

EFFECTS OF POLYPROPYLENE FIBER ON THE PROPERTIES OF CONCRETE CONTAINING RICE HUSK ASH AS CEMENTITIOUS MATERIAL

SAJJAD ALI MANGI^{1,*}, AAMIR SHAKOOR², MADHUSUDHAN BANGALORE RAMU^{3,*}, HEMU KARIRA⁴, RAM KUMAR⁵

¹Department of Civil Engineering, Mehran University of Engineering and Technology, SZAB Campus Khairpur Mir's, Sindh, Pakistan

²Department of Civil Engineering, Mehran University of Engineering and Technology, SZAB Campus Khairpur Mir's, Sindh, Pakistan

³Department of Civil and Construction Engineering, College of Engineering, A'Sharqiyah University, Ibra, Sultanate of Oman

⁴Department of Civil Engineering, Mehran University of Engineering and Technology, SZAB Campus Khairpur Mir's, Sindh, Pakistan

⁵Department of Civil Engineering, Mehran University of Engineering and Technology, SZAB Campus Khairpur Mir's, Sindh, Pakistan

*Corresponding Authors: sajjad.nec@muetkhp.edu.pk, madhusudhan.ramu@asu.edu.om

Abstract

Concrete production relies heavily on Ordinary Portland Cement (OPC), which depletes natural resources and contributes to environmental challenges. To address this, the present study explores the use of Rice Husk Ash (RHA) as a supplementary cementitious material and polypropylene (PP) fibres as reinforcement to improve concrete performance. The research problem centres on reducing cement consumption while overcoming the brittle nature of concrete. The objective is to evaluate how different lengths of PP fibres affect the mechanical properties of RHA-modified concrete, with the guiding question: how fibre length influences compressive and tensile strength in concrete containing RHA as a partial cement replacement. M15 grade concrete was prepared using a mix ratio of 1:2:4 with a water cement ratio of 0.50, where cement was replaced with RHA at 5%, 10%, and 15%, and 0.1% PP fibres of 0.5", 1.0", and 1.5" were added in mixes with 10% RHA. A total of 84 cube specimens were tested for workability, compressive strength, and splitting tensile strength at 7 and 28 days. Results showed that workability decreased with increasing RHA and fibre length, compressive strength improved with 10% RHA (6.4% higher than control) and was further enhanced by PP fibres, with 0.5" fibres giving the highest gain (17.8%). Splitting tensile strength also improved with RHA and PP fibres, with 0.5" fibres achieving the maximum increase (46.7% over control).

Keywords: Compressive strength, Propylene fibre, Rice husk ash, Tensile strength, Workability.

1. Introduction

Cement and aggregates are crucial to the construction industry [1]. However, the increasing demand for these materials is depleting natural resources and harming the environment [2]. Ordinary Portland Cement (OPC) production is highly energy-intensive and contributes about 7-8% of global CO₂ emissions. The sector faces the combined problem of achieving performance criteria and minimising environmental effect due to the continually increasing demand for building. This situation highlights the importance of developing substitute binders that reduce cement use and support sustainable construction. Addressing these issues, it is crucial to preserve natural resources and encourage the utilization of waste materials in construction practices [3, 4]. With enormous volumes of waste being produced every day, the globe is currently struggling with the problem of waste disposal [5]. Therefore, finding ways to reuse waste in construction has become important. Rice is a major global crop. It is cultivated in more than 100 countries across the globe on around 158 million hectares, yielding nearly 700 million tons of milled rice yearly. Asia is the dominant rice producer, contributing about 90% of the world's total production [6]. The worldwide production of RHA annually is approximately twenty million tons [7, 8].

Polypropylene fibre is a lightweight synthetic material derived from petroleum oil [9]. It is produced through a chemical process which involves the extraction of propylene gas from crude oil and subsequent polymerization. Known for its crack resistance, polypropylene fibre is commonly used as a reinforcing agent in concrete [10]. The study found that concrete strength is greatly impacted by the characteristics of wood waste ash (WWA), such as its size, shape, source, manufacturing process, and chemical or physical makeup [11]. Similarly, fibre shape and size should be carefully considered. A previous study found that using 5% rice husk ash (RHA) improved strength compared to the control, but higher RHA percentages led to a notable strength reduction [12].

Previous research on RHA and PP fibre has generally considered them independently. According to reports, RHA increases compressive strength to an ideal degree but decreases workability at greater replacement percentages [13]. On the other hand, PP fibres improve tensile strength but may decrease workability and sometimes compressive strength, depending on fibre content and geometry [14, 15]. Although some recent works explored their combined use and confirmed performance improvements the role of fibre length in RHA-modified concrete remains underexplored [13, 16, 17]. Fibre shape is crucial because shorter fibres promote stress transmission and scatter uniformly, whereas longer fibres may enhance crack control but often reduce workability [16]. This inconsistency in earlier findings highlights the need for systematic investigation.

