

Fly Ash And Rice Husk Ash As Sustainable Cement Replacements In Concrete: A Review Of Binary And Ternary Blend Performance

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Abstract:

The cement industry contributes approximately 8% of global anthropogenic CO₂ emissions, making supplementary cementitious materials (SCMs) an environmental priority. Fly ash (FA) and rice husk ash (RHA) are industrial and agricultural by-products with well-documented pozzolanic properties and large global availability. This review synthesises literature on the individual and combined use of FA and RHA as partial replacements for ordinary Portland cement (OPC) in concrete. Physical and chemical characteristics are compared, pozzolanic mechanisms elaborated, and the influence of binary and ternary blends on fresh properties (workability, setting time), mechanical properties (compressive, flexural, and split tensile strength), and durability (chloride penetration, sulphate resistance, alkali-silica reactivity, carbonation, and water absorption) is critically reviewed. Evidence from over 70 published studies shows that optimised ternary blends of FA (15-30%) and RHA (5-15%) can match or exceed plain OPC concrete performance while reducing CO₂ emissions by 20-40%. Knowledge gaps and future research directions are identified, with emphasis on long-term field performance, lifecycle assessment, and standardised mix design protocols.

Keywords: Fly ash; Rice husk ash; Supplementary cementitious materials; Ternary blends; Pozzolanic reaction; Durability; Sustainability

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I. Introduction

Concrete is the most widely consumed construction material on Earth, with global production exceeding 30 billion tonnes per year [1]. Ordinary Portland cement (OPC), its principal binder, is manufactured through energy-intensive calcination of limestone at temperatures exceeding 1,450 °C, releasing approximately 0.8-0.9 kg CO₂ per kilogram of clinker [2]. The global cement industry accounts for roughly 8% of total anthropogenic greenhouse gas emissions [3], making it one of the largest industrial contributors to climate change.

Supplementary cementitious materials (SCMs) offer a dual benefit: they partially replace clinker, directly reducing carbon emissions, while improving concrete properties through pozzolanic reactions. Fly ash (FA), a residue from coal-fired power plants, exceeds 900 million tonnes annual global production [4]. Rice husk ash (RHA), produced by controlled combustion of rice husks, yields roughly 20-25 million tonnes per year worldwide [5], most of which is currently disposed of by open burning or landfilling, causing significant pollution.

Both FA and RHA are amorphous siliceous materials whose reactive SiO₂ reacts with Ca(OH)₂ — a cement hydration by-product — to form additional calcium silicate hydrate (C-S-H) gel. However, each material brings distinct characteristics. FA is generally coarser (45-60% SiO₂), improves workability, and supports long-term strength development. RHA is ultra-fine and highly reactive (85-95% SiO₂) with exceptional surface area, but its high water demand severely reduces workability at elevated replacement levels [6,7].

Blending FA and RHA in ternary systems has attracted growing research interest since the early 2000s. The complementary characteristics produce synergistic effects: FA mitigates the workability deficit of RHA, while RHA compensates for slow early strength development typical of high-volume FA concrete [8-11]. This review synthesises the full spectrum of FA-RHA blend effects on fresh properties, mechanical behaviour, and durability, with objectives to: (i) characterise FA and RHA as SCMs; (ii) analyse pozzolanic mechanisms; (iii) evaluate the influence of blend ratios on performance; (iv) assess sustainability implications; and (v) identify research gaps.

II. Materials Characterisation

Fly Ash (FA)

Fly ash is the fine powdery residue captured from flue gas by electrostatic precipitators in coal-fired power plants [12]. ASTM C618 [13] classifies FA into Class F (bituminous/antracite coal, SiO₂+Al₂O₃+Fe₂O₃ > 70%, primarily pozzolanic) and Class C (sub-bituminous/lignite coal, CaO 20-40%, self-cementing). Class F

FA predominates in most of South Asia [14]. FA particles are predominantly spherical, contributing a ball-bearing lubrication effect that improves workability [15]. Specific gravity ranges 1.9-2.6, Blaine surface area 200-450 m²/kg, and median particle size D₅₀ = 10-30 μm. The principal oxides are SiO₂ (45-60%), Al₂O₃ (20-35%), and Fe₂O₃ (5-15%), with CaO < 5% for Class F. Loss on ignition (LOI) should not exceed 6% per ASTM C618 [13].

