Blast Furnace Slag and Rice Husk Ash as sustainable materials in ternary blended concrete

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Abstract. This study investigated creating a sustainable M25 grade ternary blended concrete by replacing Ordinary Portland Cement (OPC) with 30% Blast Furnace Slag (BFS) and different amounts (0%, 5%, 10%, and 15%) of Rice Husk Ash (RHA). The fresh and hardened properties (slump, compressive strength (CS), density, and water absorption (WA)) of these concrete mixes are evaluated to determine the best blend. Overall the results indicate that the blend that contains 30% BFS and 10% RHA (SR2) is the most optimum: it had an acceptable slump of 78 mm that gave it a reasonable workability and worked effectively with curial material properties; it had the highest 28-day CS of 36.5 MPa which surpassed the control mix (32 MPa) due to whole material effects of pozzolanic and filler synergy; it had a hardened density of 2220 kg/m³, which is moderate, a reasonable 5.13% decrease from the control; and it had a water absorption of 2.25% which indicated a manageable increase in porosity, balanced with high gains in strength. The control mix achieved a higher density and overall workability with less WA. However, mixes with greater (10-15%) RHA developed a lower density, lower workability and greater WA. The 10% RHA mix indicated the appropriate compromise between promoting better mechanical performance with acceptable durability, confirming to be a structurally appropriate and environmentally sustainable concrete mixture.

1 Introduction

The construction sector is one of the largest industries reliant on natural resources, and also one of the largest global contributors to anthropogenic carbon dioxide (CO_2) emissions largely linked to the use of ordinary Portland cement (OPC). The challenges posed by infrastructure development coupled with the environmental impact of cement production has inspired researchers and practitioners to look for alternative sustainable solutions that reduce impacts on the environment and do not adversely affect concrete performance. Through this effort, the use of by-products from industrial and agricultural processes as supplementary

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cementitious material (SCMs) is one exciting approach to create eco-efficient concrete systems [1]. In terms of SCMs, Rice Husk Ash (RHA) and Blast Furnace Slag (BFS) are among the more viable pin-developers. RHA, derived from the rice milling sector and made predominantly of amorphous silica, has pozzolanic activity when properly processed; it has two benefits when incorporated into concrete, in that it reduces the amount of OPC that is used, while also being a sustainable means to dispose of large amounts of an agricultural waste. BFS is a by-product of iron production, has latent hydraulic properties, is known to improve long-term strength and durability of concrete, and it can contribute to reduced OPC use in manufacturing concrete. Both RHA and BFS have been studied and implemented as SCMs in binary blended systems on their own; however, the combination of RHA and BFS in ternary blended systems using OPC, is well researched and is still a work-in-progress [2]. Ternary blended concrete systems typically feature two SCMs and OPC, and they are thought to provide benefits that a binary blended system cannot, due to improved particle packing, pore refinement, and hydration kinetics. The RHA and BFS combination are exciting because: the RHA provides early-age pozzolanic activity and micro-filler effects, while the BFS improves later-age strength development and resistance to chemical attacks. As a result, together, they can overcome the limitations of each material alone, in that RHA typically has high water demand, and BFS tends to have a slow early strength gain; and together they can reduce the wasteful use of raw materials [3]. This research assesses the possibility to create ternary blended concrete using RHA and BFS as replacements for OPC. The study considers M25 grade concrete for a constant w/b ratio of 0.4. In all experimental mixes, cement is replaced with a constant 30% BFS and the other mixes are made by replacing with RHA at levels of 0%, 5%, 10%, and 15% by weight of cement. A control mix of 100% OPC is also produced for comparison. The fresh and hardened properties of the concrete (SRBC) are measured, including workability, compressive strength (CS), and durability (measured as SRBC's water absorption (WA) capacity), to establish if RHA and BFS can be combined in a way that structural concrete that is environmentally beneficial can be produced.

