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Short Communication

Recent Trends in Construction Materials Using Bio-Ash

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Abstract

Concrete is recognized as the most widely utilized material in the field of construction, comprising aggregates, cement, and water. In recent decades, sustainable construction has emerged as a pivotal field, driven by the substantial surge in population and the consequent demand for additional buildings and construction projects. This phenomenon is associated with an increase in pollution, which is attributable to the extraction of raw materials and the manufacturing of construction materials. The production of cement is recognized as a particularly polluting process. Consequently, it is imperative to utilize materials that prioritize sustainability and environmental responsibility. Bio-ash materials have been identified as a viable solution, with the potential to serve as a substitute for aggregates, particularly fine aggregates, and ordinary Portland cement.

Keywords: *Sustainable Construction, Bio-Ash Materials, Environmentally Friendly.*

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Introduction

The expanding human population has led to an increased demand for additional buildings and infrastructure, as evidenced by numerous studies (Khatib et al., 2025a). Concrete is the most widely used material in the field of construction due to its various useful properties (Gagg, 2014). A number of these distinctive characteristics are worthy of mention, including but not limited to the following: adequate compressive strength, the availability of the necessary raw materials, relatively low cost, flexibility, the capacity for use in a variety of locations, the possibility of being formed into a range of sizes and shapes, and durability properties. Cement is an indispensable component in the production of concrete. However, the production of one ton of cement results in the emission of approximately 850 kilograms of carbon dioxide (CO_2) into the atmosphere. This substantial emission is attributable to the combustion of fuel and the decomposition of limestone (Wu et al., 2025; Zannerni et al., 2020). Consequently, researchers and professionals have identified the need to explore alternative building materials that necessitate less energy during manufacturing in order to minimize the carbon footprint and foster a sustainable environment (Bawab et al., 2021; Khatib et al., 2025b; Zhang et al., 2023).

Bio-ash materials, which can be derived from various botanical sources such as stems, leaves, husks, straws, and shells, have emerged as a promising solution for replacing cement in various applications. A multitude of studies have demonstrated the viability of bio-ash materials as a substitute for cement in concrete, mortar, or paste (Onsongo et al., 2025). Bio-ash materials are regarded as ecofriendly and cost-effective (ElKhatib et al., 2022; He et al., 2020). Examples of bio-ash materials include rice husk ashes, wheat straw ashes, sugarcane bagasse ashes, palm oil fuel ashes, walnut shell ashes, corn cob ashes, and phragmites australis ashes (Elkhatib et al., 2023; Shebli et al., 2023; Thomas et al., 2021). Bio-ash materials exhibit pozzolanic properties, a characteristic that is attributed to their high content of amorphous silica and alumina (Gunarathne et al., 2019). The replacement of traditional Portland cement in concrete or mortar can be executed in a partial or complete manner, as evidenced by the works of Akbar et al. (2021) and Al-Alwan et al. (2024).

Research has demonstrated that the incorporation of Bermuda grass ash as a partial cement replacement in concrete results in a modest reduction in water absorption (Patnaik et al., 2022). Additionally, the findings of the study demonstrated that the compressive strength of concrete exhibited an increasing trend as the percentage of wheat straw ash increased from 0% to 10%, followed by a subsequent decrease after the percentage of wheat straw ash was increased as a partial cement replacement from 10% to 20% (Shar et al., 2019). The utilization of rice husk ash as a partial substitute for cement has been demonstrated to enhance the durability of concrete, thereby improving its resistance to water absorption, corrosion, sulfate, and chloride (Endale et al., 2023). Moreover, the incorporation of phragmites australis ash as a partial cement replacement has been observed to result in a modest augmentation of the length change of mortar, encompassing expansion, drying, and autogenous shrinkage (Khatib et al., 2023). A body of research has demonstrated the viability of geopolymer concrete, which involves substituting a portion or all of the conventional Portland cement with bio-ash materials. Recent studies have demonstrated that the incorporation of sugarcane bagasse ash as a substitute for cement can enhance the ultrasonic pulse velocity, thereby indicating an improvement in the quality of the mortar. This phenomenon can be attributed to the enhanced internal structure and denser microstructure of the bagasse ash geopolymer matrix (Akbar et al., 2021). Moreover, the tensile strength of geopolymer mortar incorporating sugarcane bagasse ash exhibited higher values compared to the control mix comprising cement (Akbar et al., 2021). A similar trend was observed in the flexural strength measurements. This phenomenon can be attributed to the occurrence of a strong covalent bond, which is formed during the geo-polymerization chain reaction in the bagasse ash-based geopolymer composites. With respect to compressive strength, geopolymer mortar containing bagasse ash demonstrates higher values than those recorded for the control mix. This is attributable to the denser microstructure resulting from the finer particles of the bagasse ash and the polymerization reaction, which leads to a denser and more stable microstructure. However, the geopolymer mix containing bagasse ash demonstrated lower values in terms of water absorption when compared to the control mix. This phenomenon can be attributed to the chain geo-polymerization reaction, which results in the formation of closed packing of bonds, thereby impeding water absorption (Akbar et al., 2021).