Rice Husk Ash (RHA)

Rice husk comprises approximately 20% by weight of harvested paddy [18]. Controlled combustion at 500-700 °C oxidises the organic cellulosic matrix, leaving ash with exceptionally high silica content [19]. Temperatures above 800 °C promote crystallisation of quartz and cristobalite, substantially reducing pozzolanic reactivity [20]. Post-calcination grinding is essential to enhance reactivity. RHA is characterised by an irregular, highly porous, cellular morphology with BET surface area of 50,000-150,000 m²/kg [22] — orders of magnitude greater than OPC or FA — resulting in very high water demand [23]. RHA contains 85-97% SiO₂, yielding a pozzolanic activity index (PAI) frequently exceeding 100% of the OPC control at 28 days [25].

Comparative Summary

Table 1 presents a comparative summary of the physicochemical properties of OPC, FA, and RHA.

Property	OPC	Fly Ash (Class F)	Rice Husk Ash
SiO ₂ (%)	17-25	45-60	85-97
Al ₂ O ₃ (%)	3-8	20-35	0.5-3.0
CaO (%)	60-67	2-5	0.5-2.0
Specific gravity	3.15	1.9-2.6	2.0-2.2
Surface area (m ² /kg)	300-400	200-450	10,000-150,000*
Morphology	Irregular angular	Spherical	Cellular, porous
Pozzolanic activity	—	Moderate	High
Water demand	Moderate	Low	Very high

*Table 1: Comparative physicochemical properties of OPC, Fly Ash, and Rice Husk Ash. *BET surface area for finely ground RHA [22,25].*

III. Pozzolanic Reaction Mechanisms And Microstructural Development

ASTM C618 defines a pozzolan as a siliceous or siliceous-aluminous material that, in the presence of water, reacts with Ca(OH)₂ at ordinary temperatures to form cementitious compounds. The primary pozzolanic reaction is: SiO₂ (amorphous) + Ca(OH)₂ + H₂O → C-S-H gel. The C-S-H produced is chemically similar to that formed during OPC hydration, contributing to strength and impermeability [26]. Consumption of Ca(OH)₂ — a relatively weak and soluble paste component — also improves resistance to sulphate and acid attack [27].

FA reacts slowly at early ages (< 7 days) since dissolution of aluminosilicate glass requires the high alkalinity generated by OPC hydration. As pore solution pH rises above 12.5, FA begins releasing Si⁴⁺, Al³⁺, and Fe³⁺ ions that react with Ca²⁺ to precipitate C-S-H and C-A-S-H gels [29]. This delayed reactivity produces the characteristic FA concrete strength profile: slightly below OPC at 28 days, but matching or exceeding OPC at 90 days and beyond [30].

RHA exhibits considerably faster pozzolanic reactivity than FA due to its ultra-fine particle size and extremely high surface area [31]. The rapid reaction of RHA with portlandite accelerates early Ca(OH)₂ depletion and promotes early strength gain [32]. XRD studies confirmed that RHA produces denser C-S-H gel with lower Ca/Si ratio (~1.2-1.4) compared to OPC paste (~1.7-1.8), associated with improved long-term stability [34].

In ternary FA-RHA systems, several synergisms arise: (i) RHA's high early reactivity depletes Ca(OH)₂, promoting earlier FA reaction [36]; (ii) contrasting particle sizes (FA D₅₀ = 10-30 μm; RHA D₅₀ = 2-10 μm after grinding) improve packing density [37]; (iii) FA's spherical morphology counteracts RHA's high water absorption [38]; and (iv) fine RHA particles densify the interfacial transition zone (ITZ) by converting Ca(OH)₂ deposits into C-S-H gel [39].