The research problem addressed in this study is the dual challenge of reducing the environmental footprint of cement production and overcoming the brittle nature of conventional concrete. Rice husk ash offers a sustainable substitute for cement, while polypropylene fibres increase tensile resistance and prevent cracking. Investigating their combined use, particularly the influence of fibre length, is important for developing eco-friendly concrete mixes with improved performance. This study focuses on evaluating how the variation in polypropylene fibre length influences the mechanical behaviour of concrete when rice husk ash is used as a partial substitute for cement. It is anticipated that RHA will increase strength up to

an ideal replacement level based on prior research, that the inclusion of PP fibres will further improve tensile performance with shorter fibres performing more effectively due to better dispersion and that the combined use of RHA and PP fibres will create a synergistic improvement in overall concrete performance [18, 19].

The novelty of this study lies in systematically evaluating different PP fibre lengths in RHA-modified concrete, which has not been comprehensively investigated in earlier works [13, 18]. This investigation contributes to sustainable construction by reducing cement consumption, reusing agricultural waste, and improving the mechanical properties of concrete. Its usefulness lies in offering recommendations for environmentally appropriate mix designs that can be used in infrastructure projects, stiff pavements, and structural components, especially in areas with an abundance of rice husk waste. Its scientific impact lies in filling a knowledge gap by clarifying how fibre length influences the behaviour of RHA-based concrete, offering new insights for optimizing fibre-reinforced sustainable concrete. Although several studies have examined concrete containing either rice husk ash or polypropylene fibres, mainly concentrated on their effects on their own. Only limited work has investigated how the geometry of polypropylene fibres, particularly fibre length, influences the behaviour of concrete that already contains RHA as a cement substitute. By methodically examining the effects of three fibre lengths (0.5", 1.0", and 1.5") on the compressive and tensile strengths of RHA-modified concrete, this study deviates from earlier research. By establishing the relationship between fibre length, workability, and strength development, this work fills a gap in existing knowledge and provides a clearer understanding of how fibre geometry can be optimized for sustainable, high-performance concrete.

2. Literature Review

Several studies have explored the effects of rice husk ash (RHA) and polypropylene (PP) fibres on the mechanical performance of concrete. Fernando investigated concrete mixes incorporating RHA at levels of 5% to 25% by weight of cement, along with 10% micro-silica, and reported that a 15% replacement improved compressive strength by up to 20%, while higher replacement levels led to strength reduction [12]. In contrast, Ayesha Siddika found that RHA replacements up to 15% generally reduced compressive strength by 10-12% and flexural strength by 25%, concluding that the optimum level is around 10% due to the coarse characteristics of RHA [13].

Recent studies have expanded on these findings, emphasizing the microstructural and sustainability aspects of RHA-based binders. For example, SaiMadhu et al. [3] reported that highly reactive amorphous silica is produced by carefully burning and finely crushing rice husk, which enhances C-S-H formation and long-term strength. Al-Alwan et al. [4] confirmed that RHA replacement up to 10-15% reduces cement demand and CO₂ emissions without compromising structural performance. Similarly, Channa et al. [8] and Vieira et al. [15] observed that RHA fineness and silica purity strongly influence hydration kinetics and matrix densification, making it a viable supplementary cementitious material for sustainable construction.

Studies show rice husk ash improves strength due to its pozzolanic activity, while recycled concrete aggregate supports sustainability but can reduce strength at higher levels. Fibers, especially steel, help offset these losses by enhancing tensile and

flexural performance [20]. While recycled brick aggregate aids in reducing the use of natural resources but frequently reduces strength, research indicates that rice husk ash can enhance the sustainability of concrete. Fibers are widely studied for countering these drawbacks, with steel fibres, in particular, enhancing crack resistance and overall performance. This background supports evaluating fibre-reinforced RHA-RBA concrete as a sustainable structural material [21].

Research on polypropylene fibres has similarly shown notable improvements in concrete strength. Kathikara and Wankhede reported that incorporating 1.5% blended-length PP fibres enhanced compressive strength by 17% and flexural strength by 22% compared to conventional concrete, identifying this dosage as the most effective [22]. Ahmed and Daoud [23] observed that 0.1% PP fibres with 12 mm length produced maximum gains in both compressive and tensile strength. Similarly, Yilmaz and Ozmen [24] concluded that incorporating up to 0.1% PP fibres significantly increased both compressive and flexural strength. Recent research trends highlight that shorter and well-dispersed PP fibres provide superior micro crack control and fibre–matrix adhesion compared to longer fibres.