This paper analyzes recent studies on the utilization of bio-ash materials, specifically phragmites australis ash (PAA) and walnut shell ash (WSA), as a partial green alternative for cement. Tests of ultrasonic pulse velocity and compressive strength have yielded encouraging results, contributing to the development of sustainable construction.

Results and Discussion

Ultrasonic Pulse Velocity (UPV)

The UPV is a metric that provides insight into the quality of the mortar or concrete. UPV values decrease as the percentage of PAA, indicative of partial cement replacement, increases from 0% to 30% (Khatib et al., 2025a). This trend is replicated in scenarios where cement is partially substituted by WSA, resulting in diminished values as the percentage of WSA varies from 0% to 15% (Shebli et al., 2023). This phenomenon can be attributed to the denser composition of the control mix as compared to mixes comprising bio-ash materials. However, as the curing age increases from one day to 56 or 90 days, the UPV is enhanced for all tested mixes (Khatib et al., 2025a; Shebli et al., 2023). This phenomenon can be attributed to the densification of concrete or mortar over time, as evidenced by studies such as those by Safiuddin et al. (2007). The results are displayed in **Figure 1** (Khatib et al., 2025a; Shebli et al., 2023).

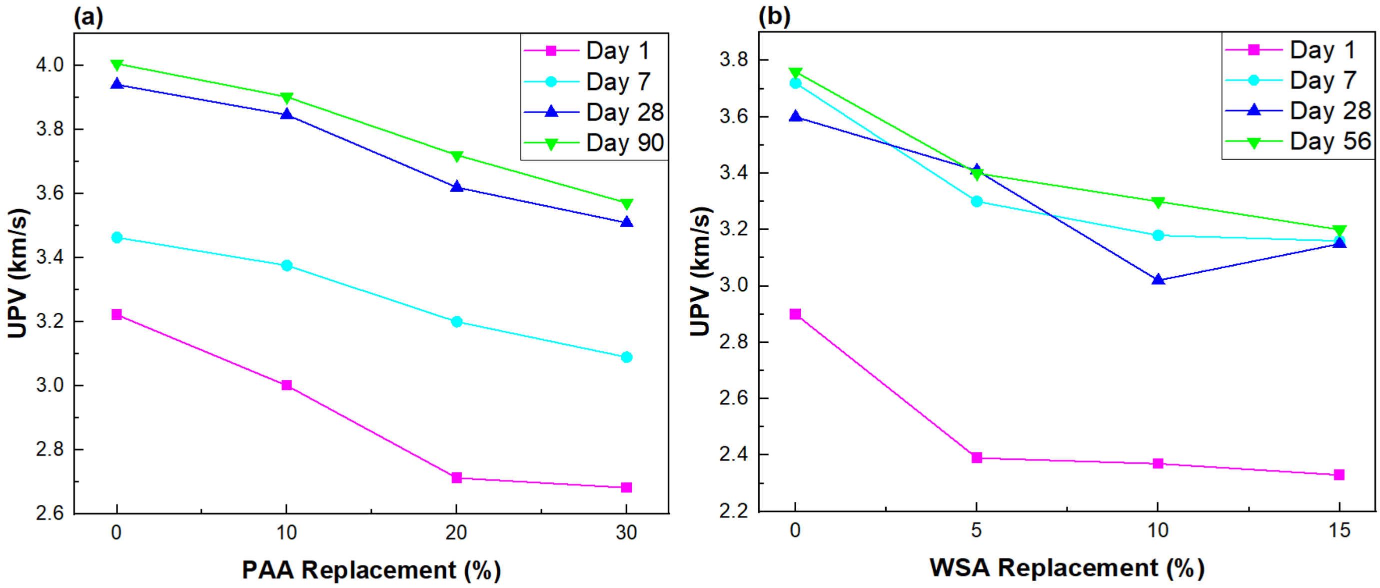

Figure 1: Ultrasonic Pulse Velocity of Mortar at Different Curing Ages (a): PAA as Cement Replacement (Khatib et al., 2025a) and (b): WSA as Cement Replacement (Shebli et al., 2023)

Compressive Strength

The compressive strength of mortars containing PAA as a partial alternative to cement has been shown to exhibit lower values in comparison to mortars composed exclusively of cement (Khatib et al., 2025a). However, a marginal decline in compressive strength was observed for the mix containing 10% PAA in comparison with the control mix. The findings suggest that PAA can be regarded as a pozzolanic material (Khatib et al., 2025a). Furthermore, in mixtures incorporating WSA as a cement substitute, the compressive strength of the mixture declines as the percentage of WSA is augmented. With regard to the variation of compressive strength according to curing age, it has been demonstrated that as time progresses from one day to 56 or 90 days, the compressive strength is enhanced for all of the tested mixes (Khatib et al., 2025a; Shebli et al., 2023). This phenomenon can be attributed to the hydration reaction that occurs, leading to the formation of C-S-H gel and subsequent densification of the matrix microstructure (Mir et al., 2020). The results are displayed in **Figure 2** (Khatib et al., 2025a; Shebli et al., 2023).