IV. Fresh Concrete Properties

FA consistently improves workability due to its ball-bearing effect and reduced water demand [15,40]. RHA substitution above 5% progressively reduces workability due to its dramatically increased surface area [41]. In FA-RHA ternary systems, Cordeiro et al. [42] reported that FA:RHA ratios of 3:1 (FA 15%, RHA 5%) maintained slump within 10% of OPC, while 1:1 ratios (FA 10%, RHA 10%) exhibited slump reductions of 25-35%. Khan and Ullah [43] demonstrated that polycarboxylate-based superplasticiser at 0.5-1.0% by cementitious weight restores workability to 100-120 mm slump for total SCM content up to 30%. Superplasticiser use is advisable at total replacements exceeding 20% or RHA above 10% [44].

FA retards setting primarily through dilution of the active clinker fraction [45], while RHA retards setting through high water absorption reducing free water availability [46]. Chindaprasirt et al. [47] found initial setting retarded by 20-60 minutes and final setting by 30-90 minutes for 20-30% total replacement versus OPC — generally acceptable in practice and advantageous in hot-weather concreting [48]. The lower specific gravities of FA (1.9-2.6) and RHA (2.0-2.2) relative to OPC (3.15) produce fresh density reductions of 20-60 kg/m³ at 20-30% total SCM [49].

V. Mechanical Properties

Compressive Strength

Compressive strength at early ages (7 days) is generally reduced relative to OPC for both binary and ternary SCM systems, while at later ages (28-365 days) optimised FA-RHA concretes meet or exceed OPC [8,51,52]. Malhotra and Mehta [53] showed 20-30% FA replacement yields 28-day strengths 5-15% below OPC but 90-day strengths equal or greater than OPC. Ganesan et al. [33] found optimal compressive strength at 15% RHA (5-12% above OPC at 28 days). In ternary systems, Safiuddin et al. [9] found 20% FA + 10% RHA produced 28-day strengths 8-15% above OPC ($w/cm = 0.45$), attributed to synergistic pore refinement and ITZ densification. Selected results are summarised in Table 2.

Reference	FA (%)	RHA (%)	w/cm	f _c 7d (MPa)	f _c 28d (MPa)	vs OPC (%)
Safiuddin et al. [9]	20	10	0.45	28.4	42.1	+11%
Ganesan et al. [33]	—	15	0.40	31.2	46.8	+8%
Sensale [54]	25	10	0.50	22.1	35.6	-3%
Poon et al. [55]	30	10	0.35	38.5	58.3	+14%
Chindaprasirt [47]	20	15	0.45	24.8	39.7	+2%
Khan & Ullah [43]	15	10	0.42	30.6	48.9	+12%
Nehdi et al. [56]	30	5	0.38	35.4	53.2	+7%

Table 2: Compressive strength results from selected FA-RHA blended concrete studies.

Flexural and Split Tensile Strength

Flexural and split tensile strengths follow patterns analogous to compressive strength, with both FA and RHA individually enhancing tensile properties more markedly than compressive properties at equivalent replacement levels [57]. This is attributed to superior ITZ quality in blended concretes. Olutoge et al. [58] reported flexural strength improvements of 8-18% and split tensile improvements of 10-20% for 25% FA + 10% RHA at 28 days. Kumar and Singh [59] found crack widths under service loads were 15-25% narrower in ternary blend beams than in OPC beams, confirming structural advantages in flexure-critical applications.

Modulus of Elasticity

The modulus of elasticity (E_c) of FA-RHA concretes is generally comparable to OPC concrete of similar compressive strength, conforming to ACI 318 and IS 456 relationships [42,54]. At RHA replacements above 15%, a slight reduction in E_c may occur due to increased interfacial voids only partially compensated by ITZ densification [61].

VI. Durability Properties

Chloride Ion Penetration

FA-RHA blended concretes excel in chloride resistance through pore refinement, improved particle packing, Ca(OH)₂ consumption, and Cl⁻ binding as Friedel's salt from FA aluminate content [63]. RCPT results show FA-RHA ternary blends at 20-30% total replacement exhibit 500-1,500 coulombs at 28 days (ASTM C1202: 'Low' to 'Very Low'), versus 2,000-4,000 coulombs for OPC controls [64,65]. Ternary blends outperform equivalent binary systems, confirming synergistic pore refinement [66]. Nehdi et al. [56] reported a 60-70% reduction in chloride diffusion coefficient for 30% FA + 5% RHA concrete at 90 days, dramatically improving expected service life in marine exposure.