Manfredi and Silva [9] and Hossain et al. [11] demonstrated that PP fibres enhance ductility and impact resistance but may reduce workability if dosage exceeds the optimum level. Furthermore, Kumar et al. [20, 21] showed that integrating RHA with PP fibres and recycled aggregates can produce high-strength, Concrete that is sustainable and appropriate for structural uses. These studies underscore the importance of optimizing both fibre geometry and RHA content to balance mechanical performance and workability.

However, few studies have systematically investigated the combined influence of RHA and PP fibres, particularly regarding fibre length and its effect on microstructure and bonding behaviour. In order to close this gap, the current study assesses the mechanical and microstructural performance of RHA-modified concrete reinforced with different-length polypropylene fibres, offering fresh perspectives pertinent to high-performance and sustainable concrete design.

3. Materials and Methodology

The primary materials utilized in this study include cement, fine and coarse aggregates, RHA, Polypropylene (PP) fibre, and water. The research methodology involves the several steps during the experimental work. Initially the materials were collected then preparation of materials was carried out in the laboratory. The local market provided the OPC. The physical properties of RHA and OPC illustrated in Table 1. The 4.75 mm sieve was used to filter the fine aggregates made from the hill sand. Along with that crushed stone was also used as coarse aggregates between size range of 5 mm to 20 mm free from clay and other contaminants.

Table 1. Physical characteristics of OPC and RHA.

| Properties | OPC | RHA |
|--------------------------------------------|-------|-------|
| Specific surface area (cm ² /g) | 3400 | 17185 |
| Specific gravity (g/cm ³) | 3.20 | 2.15 |
| Passing from sieve 45 µm (%) | 100 | 75 |
| Colour | Black | Black |

3.1. Preparation of RHA

Rice husk was collected from local rice mills and burned in an open drum under uncontrolled conditions as shown in Fig. 1. The resulting ash was ground in a ball mill for one hour to obtain fine particles. The ash was then sieved through a 45 μm sieve, as recommended by ASTM C618 [25], and used as a partial replacement for cement.



Fig. 1. Preparation rice husk ash.

3.2. XRF (X-ray fluorescence) analysis of RHA

To assess rice husk ash's (RHA) potential as a partial cement alternative, its chemical characteristics were investigated. The silica (SiO_2) content of the treated RHA exceeded 60%, according to XRF analysis, which is consistent with values frequently reported in earlier research. The high silica level contributes to the strong pozzolanic activity of RHA, making it an important addition to cementitious applications. Table 2 displays the entire XRF composition of the RHA employed in this study.

Table 2. Chemical properties of OPC and RHA.

| Description (%) | SiO_2 | Al_2O_3 | Fe_2O_3 | CaO | MgO | SO_3 | LOI |
|-----------------|----------------|-------------------------|-------------------------|--------------|--------------|---------------|------|
| OPC | 22.5 | 5.5 | 3.5 | 64.2 | 2.3 | 2.0 | 3.20 |
| RHA | 92.5 | 0.2 | 0.65 | 1.05 | 0.45 | 0.10 | 2.50 |

3.3. Mix proportion

Concrete was prepared with a mix ratio of 1:2:4 (cement: fine aggregate: coarse aggregate) and a constant water-to-cement ratio of 0.50. RHA was used to replace cement at 5%, 10%, and 15% by weight. Polypropylene fibres were incorporated at 0.1% volume fraction with lengths of 0.5", 1.0", and 1.5" in mixes containing 10% RHA.

The polypropylene fibre dosage of 0.1% by volume was selected based on evidence from previous studies indicating that this level provides optimal improvements in strength and crack resistance without significantly affecting workability. Kathikara and Wankhede [22] and Ahmed and Daoud [23] found that

while greater dosages resulted in fibre tangling and decreased compaction efficiency, adding 0.1% PP fibre produced the greatest gains in compressive and tensile strength. Likewise, Yilmaz and Ozmen [24] observed that fibre contents around 0.1% ensured uniform dispersion and effective stress transfer within the concrete matrix. Considering these consistent results, a 0.1% fibre dosage was adopted in this study to balance mechanical enhancement with adequate workability and homogeneity.

3.4. Casting and curing of samples

Standard cube specimens of size 150 mm × 150 mm × 150 mm were cast in accordance with ASTM C192 / C192M [26]. A total of 84 specimens were prepared: three for each mix and testing age. Three layers of fresh concrete were put into moulds, and a tamping rod was used to compact each layer. All specimens were cured in clean water tanks at room temperature following a 24-hour demoulding period. The curing ages selected for testing were 7 and 28 days, following BS EN 12390-2 [27].