2 Materials and Methods

2.1 Binders

In this study OPC 53 Grade supplied by Ultratech Cement Ltd is the primary binder which is consistent with IS 12269: 2013 and has a specific gravity of 3.01 and fineness of 96%. The RHA is supplied by Sri Rajalakshmi Rice Mill, Hyderabad which is obtained from burning rice husk under controlled conditions. With a specific gravity of 2.1 and fineness of 91%, RHA is ultra-fine which contributes to the pozzolanic reactivity in the concrete matrix, and acts as a filler. BFS is supplied by JSW Cements, Hyderabad, and also has a specific gravity of 2.9. BFS is a latent hydraulic material and is used in the grounded form to ensure reactivity with OPC during mixing, and no further processing or grinding is completed prior to use. All three binders (OPC, RHA, and BFS) are kept in closed containers under dry conditions until mixing to prevent moisture uptake. The percentage of oxide composition of the three binders employed in this work is given in Table 1, while Figure 1 shows the physical appearance of BFS and RHA.

Table 1 Percentage Oxide composition of OPC, BFS and RHA

Oxide	OPC	BFS	RHA
SiO_2	21.5	34.2	79.5
Al_2O_3	5.2	17.3	0.2
Fe_2O_3	3.5	0.7	1.2
CaO	63.5	37.4	0.5

MgO	2.1	7.3	0.2
SO_3	2.4	0.2	-
$Na_2O + K_2O$	0.6	-	2.98
Loss on Ignition (LOI)	1.2	0.4	4.4

Fig. 1. Binders (a) BFS (b) RHA

2.2 Aggregates

Aggregates form the largest percentage in the concrete and serve an important purpose in providing volume stability, and wear resistance. In this study, natural river sand satisfying Zone III grade (as per IS 383–2016) is utilised as a fine aggregate. River sand is a naturally occurring material, created through long-term weathering and erosion of the rocks, which is typically fine granular, and comes in rounded particles due to constantly being abraded and moved within water currents. The coarse aggregate utilized in this study consisted of crushed stone at 20 mm nominal maximum size specified in IS 383–2016. The coarse aggregate is well graded, with water absorption of 0.83%, ensuring good performance in the concrete mixing process and durability aspects. Portable water is used for mixing and curing. Table 2 displays the mix designations implemented in the study.

Table 2 Mix designations of SRBC

Mix	BFS (%)	RHA (%)
Control mix	0	0
SR0	30	0
SR1		5
SR2		10
SR3		15

2.3 Tests

To determine workability, the slump test is carried out according to IS 1199: Part 2: 2018 to evaluate fresh concrete mixes consistency and flowability. The slump test provides an indication of how easily the concrete can be placed and consolidated with little or no segregation. Overall CS is determined at 7 and 28 days to understand the complete mechanical property of concrete to determine load bearing capacity and structural performance according to IS 516:2021. WA capacity is assessed after 28 days of curing, as an indication of durability, in terms of the percentage increase in mass of oven dry specimens after immersion in water for 24 hours. The lower the absorption, the denser the microstructure and less permeable.

3 Results and Discussions

3.1 Workable nature

The slump test is the most common method used to determine workability, providing a straightforward measurement of the flowability of concrete. In this study, slump values are recorded for all mixes to understand how the replacement of OPC with BFS and RHA affected fresh concrete behaviour. The slump results show a clear and significant trend of decreasing concrete workability, as the % of RHA increased while BFS remained a fixed replacement level at 30% as shown in Table 3. The Control Mix (100% OPC) is found to have the greatest slump of 132 mm, consistent with conventional concrete presented with useful grading of particles of, OPC, providing lubrication and deformation properties in a fresh state for concrete. The properties of the smooth spherical morphology of OPC and reasonable fineness results in lower interparticle friction and higher flowability under standard mixing water [4]. SR0 slump is tremendously decreased to 114 mm, as there is a slight reduction of workability due to the addition of BFS alone. It is understood that whilst BFS enhances long-term strength and durability, BFS has a coarser and slightly more angular particle structure in comparison to OPC. Furthermore, BFS also has the latent hydraulic mechanism which permits it to not add to the fluidity of the paste, representing a buffer effect and a denser less lubricated matrix in the fresh state. The addition of RHA in SR1 (5% RHA) reduced the slump to 97 mm. This is because RHA is ultra-fine and comprised of highly porous, irregularly shaped particles and thus has a much larger specific surface area compared to both OPC or BFS. Fine particles require more water for complete wetting and coating when compared to heavier particles and this reduces the free water available for lubrication. RHA is pozzolanic and does not contribute to early rheological enhancement by means of workability loss, but rather absorbs mixing water, and probably has a positive effect on initial stiffening because of early surface reactions [5]. RHA in SR2 (10% RHA) resulted in a slump of only 78 mm and then only 56 mm in SR3 (15% RHA). This indicates a very strong nonlinear relationship between loss in workability with increasing addition of RHA. The combination of the high surface area and water absorption capacity of RHA particles, and the filling action of the particles with relatively small slender surface area, creates a stiffer, drier and less cohesive mix. At 15 % replacement, the paste becomes infinitely more viscous, and without some means of assistance placement and compaction become limited. This trend corresponds with previous studies that show there is a limit after which workability decreases rapidly with high ash percent and except where chemical admixtures are used to replace cement, restoration of workability becomes problematic [6].

