed ratio of 2:2:2:4 (coal ash: wood ash: crop ash: cement), materials were precisely weighed and mixed with clean water to form a uniform, moldable paste. Rectangular molds were used, and the bricks were compacted under consistent pressure before drying in sunlight or ventilated areas for 2–3 weeks. Commercial bricks were used as a baseline to evaluate the strength, water absorption, and overall performance of the eco-friendly bricks.

Instruments

Key instruments included digital scales, measuring tapes, molds, hammers, and drying racks, which were used to measure weight, dimensions, compressive strength, and moisture absorption. Testing procedures followed ASTM standards to ensure accuracy and reliability (ASTM C67-20, 2020). Pilot testing was conducted to validate the instruments and procedures, ensuring consistency across all experimental bricks.

Data Gathering Procedures

A. Collection and Preparation of Raw Materials
- Coal, wood, and crop ashes were collected, air-dried, and stored in separate containers. Materials were free from impurities such as plastic or metal.

B. Grinding and Sieving
- Ashes were ground using a mortar and pestle or mechanical grinder, then sieved to remove large particles. Uniform particle size promotes better mixing and compaction.

C. Weighing Materials
- Each component was measured using a digital scale according to the standard ratio of 2:2:2:4 (coal:wood:crop:cement).

D. Mixing
- Dry ashes were combined with cement and water to achieve a uniform, moldable mixture. A starch-based binder was added gradually to enhance cohesion.

E. Molding
- The mixture was placed into rectangular molds and compacted with a hammer or press to ensure structural integrity.

F. Drying
- Molded bricks were dried in sunlight or a ventilated area for 2–3 weeks, depending on weather conditions. Complete drying prevented cracking and ensured reliable measurements of moisture content and compressive strength (Thomas et al., 2021; Martirena & Monzó, 2018).

RESULTS AND DISCUSSION

This section presents and analyzes the effects of coal, wood, and crop ashes on the physical properties, moisture content, and compressive strength of eco-friendly bricks.

As shown in Table 1, both commercial and ash-based bricks exhibited comparable physical dimensions. This indicates that the production process for ash-based bricks achieved a level of uniformity similar to that of standard commercial bricks. The incorporation of coal, wood, and crop ashes did not negatively affect the molding and shaping process, suggesting that these materials are suitable for brick fabrication.

Table 1. *Physical Characteristics*

Property	Commercial Bricks	Ash-based Bricks
Length	19.5cm	19.5cm
Width	9.5cm	9.5cm
Height	4.5cm	4.5cm
Volume (cm^3)	833.625 cubic cm^3	833.625 cubic cm^3
Density (g/cm^3)	2.1 g/cm^3	1.5 g/cm^3

In terms of mass and density, ash-based bricks demonstrated lower density than commercial bricks, indicating that the incorporation of ash materials produced lighter and more porous bricks. Lower-density materials are advantageous in reducing the overall weight of structures; however, they may also influence strength and durability (Neville, 2011). Despite this, the results suggest that ash-based bricks meet the basic physical requirements for construction materials.

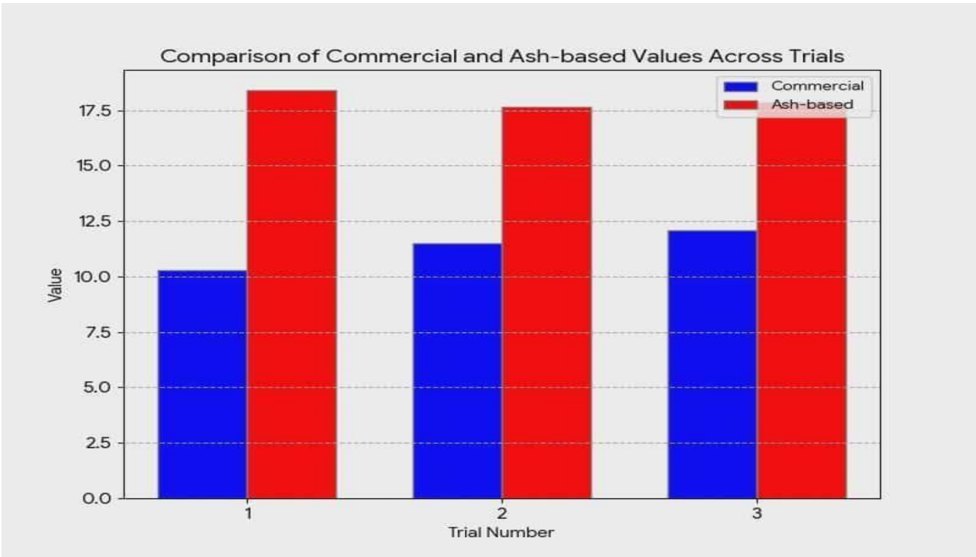

Figure 1. *Moisture content of commercial and ash-based bricks*

Figure 1 illustrates the moisture content of commercial and ash-based bricks across three trials. The results show that ash-based bricks consistently recorded higher moisture content values compared to commercial bricks. While the commercial bricks showed a gradual increase across trials, their values remained lower overall.