3.5. Testing procedure

The fresh and hardened properties of concrete were assessed through workability, compressive strength, and splitting tensile strength tests. Workability was measured using the slump test in accordance with ASTM C143 / C143M [28], where the height reduction was measured in millimetres to show ease of installation after the slump cone was filled in three layers and tamped. Compressive strength was determined on 150 mm cube specimens following ASTM C39 / C39M [17]; specimens were cured for 7 and 28 days, then tested in a compression machine at a loading rate of 0.25 MPa/s, with the average of three readings reported. Splitting tensile strength was measured as per ASTM C496 / C496M [29], where specimens were loaded diametrically between plywood strips until failure, and the maximum load was used to calculate tensile strength. These protocols guaranteed uniform assessment of RHA and polypropylene fibre (shown in Fig. 2) concrete's fresh and hardened performance. All measurements were conducted on three replicate specimens for each mix. The reported values in the Results section represent the mean ± standard deviation (SD), and all graphical findings now include error bars to show data variability and enhance statistical reliability.



Fig. 2. Polypropylene fibre.

3.6. Methodology flow chart

Figure 3 illustrates the methodological steps in a clear, sequential manner, outlining each stage of the research process from initial steps to final outcome.

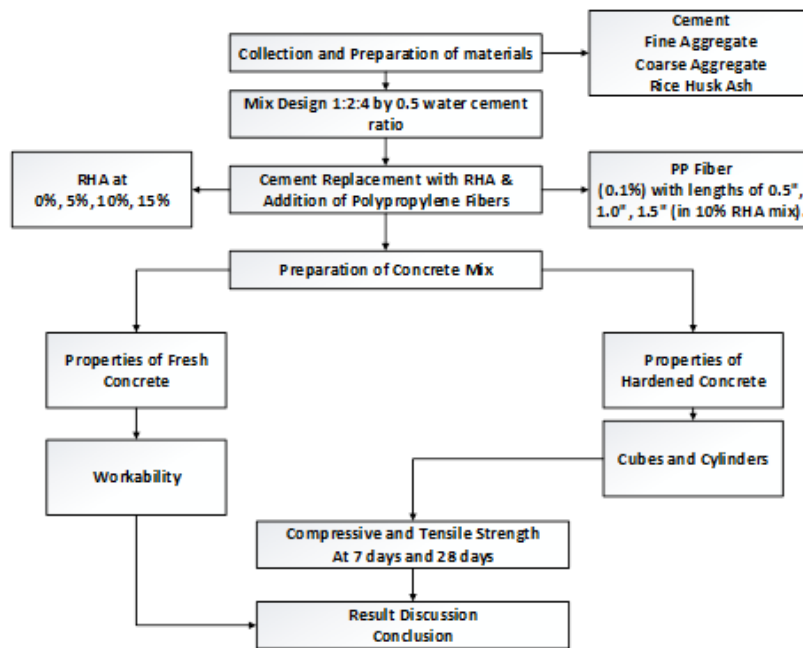


Fig. 3. Methodology flow chart.

4. Results and Discussion

4.1. Workability

The workability of freshly prepared concrete was evaluated using the slump test in accordance with ASTM C143 / C143M standards [28]. The results demonstrated that compared to the mixes containing RHA, the control mixture had a larger slump (75 mm). The inclusion of PP fibres further reduced workability in RHA concrete. The lowest slump of 10 mm was recorded for a mix with 10% RHA and 0.1% PP fibre of 1.5 inch length (Fig. 4).

The reduction in workability is mainly due to two factors. First, RHA has a very fine particle size and high surface area, which increases water demand and absorbs part of the mixing water, lowering the effective water available for lubrication in the fresh mix [16]. Second, due to their propensity to create a three-dimensional network within the matrix, polypropylene fibres restrict flow and increase internal friction. When PP and RHA fibres are utilised in together, these effects combine and result in a severe loss of slump. From a microstructural standpoint, the hydrophobic properties of polypropylene fibres limit paste flow and water movement, whereas the extremely tiny and angular particles of RHA increase surface reactivity and internal friction. Longer fibres form interlaced networks that trap air and raise internal resistance, which collectively explain the pronounced reduction in workability observed in the blended mixes.