Table 3 Slump values (mm) of SRBC

Mix	Slump value (mm)
Control mix	132
SR0	114
SR1	97
SR2	78
SR3	56

3.2 Compressive Strength (CS)

CS is one of the most recognized mechanical properties of concrete, and it is the primary indicator of load-carrying capacity and overall performance of structural concrete. In this research, CS is conducted at 7 and 28 days for both the control and the BFS-RHA mixes to assess the effect at a various level of replacement on strength development. The control mix achieved 14.7 MPa at 7 days and 32MPa at 28 days as shown in Figure 2. This behaviour is expected from OPC-based concrete, where the hydration of the phase C_3S and C_2S develop both C-S-H gel and calcium hydroxide (CH) [7]. The system has a sufficient level of strength, yet becomes an incomplete system without the advantage of additional pozzolanic reactions that may consume CH and refine pore structure. Thus, this mix provides a control for determining the effects of mineral admixtures. Replacing 30% OPC with BFS result in a 7-day strength of 17.8 MPa and a 28-day strength of 33.5 MPa. BFS is a latent hydraulic material, and reacts slower than OPC, showing moderate strength gain at early ages but higher than the control due to filler effect and partial hydration, and later on, BFS participates in secondary hydration, consuming CH and forming more C–S–H to create a denser microstructure which in turn will provide greater long-term CS. Along with the fact there is no RHA for better reactivity the system is only partially optimized. SR1 has additional performance developments, 7-day strength of 18.8 MPa and 28-day strength of 35 MPa. The 5 % RHA, as it contains a considerable amount of highly reactive amorphous silica, reacts quickly with CH created during cement hydration at an early stage, in addition to generating more C–S–H gel due to pozzolanic reaction, thus resulting in a higher 7-day strength at the SR1 mixes. At 28-days, the synergistic effect of BFS and RHA (long-term strength contributor, early reactive improver) influencing CS and pore structure in addition to improved strength due to high density packing of volumes from total RHA content while retaining an effective cementitious binder, even with the 5 % level optimum. This combination has the best outcomes, with 20.5 MPa at 7 days and 36.5 MPa at 28 days showing that the strength is the highest of all mixtures at 7 days, meaning there is adequate RHA for the range of reactive silica for rapid pozzolan reactions [8]. The CH created by the hydration of the OPC is almost completely utilized, thereby minimizing its porosity while allowing for more C–S–H gel formation. By 28 days, the BFS still has moisture and is continuing to hydrate, while the RHA continues to contribute pozzolanic activity, hence creating a very dense and compact matrix. The combination of a filler effect, improved hydration, and refinement of pores create superior mechanical performance. This shows that the optimum replacement is 30% BFS + 10% RHA in this study. SR3 has a strength at 7 days of 18.2 MPa and at 28 days of 34 MPa, higher than the control but lower than SR1 and SR2. The decrease in strength values with higher RHA % can be explained by the dilution effect; excessive replacement has reduced the % of OPC to such a condor there are much fewer hydration products at ages when they would be available for use. Furthermore, high levels of RHA may increase a materials water demand; this is caused by the particles being very fine and having higher surface areas which yield poorer workability and eventual less effective compaction on the RHA containing mixes if not adjusted accordingly. Therefore, whilst there is a some pozzolanic influence of RHA, there is little binder efficiency from the excessive amount of RHA, causing a slight reduction in CS when compared to the optimum (SR2) [9].

