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Experimental Evaluation of Coconut Husk Mortar for Sustainable Ferrocement

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Abstract

The continuous exploitation of natural river sand for mortar production has raised significant environmental concerns, necessitating the development of sustainable alternative materials. Coconut husk, an abundant agricultural by-product, offers considerable potential as a renewable fine aggregate while simultaneously addressing waste management challenges. This study investigates the feasibility of utilizing coconut husk as a partial and full replacement for river sand in mortar developed for ferrocement applications. An experimental program was conducted to develop mortar mixes capable of achieving the target compressive strength of 35 MPa in accordance with ACI 549.1R and the Ferrocement WRD Handbook. Conventional cement-sand mortar and coconut husk mortar incorporating steel fibres and chemical admixtures were produced and evaluated. The mechanical performance was assessed. The optimized coconut husk mortar mix is recommended for structural ferrocement applications, whereas lightweight coconut husk mortar is suitable for non-structural components. Overall, the study confirms that coconut husk is a technically feasible and environmentally sustainable alternative to natural river sand, contributing to resource conservation, agricultural waste utilization, and the advancement of sustainable ferrocement construction.

Keywords: Coconut husk, Ferrocement, Strength, Mortar

1. Introduction

The rapid growth of the construction industry has substantially increased the demand for natural resources, particularly river sand, which is extensively used as fine aggregate in cement mortar and concrete. Continuous extraction of river sand has resulted in severe environmental consequences, including riverbank erosion, habitat degradation, groundwater depletion, and ecological imbalance. These concerns have intensified the search for sustainable alternative materials that can reduce dependence on natural aggregates while maintaining the required engineering performance of cementitious composites [1-5].

Agricultural and industrial wastes have emerged as promising alternatives for the development of eco-friendly construction materials. The utilization of such waste materials not only conserves natural resources but also minimizes landfill disposal and promotes a circular economy. Among various agricultural by-products, coconut husk is generated in large quantities in tropical countries, particularly India, Indonesia, and the Philippines, where coconut cultivation is widespread. Although coconut husk is primarily considered an agricultural waste, its fibrous and lightweight characteristics make it a potential material for construction applications. The effective utilization of coconut husk can therefore contribute to sustainable waste management while reducing the environmental footprint associated with conventional construction materials[6-15].

Ferrocement is a thin, lightweight composite material consisting of rich cement mortar reinforced with closely spaced layers of steel wire mesh. Owing to its high tensile strength, crack resistance, durability, and ease of fabrication, ferrocement has been widely employed in roofing elements, water tanks, precast panels, shells, and rehabilitation works. Since mortar constitutes nearly 95% of the ferrocement volume, its quality largely governs the structural performance, durability, and serviceability of ferrocement elements. Consequently, the development of sustainable mortar using renewable alternative fine aggregates is essential for enhancing the environmental sustainability of ferrocement construction.

Previous studies have extensively investigated the incorporation of agricultural wastes such as coconut shell, rice husk ash, palm oil fuel ash, and sugarcane bagasse ash in cement-based materials. However, research on the direct utilization of crushed coconut husk as a fine aggregate replacement in mortar remains limited, particularly for ferrocement applications. Moreover, comprehensive investigations integrating mechanical performance, microstructural characteristics, and structural behaviour of ferrocement panels produced with coconut husk mortar are scarce. This research gap highlights the need for systematic studies to evaluate the feasibility of coconut husk as a sustainable fine aggregate in ferrocement mortar.

The present study investigates the feasibility of incorporating coconut husk as a fine aggregate in mortar developed for ferrocement applications. Conventional mortar and coconut husk mortar were designed following the recommendations of ACI 549.1R and the Ferrocement WRD Handbook to achieve a target compressive strength of 35 MPa. The developed mortar mixes were evaluated through compressive strength, splitting tensile strength, flexural strength, and impact resistance tests. Furthermore, the hydration mechanism and interfacial characteristics were examined using scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDX), and X-ray diffraction (XRD). Finally, ferrocement panels incorporating steel mesh reinforcement were investigated to assess their structural behaviour and practical applicability.

The outcomes of this study demonstrate the potential of coconut husk as an environmentally sustainable alternative to natural river sand in mortar production. By combining agricultural waste utilization with lightweight ferrocement technology, the proposed material contributes to resource conservation, reduced environmental impact, and the development of sustainable infrastructure, particularly in coconut-producing regions where coconut husk is abundantly available.