In contrast, ash-based bricks maintained higher moisture levels, although a slight decrease was observed. This indicates that ash-based bricks have greater water retention capacity. Such behavior may be attributed to the finer particles and porous structure of ash materials, which allow them to absorb and retain more moisture (Martirena, F. & Monzó, J., 2018).

Overall, the figure demonstrates that ash-based bricks perform better in terms of moisture retention, which is essential for proper curing and bonding in cement-based materials (Neville, A. M., 2011).

Table 2 presents the statistical analysis of moisture content for both commercial and ash-based bricks. The results show that ash-based bricks obtained a mean moisture content of 17.97% (≈18.40%), which falls within the acceptable standard range of 15–20%. This indicates that the ash-based bricks have sufficient moisture for effective cement hydration and bonding (Neville, A. M., 2011).

On the other hand, commercial bricks recorded a lower mean moisture content of 11.63% (≈10.29%), which is below the recommended range. This suggests that commercial bricks may have limited water retention capacity.

The independent t-test yielded a value of t = -7.52 with a decision to reject the null hypothesis, indicating a statistically significant difference between the two groups ($p < 0.05$). This confirms that the higher moisture content observed in ash-based bricks is not due to chance.

These findings suggest that ash-based bricks exhibit better moisture-related properties, which are beneficial for curing and internal cohesion. This aligns with previous studies highlighting that biomass ash improves water absorption due to its high surface area (Martirena, F. & Monzó, J., 2018).

Table 2. *Moisture Content Analysis*

Group	Mean	Variance	Standard Deviation	n	t-df value	Decision	Interpretation
Commercial Bricks	11.63	1.99	1.41	3		4	Reject
Ash-based bricks	17.79	0.15	0.38	3			
t-test					-7.52	4	Reject

Note. Significant if p< a (0.05)

Figure 2 presents the comparative compressive strength of commercial and ash-based bricks using the drop test method. The results indicate that several ash-based brick samples performed well during the drop test and, in some trials, obtained higher scores than the commercial bricks. However, the ash-based bricks also showed noticeable variations in performance across trials, indicating inconsistencies in strength and durability.

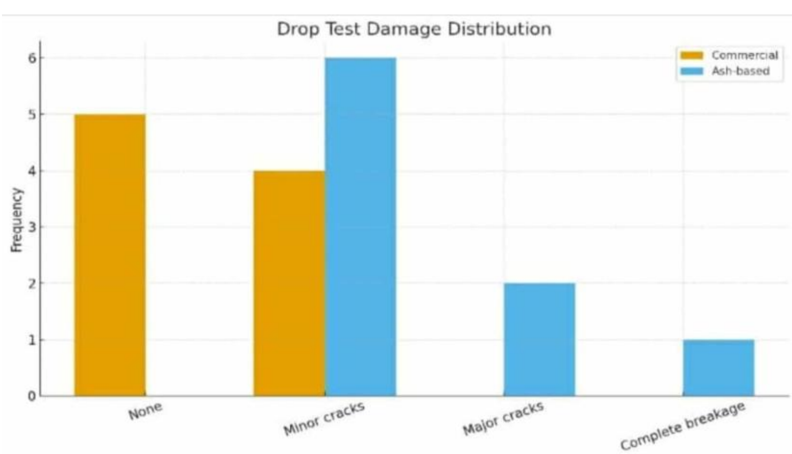

Figure 2. *Compressive strength of the commercial and ash-based bricks*

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This variability may be influenced by differences in ash composition, particle distribution, and curing conditions, which are known to affect the mechanical behavior of biomass-based materials (Thomas, S. et al., 2021).

In contrast, commercial bricks demonstrated more uniform and stable behavior throughout the testing process. Although their average score was lower, the consistency of their performance suggests greater structural reliability. The variability observed in ash-based bricks may have been influenced by differences in ash composition, particle distribution, moisture retention, and curing conditions, which are known to affect the mechanical properties of biomass-based construction materials.