Conclusion

It can be concluded that the utilization of bio-ash in concrete production has the potential to significantly impact the future of the construction industry. This impact can be twofold: first, it can contribute to a reduction in the carbon footprint of construction activities; and second, it can result in the production of more economical products, thereby contributing to sustainable development. In addition, professionals should endeavor to identify methods for the effective utilization of materials. The utilization of lightweight materials comprising bio-ash has been demonstrated as a viable method for achieving this objective, particularly in regions characterized by compressive stresses. Further research and additional field trials are necessary to validate these findings. Further research is necessary to investigate the durability of cementitious materials that contain bio-ash. These include chemical resistance, chloride penetration, alkali aggregate reactivity, and dimensional stability under various environmental conditions. The presence of a substantial volume of data facilitates the utilization of artificial intelligence (AI) for the prediction of the performance of bio-ash in cementitious systems. This hypothesis should be confirmed through field testing.

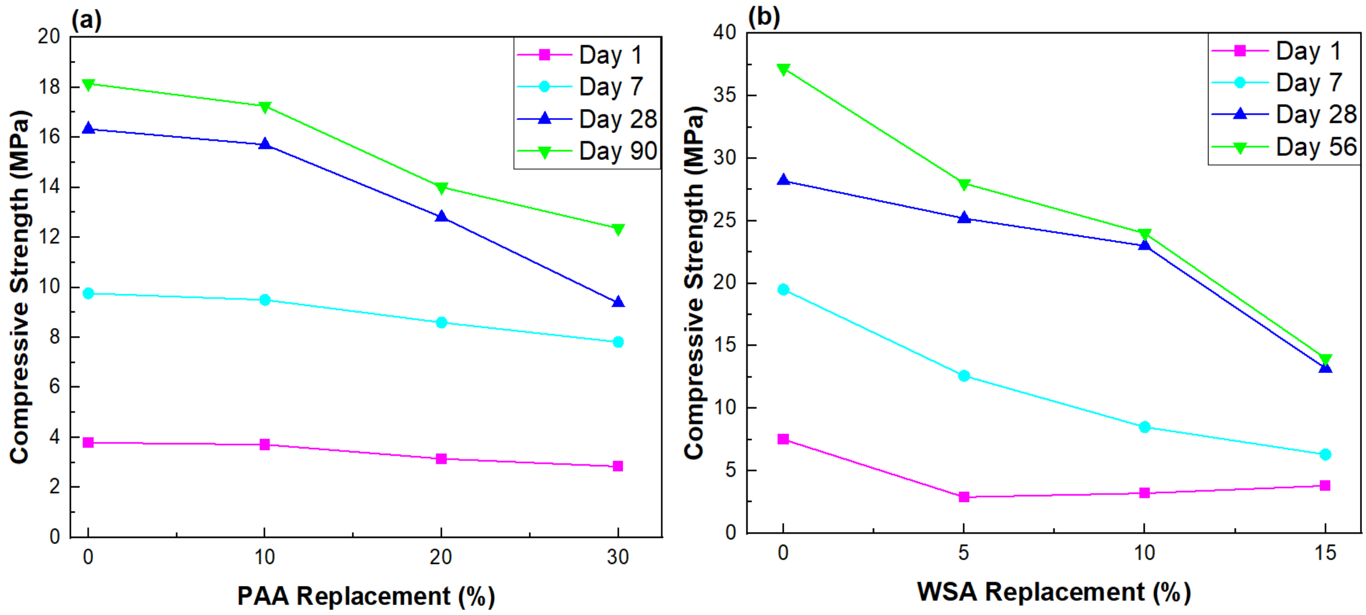

Figure 2: Compressive Strength of Mortar at Different Curing Ages (a): PAA as Cement Replacement (Khatib et al., 2025a) and (b): WSA as Cement Replacement (Shebli et al., 2023)

Declarations

Author Contribution

J.K: was responsible for the conceptualization, methodology, Investigation, resources, data curation, writing and review & editing, supervision and project administration.

L.W.E: Conceptualization, methodology, software, formal analysis, resources, data curation and writing of the original draft.

H.G: Conceptualization, methodology, investigation, resources, data curation, writing of the original draft, supervision and project administration.

A:E: Conceptualization, methodology, validation, investigation, resources, data curation, writing and review & editing, visualization, supervision and project administration.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Declaration on the Use of Generative AI and AI-Assisted Technologies

No generative AI or AI-assisted technologies were used in the preparation of this manuscript.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Acknowledgement

The authors declare that there is no acknowledgement to be made.

Ethics

This study did not involve human participants or animals; hence, no ethical approval was required.

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