2. Literature Review

The increasing demand for sustainable construction materials has encouraged researchers to investigate the utilization of agricultural and industrial wastes as alternatives to conventional construction materials. Among these, coconut-derived materials have gained considerable attention because of their abundance, low density, biodegradability, and renewable nature. The replacement of natural river sand with

agricultural by-products offers a promising solution for conserving natural resources while reducing environmental pollution associated with waste disposal [15-18].

Several studies have demonstrated the successful incorporation of agricultural wastes such as rice husk ash, sugarcane bagasse ash, palm oil fuel ash, coconut shell, and coconut fibres into cement-based composites. These materials have been reported to improve specific engineering properties while reducing the environmental impact of concrete and mortar production. Coconut shell has been extensively investigated as a lightweight coarse aggregate, whereas coconut fibres have been employed to enhance the ductility, crack resistance, and toughness of cementitious composites. However, comparatively fewer studies have explored the potential of crushed coconut husk as a fine aggregate replacement in mortar, particularly for ferrocement applications. Ferrocement is a thin composite material consisting of cement-rich mortar reinforced with multiple layers of closely spaced steel wire mesh. Owing to its high strength-to-weight ratio, excellent crack control, impact resistance, and ease of fabrication, ferrocement has been widely used in water tanks, roofing units, precast panels, rehabilitation works, and marine structures. Since mortar occupies nearly 95% of the total volume of ferrocement, its mechanical and durability characteristics significantly influence the structural performance of ferrocement elements. Consequently, developing sustainable mortar with alternative fine aggregates has become an important research objective.

Previous investigations have shown that replacing river sand with lightweight natural materials generally reduces mortar density while improving ductility and energy absorption capacity. However, excessive replacement levels often lead to reductions in compressive strength because of the porous structure and lower stiffness of the alternative aggregates. To overcome this limitation, researchers have incorporated supplementary cementitious materials, chemical admixtures, and steel fibres to enhance strength and improve the bond between the aggregate and cement matrix. Steel fibre reinforcement has been particularly effective in controlling crack propagation, increasing tensile and flexural strength, and improving the impact resistance of mortar[18-20].

Microstructural characterization techniques such as scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDX), and X-ray diffraction (XRD) have become valuable tools for understanding the hydration mechanism and interfacial bonding in cementitious composites containing alternative materials. These techniques provide evidence of hydration products, elemental composition, and phase development, enabling researchers to correlate microstructural characteristics with mechanical performance. Such investigations are essential for establishing the long-term feasibility of sustainable mortar systems.

Although previous studies have highlighted the potential of coconut-based materials in construction, limited research has comprehensively evaluated crushed coconut husk as a fine aggregate for ferrocement mortar by integrating mix proportion optimization, mechanical characterization, microstructural analysis, and structural performance assessment. Furthermore, information regarding the behaviour of ferrocement panels produced with coconut husk mortar remains scarce.

Therefore, the present study addresses this research gap by investigating the feasibility of coconut husk as a sustainable fine aggregate replacement for river sand in ferrocement mortar. The research includes the development of optimized mortar mixes, evaluation of mechanical properties[21-25].

3. Materials and Method

Ordinary The selection of constituent materials plays a vital role in determining the performance of mortar intended for ferrocement applications. In this study, conventional materials and sustainable alternatives were carefully selected to develop eco-friendly mortar with the required mechanical and durability

characteristics. The primary materials used included Ordinary Portland Cement (OPC), river sand, crushed coconut husk, steel fibres, superplasticizer, potable water, and welded steel wire mesh.

3.1 Ordinary Portland Cement

Ordinary Portland Cement (OPC) of Grade 53 conforming to IS 12269:2013 was used as the primary binder throughout the investigation. The cement possessed a specific gravity of approximately 3.11 and was selected because of its high early strength and suitability for ferrocement applications.

3.2 River Sand

Natural river sand conforming to Zone II grading as specified in IS 383:2016 was used as the conventional fine aggregate. The maximum particle size was limited to 2.36 mm, satisfying the recommendations for ferrocement mortar. River sand exhibited a specific gravity of 2.55 and a bulk density of approximately 1665 kg/m³, providing the reference properties for comparison with coconut husk mortar.