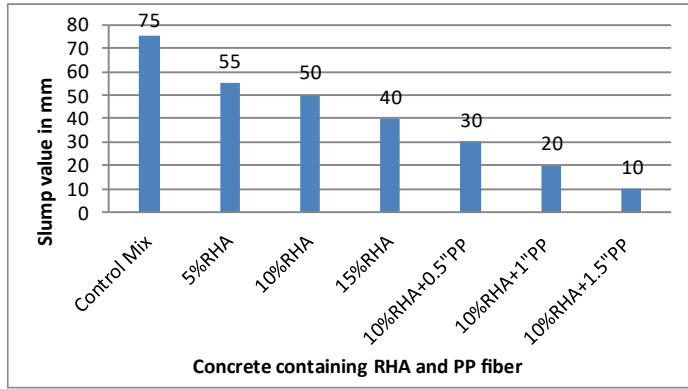


Fig. 4. Workability performance of concrete containing RHA and PP fibre.

4.2. Compressive strength

The compressive strength results are shown in Fig. 5. Replacing OPC with RHA up to 10% led to an increase in compressive strength, with a maximum gain of 9.1% compared to the control at 28 days. Beyond this level, further replacement caused a decline in strength. This pattern illustrates RHA's pozzolanic reactivity, which improves matrix densification and contributes to secondary C-S-H formation. However, at higher contents, the dilution effect dominates and strength reduces. When 0.1% PP fibres were added to concrete with 10% RHA, strength improved further, particularly with shorter fibres. At 28 days, the mixes with 0.5", 1.0", and 1.5" fibres achieved strength gains of 17.8%, 14.4%, and 10.6%, respectively, compared to the control. This indicates that fibres enhance strength by bridging micro-cracks and providing confinement to the matrix. This strength enhancement can be attributed to the pozzolanic reaction between the amorphous silica (SiO₂) in RHA and calcium hydroxide (Ca(OH)₂) released during cement hydration. The resulting secondary C-S-H gel formation densifies the microstructure and refines the pore network, improving load transfer and aggregate bonding. Polypropylene fibres further strengthen the matrix through fibre-matrix interfacial bonding, where shorter fibres disperse more uniformly and bridge micro cracks effectively.

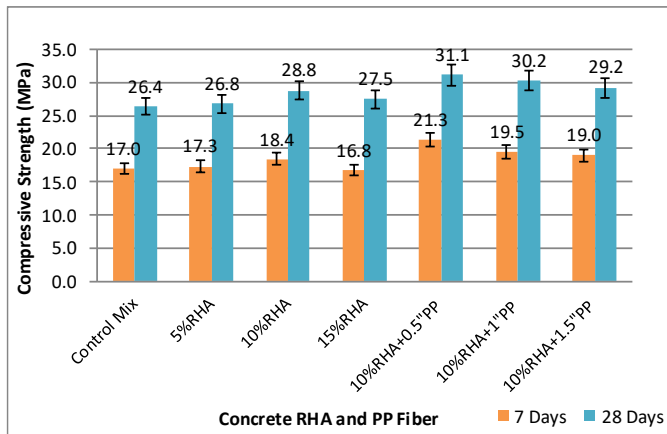


Fig. 5. Compressive strength of concrete with RHA and PP fibre.

Longer fibres, on the other hand, might entangle and produce localised voids, which would marginally lower compressive strength and homogeneity. Hence, the combined effect of RHA-induced chemical densification and fibre reinforcement governs the observed strength development.

4.3. Splitting tensile strength

The splitting tensile strength results are illustrated in Fig. 6. RHA improved tensile strength up to 15% replacement, with gains of 8.3%, 12.5%, and 16.7% for 5%, 10%, and 15% replacement, respectively, compared to the control.

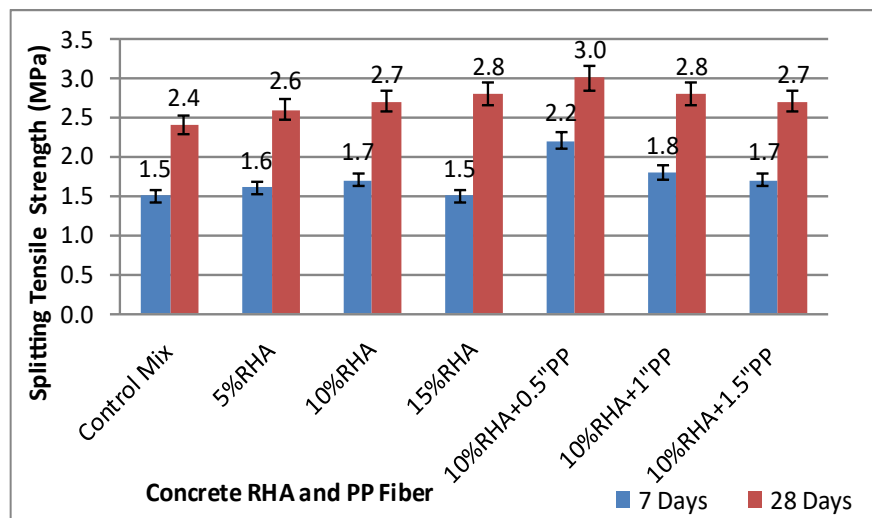


Fig. 6. Tensile strength of concrete with RHA and PP fibre.