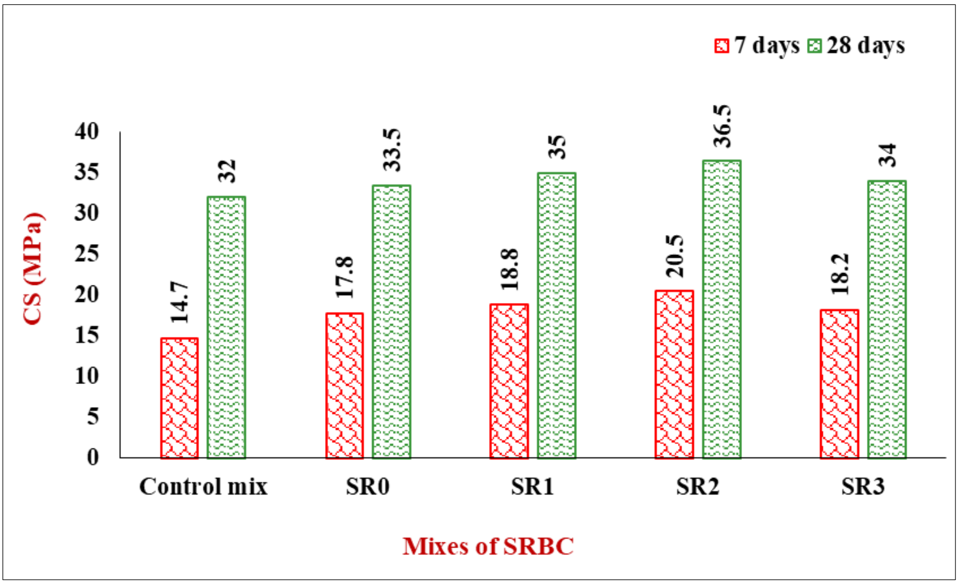

Fig. 2. 28-day CS for various SRBC mixes

3.3 Density

Density provides essential information on the compactness and quality of concrete. Typically, higher densities suggest a denser microstructure, which may provide durability against deterioration; however, this is only one of many characteristics that impact the performance of concrete. Fresh and hardened densities are determined because they lend insight as to the unit weight during the casting and hardening periods respectively. In the current study density results are assessed for both the control and blended mixes to assess the effect on BFS and RHA as it relates to the mass-to-volume characteristics of concrete. With unit weights of 2400 and 2340 kg/m³ at 28 days for the fresh and hardened state, respectively, the control values are typical for normal-weight concrete with OPC as the sole binder as shown in Figure 3. When BFS and RHA are evaluated against the overall unit weight of concrete, these values serve as a reference. When 30% of OPC is replaced by BFS, the density of the fresh mixture noticeably decreased from about 2400 to 2375 kg/m³: 25 kg/m³ or 1.04%. A decrease of 25 kg/m³ or 1.07% also manifested in the 28-day hardened density, down to 2315 kg/m³. This minimal degree of reduction in density can be explained by the fact that BFS has a specific gravity just slightly less than that of OPC; hence, there is only a slight overall change in the mass-to-volume ratio of the binder, and accordingly, the concrete remains close in density to the control [10]. With 5 % RHA usage, a considerable reduction in fresh density took place with a measurement of 2325 kg/m³, which amounted to 75 kg/m³ or 3.13 % of reduction from the control. At 28 days, the hardened density measured to be 2260 kg/m³, registering a drop of 80 kg/m³ or 3.42 %. This greater reduction compared to that of SR0 is due to the low specific gravity of RHA of 2.10, which is much lighter than both OPC and BFS: although the replacement level is low, it is enough to manifest the lighter influence of the RHA on the concrete. Increasing the RHA content further to 10 %, the fresh density then came down to 2280 kg/m³, which is 120 kg/m³ or 5% lower than that of the control mix. The hardened density came to 2220 kg/m³, indicating the same drop of 120 kg/m³ or 5.13 %. This gradual decrease indicates the accumulative effect of higher fractions of RHA: as these low-density particles occupy comparatively larger volume for the same mass, the unit weight of the mix experiences a greater reduction [11]. SR3 mix markedly offered the greatest reduction in density across all cases studied. At the maximum RHA dosage of 15 %, fresh densities dipped down to 2235 kg/m³, 165 kg/m³ or 6.88 % below the control; hardened densities, on their part, dropped to 2170 kg/m³, down 170 kg/m³ or 7.26 %. The reduction in density is therefore attributable directly to the substitution of a heavier OPC with a quantifiably greater amount of lightweight RHA; it lowers the compactness of the mix, reducing the actual weight per unit volume of the concrete [12].