3.3 Coconut Husk

Crushed coconut husk obtained from coconut-processing industries was used as an alternative fine aggregate. After crushing and sieving, the particles satisfied Zone III grading according to IS 383:2016. Coconut husk possesses a significantly lower specific gravity (1.14) and bulk density (575 kg/m³) than river sand, making it suitable for producing lightweight mortar. Owing to its porous and fibrous structure, coconut husk also exhibited relatively high water absorption, which influenced the water requirement of the mortar mixes. Its utilization contributes to the beneficial reuse of agricultural waste and reduces dependence on natural river sand.

3.4 Steel Fibres

Crimped steel fibres with an aspect ratio of approximately 26 were incorporated into selected mortar mixtures to improve crack resistance, tensile strength, flexural behaviour, and impact resistance. The addition of steel fibres also enhanced the ductility of the mortar, making it more suitable for ferrocement structural elements.

3.5 Superplasticizer

A sulfonated naphthalene-based high-range water-reducing admixture (superplasticizer) was used to improve the workability of coconut husk mortar without increasing the water-to-cement ratio. The optimized mix contained 1.5% superplasticizer by weight of cement, which facilitated adequate flowability while achieving the target compressive strength.

3.6 Water

Clean potable water free from harmful impurities was used for mixing and curing all mortar specimens. Water satisfied the requirements of relevant Indian Standards to ensure proper cement hydration and consistent strength development.

3.7 Steel Wire Mesh

Galvanized welded steel wire mesh was used as reinforcement in the ferrocement panels. The closely spaced mesh layers effectively distributed stresses, controlled crack propagation, and improved the load-carrying capacity and ductility of the ferrocement specimens.

Overall, the combination of conventional materials with coconut husk and steel fibre reinforcement enabled the development of sustainable mortar suitable for ferrocement applications. The selected materials were

characterized through physical and chemical property evaluations before being incorporated into the experimental program, ensuring the reliability and consistency of the developed mortar mixes. Table 1 summarises the chemical characteristics of cement, silica fume, GGBS and fly ash.

Table 1 summarises the chemical characteristics of cement, silica fume, GGBS and fly ash.

Description		OPC	Silica fume	GGBS	Fly ash
Oxides	SiO ₂ (%)	21.60	90.00	34.90	56.20
	Al ₂ O ₃ (%)	5.11	0.44	10.20	26.20
	Fe ₂ O ₃ (%)	2.03	0.40	0.38	7.30
	CaO (%)	64.40	1.60	42.70	1.60
	MgO (%)	0.93	0.81	6.74	0.70
	K ₂ O (%)	0.16	2.20	0.65	2.50
	Na ₂ O (%)	0.66	0.59	0.51	1.30
	SO ₃ (%)	0.20	0.40	0.66	0.70
	TiO ₂ (%)	0.44	--	2.65	1.0
	Mn ₂ O ₃ (%)	0.06	--	0.11	--
	LOI (%)	2.24	2.17	1.41	2.20
Specific gravity		3.11	2.20	2.85	2.16

4. Result

The Figure 1 illustrates the casting process of cubes with steel mesh layers. The hardened densities of the four selected mortar mixes (CSM3, CSSFM1, CCHM1, and CSCHSFM8) were evaluated to examine the influence of coconut husk and steel fibre incorporation. The results indicated significant variations in density among the mixes. The CCHM1 mix exhibited a reduction in hardened density of approximately 37.7% and 33.9% compared with the CSM3 and CSCHSFM8 mixes, respectively. Similarly, the CSCHSFM8 mix showed density reductions of about 5.83% and 6.84% relative to the CSM3 and CSSFM1 mixes, respectively. An increase in hardened density was observed with curing age for all mortar mixes, which can be attributed to the continued hydration and pozzolanic reactions of the cementitious materials. These reactions promoted the formation of additional calcium silicate hydrate (C-S-H) gel, resulting in a denser microstructure through pore refinement and reduced void content. The SEM observations further confirmed the development of a compact matrix with increasing age.

The incorporation of coconut husk as a fine aggregate significantly reduced the self-weight of the mortar, producing a lightweight mortar with substantially lower density than conventional river sand mortar. This reduction in density offers practical advantages for lightweight construction while maintaining satisfactory mechanical performance.