The increase is attributed to the pozzolanic reaction of RHA, which enhances bond strength and improves the transition zone between cement pastes and aggregates [30]. Additional gains were obtained by adding 0.1% PP fibres to the 10% RHA mix. Tensile strength rose by 25.0%, 16.7%, and 12.5% after 28 days using 0.5", 1.0", and 1.5" fibres, respectively. Shorter fibres performed better because they dispersed more uniformly, provided effective crack-bridging, and improved stress transfer across the matrix. However, due to void development, poor dispersion, and fibre clumping, longer fibres reduced efficiency. The reduction in strength with higher fibre content or longer fibre lengths can thus be attributed to reduced workability, poor compaction, and the creation of internal flaws.

The improvement in tensile behaviour can be explained by both pozzolanic and mechanical mechanisms. The RHA reaction produces more C-S-H gel, which strengthens the binding between cement paste and aggregates by improving the interfacial transition zone (ITZ). Simultaneously, polypropylene fibres act as micro-reinforcement, bridging cracks and transferring tensile stresses across the matrix. The mechanical interlock between fibre and paste provide frictional resistance that delays crack propagation. Shorter fibres perform more efficiently due to better dispersion, whereas longer fibres can cluster, leading to uneven stress distribution and increased porosity.

4.4. Correlation of Compressive with splitting tensile strength

A relationship between the compressive strength and the splitting tensile strength of concrete incorporating rice husk ash (RHA) and polypropylene (PP) fibre was developed at 28 days of curing. The concept of this correlation has been previously discussed in earlier studies [18, 19, 31]. Figure 7 illustrates the graphical representation derived from computational analysis. The correlation between compressive and tensile strength, along with the coefficient of determination (R^2), is expressed in Eq. (1):

$$y = 7.8767x + 7.1918 \quad (1)$$

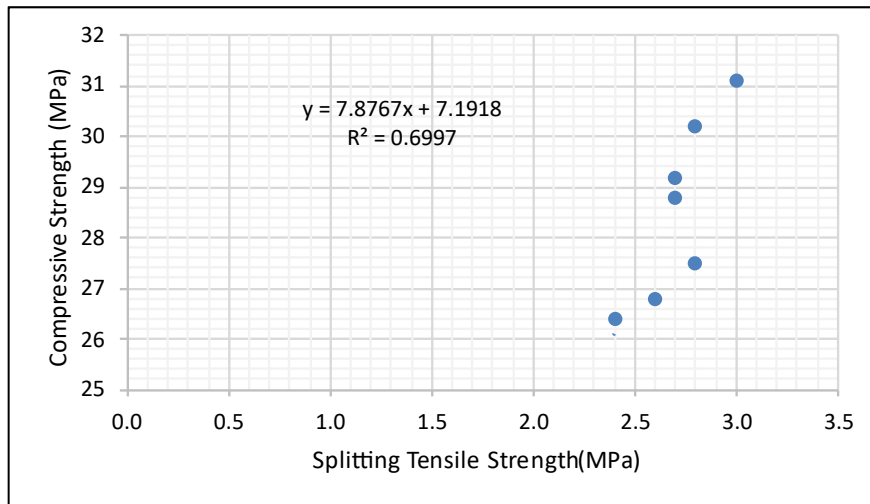


Fig. 7. Correlation of compressive with tensile strength of concrete.

Here, “y” represents the compressive strength in MPa, while “x” denotes the splitting tensile strength in MPa. The coefficient of determination R^2 was found to be 0.6997. This association suggests that similar microstructural mechanisms, primarily the densification brought on by secondary C-S-H gel formation and the crack-bridging effect of PP fibres, are responsible for both compressive and tensile strength enhancements. Together, these mechanisms enhance matrix cohesion and reduce porosity, resulting in a strong positive relationship between the two strength parameters.

5. Conclusions

This study provides new insight into the combined effects of Rice Husk Ash (RHA) and Polypropylene (PP) fibres on the mechanical behaviour of concrete. The findings confirm that an optimum 10% replacement of cement with RHA enhances compressive strength due to its pozzolanic reactivity and microstructural densification, while a 0.1% volume fraction of short PP fibres (0.5") further improve tensile strength by bridging micro cracks and increasing matrix toughness.