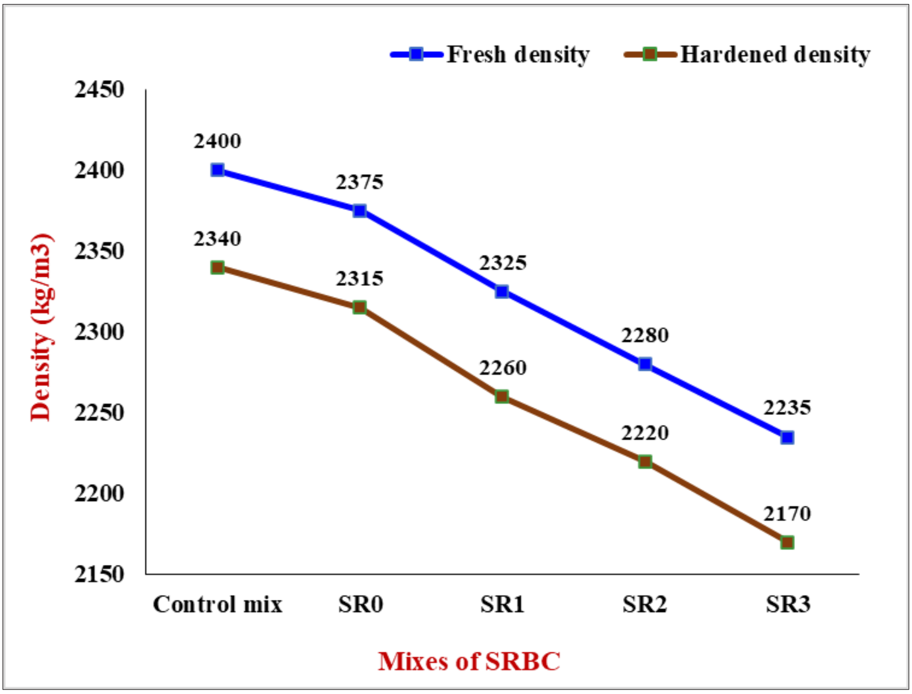

Fig. 3. Fresh and Hardened densities for various SRBC mixes

3.4 Water Absorption (WA)

WA indicates the pore structure and durability aspects of concrete, as it is indicative of how well the hardened matrix can resist water ingress, which relates directly to its density and ultimately compactness. In this study, WA values are determined for all mixes to investigate the effect of partial replacement of OPC with BFS and RHA. The control mix has a water absorption value of about 2.10%, which is normal for M25 grade concrete made from 100% OPC as displayed in Figure 4. This amount reflects the optimal performance of ordinary concrete, as the pore structure is relatively dense, and thus, provides restrictions on the entry of limited amounts of water. When 30% of OPC is replaced with BFS (SR0), the WA amount decreased slightly to about 1.95%. This further reduction in WA is due to the improved packing and pore refinement of the glassy BFS particulate to implement a denser microstructure, thereby decreasing the permeability surrounding the paste [13]. The inclusion of RHA (5%) in combination with BFS (SR1) increased the WA to 2.05%. This slight increase compared to SR0 is primarily due to the low specific gravity and porous nature of RHA, which results in increased void content. However, since the replacement was low, the accumulated influence of BFS (solid) and RHA (lighter and higher in void, but pozzolanic) action is indirect, keeping the structure densely intact enough to maintain water absorption values comparative to the control mix. When working with RHA as a replacement (10%) of OPC (SR2), it is plausible to assert that the WA value increased to 2.25%. The link to the control indicates a definitive increase due to the extent of replacing more paint with RHA and the nature of RHA i.e. it adds greater porosity and decreases further the compactness of the binder matrix [14]. Although, RHA has pozzolanic activity therefore, it could be claimed it refines the microstructure in a sense dilute the porosity of the mix. The end result of the 10% RHA consequentially increases WA, as density is sacrificed for the pozzolanic nature of the RHA. Finally, having (15%) RHA (SR3) increased the WA of the mixes; higher at 2.50% the overall increased WA is primarily due to the introduce of the lightweight RHA, which decreased density - increased pore connectivity which allowed for more water to enter the matrix onto the samples. Overall, the trend indicates that BFS on its own is effective at reducing WA due to pore refinement with incorporation of RHA an increased WA with each higher level of replacement. This suggests that for appropriate amounts of RHA, there is no impact on absorption, but higher levels of RHA will reduce the impermeability of the concrete [15].