The feasibility of coconut husk mortar for ferrocement applications was evaluated in accordance with the recommendations of ACI 549.1R-93, ACI 549.1R-97, and the WRD Handbook. Three mortar mixes (CSM3, CSSFM1, and CCHM1) with a cement-to-aggregate ratio of 1:3 were initially investigated. While the conventional mortar mixes (CSM3 and CSSFM1) successfully achieved the target compressive strength of 35 MPa, the CCHM1 mix attained only 17% of the required strength because of the complete replacement of river sand with coconut husk. To overcome this limitation, an optimized mix (CSCHSFM8) containing 60% river sand, 40% coconut husk, 6% crimped steel fibres, and a superplasticizer was developed. This optimized composition successfully achieved the target compressive strength while retaining the advantages of reduced density and improved ductility, demonstrating its suitability for sustainable ferrocement applications. The hardened properties of the selected mortar mixes are summarized.



Figure 1 compressive strength- Steel mesh reinforcement

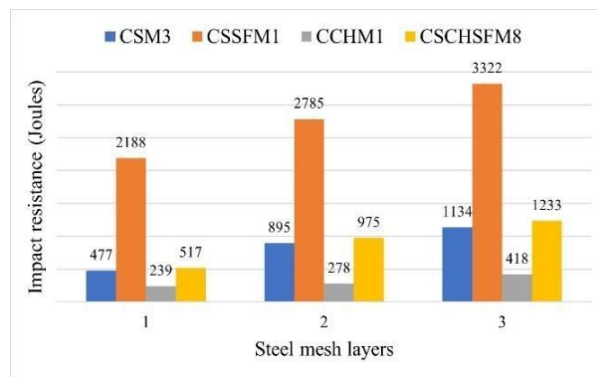


Fig. 2 - Initial failure of disc with steel mesh

5. Conclusion

The The hardened properties of the selected mortar mixes demonstrated that the incorporation of coconut husk significantly influences both density and compressive strength. Among the four mixes investigated, the conventional mortar (CSM3) achieved a 28-day compressive strength of 37.00 MPa with a hardened density of 2310 kg/m³, while the steel fibre-reinforced conventional mortar (CSSFM1) exhibited the highest mechanical performance, attaining a compressive strength of 40.25 MPa and a density of 2340 kg/m³. The inclusion of steel fibres enhanced the strength development and contributed to a denser mortar matrix.

The mortar prepared with 100% coconut husk as the fine aggregate (CCHM1) exhibited a substantially lower hardened density of 1440 kg/m³, representing approximately 38% reduction compared with the conventional

mortar. However, its 28-day compressive strength was limited to 5.90 MPa, indicating that complete replacement of river sand is unsuitable for structural ferrocement applications despite its lightweight characteristics. Nevertheless, the significant reduction in self-weight suggests that this mix may be considered for lightweight and non-structural components where high strength is not a primary requirement.

The optimized mortar mix CSCHSFM8, consisting of 60% river sand, 40% coconut husk, 6% crimped steel fibres, and superplasticizer, successfully achieved the target compressive strength of 36.10 MPa with a hardened density of 2180 kg/m³. This mix provided an effective balance between strength and weight reduction, exhibiting only a marginal decrease in compressive strength compared with CSM3 while offering approximately 6% lower density. The results demonstrate that the combined use of partial coconut husk replacement and steel fibre reinforcement effectively compensates for the strength loss associated with lightweight aggregates.

Overall, the study confirms that coconut husk can be successfully utilized as a sustainable partial replacement for river sand in ferrocement mortar. While complete replacement is appropriate only for lightweight, non-structural applications, the optimized CSCHSFM8 mix satisfies the target strength requirements and offers improved sustainability through reduced natural aggregate consumption, lower self-weight, and beneficial utilization of agricultural waste. These findings highlight the potential of coconut husk mortar as an environmentally friendly material for sustainable ferrocement construction.

Declaration of Conflicting Interests

The authors declare no potential conflicts of interest with respect to the research, authorship and publication of this article.