Table 3 further shows that ash-based bricks obtained a higher mean value (M = 1.44) than commercial bricks (M = 0.44). However, the ash-based bricks also recorded higher variance and standard deviation values, indicating less consistent compressive strength results. The Wilcoxon signed-rank test revealed a significant difference between the two groups (p = 0.016 < 0.05).

Table 3. *Compressive Strength (Drop Test)*

Metric	Commercial Bricks	Ash-based Bricks	
Mean	0.44	1.44	
Variance	0.29	0.53	
Standard Deviation	0.53	0.73	
		p-value	0.016<0.0
		Decision	Reject
		Interpretation	
		Significant	

Note: Significant if p< α (0.05)

However, ash-based bricks also exhibited higher variance (0.53) and standard deviation (0.73), indicating greater variability in strength. This means that although some ash-based bricks performed well, others showed weaker performance, resulting in inconsistent outcomes.

The Wilcoxon signed-rank test revealed a p-value of 0.016, which is less than 0.05. This leads to the rejection of the null hypothesis and confirms that there is a statistically significant difference between the two groups.

Although ash-based bricks obtained a higher mean score in some trials, commercial bricks demonstrated more consistent structural performance, making them more reliable for construction applications. Consistency is a critical requirement in construction materials, particularly for load-bearing structures (Neville, A. M., 2011).

Thus, while ash-based bricks demonstrate promising potential, further refinement is necessary to achieve uniform and dependable compressive strength. Similar findings have been reported in studies on biomass ash materials, where performance variability remains a key limitation (Thomas, S. et al., 2021).

Overall, the statistical analysis confirmed significant differences between commercial and ash-based bricks in terms of moisture content and compressive strength. Ash-based bricks exhibited favorable moisture retention properties, which may contribute to improved bonding and curing efficiency. However, despite showing promising results in some compressive strength trials, the ash-based bricks demonstrated inconsistent structural performance compared to commercial bricks.

These findings suggest that while ash-based bricks have potential as alternative eco-friendly construction materials, commercial bricks remain more structurally dependable due to their consistent performance. Therefore, further refinement in material proportioning, mixing, and curing processes is necessary to improve the uniformity and reliability of ash-based bricks.

These results are consistent with previous studies emphasizing the environmental benefits of using biomass ash in construction, while also noting the need for optimization to achieve consistent mechanical performance (Chowdhury et al., 2021). Thus, although ash-based bricks present a viable and eco-friendly alternative, further refinement in production processes is necessary to enhance their strength and consistency.

Table 4. *Summary of Statistical Analysis*

Types of Bricks	Dimensions (Length, Width, Height)	Moisture Content	Compressive Strength
Commercial Bricks	19.5 cm 9.5 cm 4.5 cm	Rejected (10-24%)	Mean = 0.55 Variance = 0.29 Standard deviation = 0.53
Ash-based Bricks	19.5 cm 9.5 cm 4.5 cm	Accepted (15-20%)	Mean = 1.44 Variance = 0.62 Standard deviation = 0.79

CONCLUSION

The study concludes that ash-based bricks exhibit acceptable physical characteristics and moisture content comparable to commercial bricks. The ash-based bricks also demonstrated promising compressive strength performance in several drop test trials. However, the results revealed inconsistencies in strength and durability among the ash-based samples, indicating variability in material composition and curing conditions.

In comparison, commercial bricks showed more stable and consistent structural performance, making them more reliable for construction applications at present. Despite these limitations, the findings suggest that coal, wood, and crop ashes have significant potential as sustainable construction materials that can help reduce agricultural and industrial waste while supporting environmentally responsible and low-cost building practices.

Overall, ash-based bricks may serve as viable alternative materials for non-load-bearing or low-cost construction projects, provided that further refinement in production techniques is conducted to improve their consistency, strength, and long-term durability.

Based on the findings of the study, the following recommendations are proposed:

1. Improve the mixing process and standardize the proportion of ash materials to achieve more consistent compressive strength results.
2. Implement controlled curing and drying procedures to minimize cracking and improve the durability of ash-based bricks.
3. Explore alternative ash-to-cement ratios and additional binding agents that may enhance structural performance without compromising sustainability.
4. Conduct further laboratory testing using standard compressive strength equipment to obtain more accurate and reliable measurements.
5. Investigate the long-term durability, weather resistance, and load-bearing capacity of ash-based bricks under actual environmental conditions.
6. Consider pilot-scale applications of ash-based bricks in non-load-bearing and low-cost housing projects to evaluate their practical feasibility and community acceptance.

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