The research contributes to the understanding of fibre–matrix interaction in RHA-modified concrete, demonstrating that fibre length and dispersion significantly influence performance. It demonstrates that whereas longer PP fibres increase void

content and decrease homogeneity, shorter fibres produce a more homogeneous network and better stress transfer. This analytical evaluation clarifies the mechanisms linking hydration chemistry, microstructure, and mechanical performance, filling a gap in prior literature that mainly addressed RHA or fibres separately.

The results provide a foundation for the design of sustainable high-performance concrete in regions where rice husk waste is abundant. For stiff pavements, slabs, bridge decks, and precast structural components where tensile loads and shrinkage cracking are crucial, the RHA–PP fibre composite offers superior crack control, higher tensile strength, and better durability potential. Adoption of this mix can also contribute to lower carbon emissions and material costs by reducing cement usage.

In order to validate the observed performance mechanisms, further study should concentrate on long-term durability under environmental exposures such as carbonation, sulphate attack, and freeze-thaw cycles, as well as microstructural evaluation using SEM and XRD. Further exploration of different fibre geometries, hybrid fibre systems, and varying RHA fineness levels is also recommended to optimize mix performance for diverse structural and climatic conditions.

Suggestions

Although this research highlights the promising benefits of combining RHA and PP fibres in concrete, additional investigations are required to fully establish their practical potential. Future research should look at performance over a longer period of time than 28 days, with emphasis on durability under different environmental exposures such as chemical attack, freeze-thaw cycles, and aggressive weathering. Evaluating the behaviour of such concrete under seismic or dynamic loads could also provide valuable insights for structural applications in critical infrastructure. Additional tests using varying fibre percentages, varied fibre geometries, and alternative cement types would help expand the knowledge base and support the broader adoption of this sustainable technology in modern construction.

Acknowledgment

The authors would like to acknowledge financial support provided by A'Sharqiyah University, Oman, for the publication of the paper.

References

1. Naik, T.R. (2020). Sustainability of the cement and concrete industries. *Sustainable construction materials and technologies*. CRC Press, 19-25.
2. Mehta, P.K. (2009). Global concrete industry sustainability. *Concrete international*, 31(2).
3. SaiMadhu, K. et al. (2024). Mechanical characterization of Rice Husk Ash incorporated bituminous concrete. *Innovative Infrastructure Solution*, 9(7), 267.
4. Al-Alwan, A.A.K. et al. (2022). The impact of using rice husk ash as a replacement material in concrete: An experimental study. *Journal of King Saud University-Engineering Sciences*, 36(4), 249-255.
5. Zurbrugg, C. (2002). Urban solid waste management in low-income countries of Asia how to cope with the garbage crisis. *Scientific Committee on Problems*

of the Environment (SCOPE) Urban Solid Waste Management Review Session, Durban, South Africa, 6, 1-13.

6. Atique-ur-Rehman; Sarwar, N.; Ahmad, S.; Khan, M.A.; and Hasanuzzaman, M. (2022). World rice production: An overview. *Modern techniques of rice crop production*, 3-12.
7. Vecchio, C.D.; Ludovico, M.D.; and Prota, A. (2021). Cost and effectiveness of fibre-reinforced polymer solutions for the large-scale mitigation of seismic risk in reinforced concrete buildings. *Polymers*, 13(17), 2962.
8. Channa, S.H.; Mangi, S.A.; Bheel, N.; Soomro, F.A.; and Khahro, S.H. (2021). Short-term analysis on the combined use of sugarcane bagasse ash and rice husk ash as supplementary cementitious material in concrete production. *Environmental Science and Pollution Research*, 29, 3555-3564.
9. Manfredi, R.P.; and Silva, F.D.A. (2020). Test methods for the characterization of polypropylene fibre reinforced concrete: A comparative analysis. *KSCE Journal of Civil Engineering*, 24(3), 856-866.
10. Endale, S.A.; Taffese, W.Z.; Vo, D.-H.; and Yehualaw, M.D. (2022). Rice husk ash in concrete. *Sustainability*, 15(1), 137.
11. Hossain, M.T. et al. (2024). Research and application of polypropylene: A review. *Discover Nano*, 19(1), 2.
12. Fernando, K. (2021). *Investigation of rice husk ash as a sustainable source material for blended low calcium fly ash based alkali activated binders*. PhD Thesis, School of Engineering, RMIT University.
13. Bux, P.K.; Ahmed, J.A.; Jaffar, M.M.; Razzaque, S.A.; and Samiullah, S. (2020). Effect of polypropylene fibre on the strength of concrete incorporating rice husk ash. *Journal of Applied Engineering Sciences*, 10(1), 69-74.
14. Xiao, Y.; Tong, L.; Che, H.; Guo, Q.; and Pan, H. (2022). Experimental studies on compressive and tensile strength of cement-stabilized soil reinforced with rice husks and polypropylene fibres. *Construction Building Materials*, 344, 128242.
15. Vieira, A.P.; Filho R.D.T.; Tavares, L.M.; and Cordeiro, G.C. (2020). Effect of particle size, porous structure and content of rice husk ash on the hydration process and compressive strength evolution of concrete. *Construction and Building Materials*, 236, 117553.
16. Ma, Z.; Tang, Q.; Wu, H.; Xu, J.; and Liang, C. (2020). Mechanical properties and water absorption of cement composites with various fineness and contents of waste brick powder from C&D waste. *Cement and Concrete Composites*, 114, 103758.
17. ASTM C39 / C39M – 23. Standard test method for compressive strength of cylindrical concrete specimens. Retrieved October 5, 2025, from https://store.astm.org/c0039_c0039m-23.html
18. Mangi, S.A.; Ibrahim, W.M.H.; Jamaluddin, N.; Arshad, M.F.; and Ramadhansyah, P.J. (2019). Effects of ground coal bottom ash on the properties of concrete. *Journal of Engineering Science and Technology*, 14(1), 338-350.
19. Mazaheripour, H.; Ghanbarpour, S.; Mirmoradi, S.H.; and Hosseinpour, I. (2011). Polypropylene fibre reinforced concrete: Investigation of key properties. *Construction and Building Materials*, 25(1), 351-358.