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References

- [1] ACI Committee 549. (1997). Guide for the Design, Construction, and Repair of Ferrocement (ACI 549.1R-93). American Concrete Institute, Farmington Hills, MI.
- [2] ACI Committee 549. (1999). State-of-the-Art Report on Ferrocement (ACI 549R-97). American Concrete Institute, Farmington Hills, MI.
- [3] Bureau of Indian Standards. (2013). IS 12269: Ordinary Portland Cement, 53 Grade—Specification. New Delhi, India.
- [4] Bureau of Indian Standards. (2016). IS 383: Coarse and Fine Aggregate for Concrete—Specification. New Delhi, India.
- [5] Bureau of Indian Standards. (2003). IS 15388: Silica Fume—Specification. New Delhi, India.
- [6] Bureau of Indian Standards. (1988). IS 4031 (Part 6): Methods of Physical Tests for Hydraulic Cement. New Delhi, India.
- [7] Maharashtra Engineering Research Institute. (2018). WRD Handbook on Ferrocement Technology. Nashik, India.
- [8] Gunasekaran, K., Kumar, P. S., & Lakshmipathy, M. (2011). Mechanical and bond properties of coconut shell concrete. *Construction and Building Materials*, 25(1), 92–98.
- [9] Jayaprithika, A., & Sekar, S. K. (2016). Stress–strain characteristics and flexural behaviour of reinforced eco-friendly coconut shell concrete. *Construction and Building Materials*, 117, 244–250.

- [10] Kalaivani, K., Gunasekaran, K., & Annadurai, R. (2022). Innovative sustainable coconut husk mortar for ferrocement infrastructure solution. *Innovative Infrastructure Solutions*, 7, 131.
- [11] Liyanage, C. D., & Pieris, M. (2015). A physico-chemical analysis of coconut shell powder. *Procedia Chemistry*, 16, 222–228.
- [12] Das, S., Hendrix, A., Stone, D., & Neithalath, N. (2015). Flexural fracture response of iron carbonate mortar–glass fibre composites. *Construction and Building Materials*, 93, 360–370.
- [13] Das, S., Kizilkanat, A. B., Chowdhury, S., Stone, D., & Neithalath, N. (2016). Microstructural transformations in synthesized iron carbonate mortar. *Materials & Design*, 92, 189–199.
- [14] Kalimuthu, K., & Raghavi, M. D. (2019). Review on area, production and productivity of coconut in India. *International Journal of Research in Business Management*, 7(1), 1–6.
- [15] Thamban, C., Jayasekhar, S., Chandran, K. P., & Jaganathan, D. (2016). Coconut production in Kerala: Trends, challenges and opportunities. *Indian Coconut Journal*.
- [16] Lo, T. Y., & Cui, H. Z. (2004). Properties of green lightweight aggregate concrete. In *Proceedings of the International Workshop on Sustainable Development and Concrete Technology* (pp. 125–131).
- [17] Shafigh, P., Alengaram, U. J., Mahmud, H. B., & Jumaat, M. Z. (2013). Engineering properties of oil palm shell lightweight concrete containing fly ash. *Materials & Design*, 49, 613–621.
- [18] Thomas, B. S., & Gupta, R. C. (2021). Sustainable utilization of agricultural waste in cement-based composites: A review. *Journal of Building Engineering*, 39, 102267.
- [19] Siddika, A., Al Mamun, M. A., Alyousef, R., & Amran, Y. H. M. (2021). Strength and durability of concrete incorporating agricultural waste: A comprehensive review. *Journal of Cleaner Production*, 281, 124698.
- [20] Ahmad, J., Martínez-García, R., & de-Prado-Gil, J. (2023). Sustainable cementitious composites incorporating agricultural waste: Recent advances and future prospects. *Construction and Building Materials*, 387, 131620.
- [21] Rashid, K., et al. (2022). Mechanical and durability performance of sustainable mortar containing agricultural waste materials. *Case Studies in Construction Materials*, 17, e01492.
- [22] Chand, N., Singh, N., & Kumar, P. (2024). Agricultural waste as sustainable construction materials: A state-of-the-art review. *Journal of Building Engineering*, 82, 108237.
- [23] FAO. (2023). FAOSTAT Statistical Database: Coconut Production Statistics. Food and Agriculture Organization of the United Nations.
- [24] Coconut Development Board. (2024). Coconut Statistics 2023–24. Ministry of Agriculture and Farmers Welfare, Government of India.
- [25] United Nations Environment Programme (UNEP). (2023). 2023 Global Status Report for Buildings and Construction.