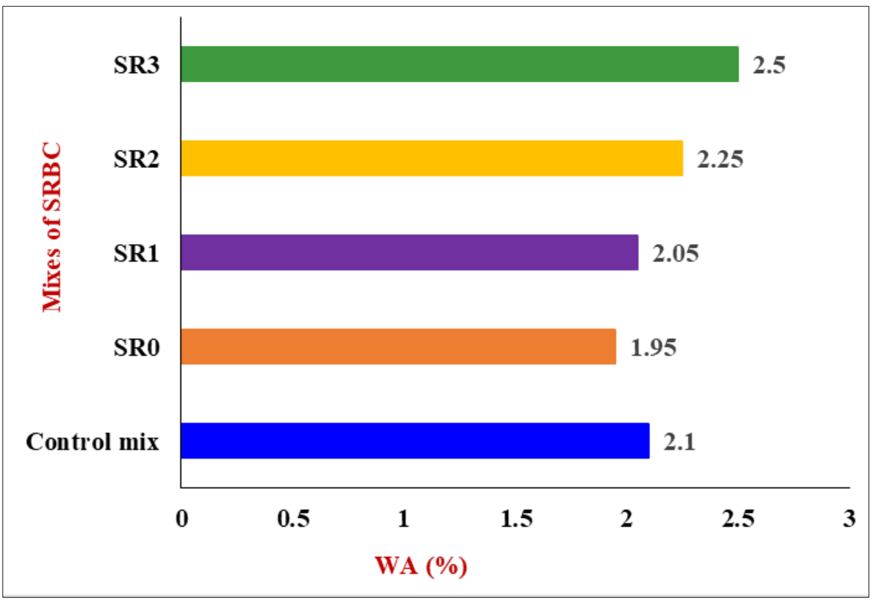

Fig. 4. WA (%) for various SFBC mixes

4 Conclusions

This research examined the effect of BFS and RHA on mechanical and durability characteristics of M25 grade concrete. The laboratory programme leads to the following conclusions:

- With a 10% replacement of RHA (SR2 mix), a slump of 78 mm was achieved with a balance of adequate placement workability and pozzolanic benefit from the RHA without requiring chemical admixtures.
- The ternary blend (30% BFS and 10% RHA (SR2)) realized the highest CS (36.5 MPa at 28 days) of all mixes. The pozzolanic reaction of the RHA results early strength gain including filler effect and benefits achieved from the BFS will impact

later-age strength development, resulting in a denser, stronger matrix than both the control and other blended mixes.

- Increasing RHA content has a constant effect on the density of the concrete, the 10% RMH mix (SR2) had a hardened density of 2220 kg/m³ which is a 5.13% reduction from the control. Maintaining structural integrity and mass efficiency is possible with the blend of 10% RHA despite the lower density of the RHA.
- WA will progressively increase with higher RHA content due to progressively more space in the matrix; only 2.25% WA is shown by the 10% RHA (SR2) age, so the trade-off for durability is limited to the 10% level, especially as durability is outdone by more gain in strength so it is a practical sustainable structural mixture.