20. Kumar, P.; Gogineni, A.; and Upadhyay, R. (2024). Mechanical performance of fibre-reinforced concrete incorporating rice husk ash and recycled aggregates. *Journal of Building Pathology and Rehabilitation*, 9(2), 144.
21. Kumar, P. et al. (2025). Mechanical performance of fibre reinforced concrete incorporating rice husk ash and brick aggregate. *Innovative Infrastructure Solutions*, 10(8), 362.
22. Kathikara, M.S.A.; and Wankhede, M.N.M. (2025). Experimental study on polypropylene fibre reinforced concrete with partial replacement of cement by fly ash and ggbs. *International Journal of Research Publication and Reviews*, 6(7), 1353-1359.
23. Ahmed, T.A.H.; and Daoud, O.M.A. (2016). Influence of polypropylene fibres on concrete properties. *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, 13(5), 9-20.
24. Yilmaz, S.; and Ozmen, H.B. (2016). *High performance concrete technology and applications*. BoD - Books on Demand.
25. ASTM C618-22 (2023). Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete. Retrieved October 5, 2025, from <https://store.astm.org/c0618-22.html>
26. ASTM C192/C192M-19 (2024). Standard practice for making and curing concrete test specimens in the laboratory. Retrieved October 5, 2025, from https://store.astm.org/c0192_c0192m-19.html
27. BS EN 12390-2: 2019 (2019). Testing hardened concrete: Making and curing specimens for strength tests. Retrieved October 5, 2025, from https://www.intertekinform.com/en-au/standards/bs-en-12390-2-2019-240772_saig_bsi_bsi_2753439/?srsltid=AfmBOoKItWtPQ4BuMXAONzTJQkdRbRCeLv5Wg0zEfGh2UkcG0LYDIbF
28. ASTM C 143/C143M (2020). Standard test method for slump of hydraulic-cement concrete. Retrieved October 5, 2025, from https://www.intertekinform.com/en-au/standards/astm-c-143-c143m-2020-156323_saig_astm_astm_2873292/?srsltid=AfmBOorx3nT_JHJ6ARXZd51_jH8dROfymRD4usZzDswk6rew2TTZ_Kj
29. ASTM C 496/C496M (2017). Standard test method for splitting tensile strength of cylindrical concrete specimens. Retrieved October 5, 2025, from https://www.intertekinform.com/en-au/standards/astm-c-496-c496m-2017-162717_saig_astm_astm_400104/?srsltid=AfmBOoM3eF57rWK311QJb3feNCK6lPf2bv1yl7D5hGXl9-uLeZkB5XH
30. Ganesan, K.; Rajagopal, K.; and Thangavel, K. (2007). Evaluation of bagasse ash as supplementary cementitious material. *Cement and Concrete Composites*, 29(6), 515-524.
31. Martínez-García, R. et al. (2022). The present state of the use of waste wood ash as an eco-efficient construction material: A review. *Materials*, 15(15), 5349.