References

1. Cunningham, P. R., Wang, L., Nassiri, S., Thy, P., Harvey, J. T., Jenkins, B. M., & Miller, S. A. (2025). Compressive strength and regional supply implications of rice straw and rice hull ashes used as supplementary cementitious materials. Resources, Conservation and Recycling, 214, 108024.
2. de Araújo Rosado, M. M. S., de Araújo Medeiros, R. L. B., Dantas, C. A. L., da Silva Batista, W. G., da Silva Curbelo, F. D., & de Oliveira Freitas, J. C. (2025). Valorization of industrial and agricultural residues in cementitious materials: A sustainable approach using blast furnace slag and rice husk ash. Waste Management, 205, 114982.
3. Naresh, T., Mallik, M., Venkateswara Rao, S., & Dubey, S. Performance and microstructural optimization of sustainable geopolymer mortars using fly ash, ground granulated blast furnace slag, and rice husk ash. Structural Concrete.
4. Nadgouda, P. A., & Sharma, A. K. (2025). Enhancing the durability of sustainable concrete: a study on ternary blended agro-waste ash incorporating rice husk ash and sugarcane bagasse ash. Clean Technologies and Environmental Policy, 27(7), 3059-3078.
5. Zhu, Z., Li, X., Liu, R., Wang, Z., Zhang, H., Zhao, D., ... & Li, W. (2025). Workability and Environmental Evaluation of Using Sunflower Stalk Ash as an Alkali Activator with Blast Furnace Slag and Black Rice Hull Ash to Prepare Geopolymer Grouts. Waste and Biomass Valorization, 16(4), 1609-1626.
6. Alharthai, M., Onyelowe, K. C., Ali, T., Qureshi, M. Z., Rezzoug, A., Deifalla, A., & Alharthi, K. (2025). Enhancing concrete strength and durability through incorporation of rice husk ash and high recycled aggregate. Case Studies in Construction Materials, 22, e04152.
7. Bashir, A., Gupta, M., & Ghani, S. (2025). Machine intelligence models for predicting compressive strength of concrete incorporating fly ash and blast furnace slag. Modeling Earth Systems and Environment, 11(2), 129.
8. Zheng, S., Gu, H., Liu, T., Dai, T., Jiang, G., Xu, H., ... & Wan, T. (2025). Effect of rice husk ash on the compressive strength and microstructural characteristics of low-density cement slurry under different temperature conditions. Geoenergy Science and Engineering, 214178.
9. Sheydaei, P., Mohsennia, E., & Toufigh, V. (2025). Fracture and mechanical properties of GGBFS-based geopolymer concrete incorporating rice husk ash and natural zeolite. Journal of Materials in Civil Engineering, 37(5), 04025079.

10. Kaya, E., Ciza, B., Yalçınkaya, Ç., Felekoğlu, B., Yazıcı, H., & Çopuroğlu, O. (2025). A comparative study on the effectiveness of fly ash and blast furnace slag as partial cement substitution in 3D printable concrete. Journal of Building Engineering, 112841.
11. Sathiparan, N., & Subramaniam, D. N. (2025). Optimizing fly ash and rice husk ash as cement replacements on the mechanical characteristics of pervious concrete. Sustainable Structures, 5.
12. Jing, Y., Lee, J. C., Moon, W. C., Ng, J. L., Yew, M. K., & Jin, Y. (2025). Durability and environmental evaluation of rice husk ash sustainable concrete containing carbon nanotubes. Scientific Reports, 15(1), 4352.
13. Sabtiwu, M., Dhandapani, Y., Drewniok, M. P., Adu-Amankwah, S., & Bernal, S. A. (2025). Influence of limestone addition on the engineering and durability performance of Portland-blast furnace slag blended concretes. Construction and Building Materials, 489, 142282.
14. Montazeri, P., Bamshad, O., Aghililotf, M., & Singh, P. (2025). Mechanical and Durability-Based Life Cycle Assessment of Rice Husk Ash Containing Concrete. Case Studies in Construction Materials, e05241.
15. Barragán-Ramírez, R., González-Hernández, A., Bautista-Ruiz, J., Ospina, M., & Aperador Chaparro, W. (2024). Enhancing concrete durability and strength with fly ash, steel slag, and rice husk ash for marine environments. Materials, 17(12), 3001.