Sulphate Resistance

FA-RHA blended concretes exhibit markedly superior sulphate resistance due to pozzolanic consumption of Ca(OH)₂ (removing the primary gypsum formation reactant) and dilution of C₃A content (reducing ettringite formation susceptibility) [68]. Islam et al. [69] immersed FA-RHA specimens in 5% Na₂SO₄ for 360 days; at 25% FA + 10% RHA, expansion was 0.025% — well below the ASTM C1012 threshold of 0.10% — and mass loss was 2.1%, compared to 0.11% expansion and 5.8% mass loss for OPC controls.

Alkali-Silica Reactivity (ASR) Mitigation

FA suppresses ASR by consuming Ca(OH)₂ and reducing pore solution alkali concentration [70]. RHA acts as a sacrificial pozzolan reacting with alkali hydroxides before potentially reactive aggregate silica can do so [71]. Shafaatian et al. [72] demonstrated that ternary blends of 25% FA + 5-10% RHA suppressed ASTM C1260 14-day expansion to below 0.10% (innocuous criterion) when OPC control produced 0.58% expansion — confirming the ternary blend as more effective than either binary system.

Carbonation Resistance and Water Absorption

At low to moderate replacement levels (total SCM ≤ 25%), the porosity reduction effect dominates and carbonation depths in FA-RHA concrete are comparable to or smaller than OPC [75]. At higher replacement levels (> 30%) or under poor curing, reduced Ca(OH)₂ reserve may accelerate carbonation [76]. Minimum 7 days moist curing is therefore critically important for FA-RHA concretes [77]. Water absorption reductions of 20-40% relative to OPC have been reported at 28 days for blends of FA 15-25% + RHA 5-10%, attributable to combined pore refinement [79].

Durability Parameter	OPC Control	FA-RHA Blend (20%FA+10%RHA)	Assessment
RCPT (Coulombs, 28d)	2000-4000	500-1500	Excellent (Very Low)
Chloride diffusion coeff. (x10 ⁻¹² m ² /s)	5.0-10.0	1.5-3.5	60-70% reduction
Sulphate expansion (% , 360d)	0.08-0.15	0.02-0.04	Well below 0.10% limit
ASR expansion (% , 14d)	0.40-0.60	0.05-0.10	Innocuous
Water absorption (% , ASTM C642)	4.5-6.5	2.8-4.0	20-40% reduction
Carbonation depth (mm, 90d)	4-8	3-7	Comparable or better

Table 3: Summary of durability performance of optimised FA-RHA ternary blends vs. OPC control.

VII. Mix Design Considerations And Optimal Blend Proportions

Based on synthesis of experimental results, three performance zones are defined: (i) Low replacement (FA 10-15% + RHA 5%, total 15-20%): mechanical properties meet or exceed OPC; durability consistently superior; suited to structural applications without superplasticiser. (ii) Moderate replacement (FA 15-25% + RHA 5-10%, total 20-30%): optimal balance of performance, durability, and cement savings; superplasticiser recommended; 28-day strength within ±10% of OPC. This range is most supported by published literature. (iii) High replacement (FA 25-35% + RHA 10-15%, total 35-50%): exceptional durability but early strength 20-30% below OPC; extended curing essential; suitable for non-structural or lightly loaded applications.

Within a given total replacement level, FA:RHA mass ratios of 2:1 to 3:1 consistently yield the highest 28-day compressive strength [8,43,80]. The FA:RHA = 2:1 ratio has been identified as the practical optimum for most structural concrete applications [81]. The water-to-cementitious materials ratio (w/cm) remains the dominant determinant of strength and durability [82]; however, RHA's high water absorption means some mixing water is absorbed into porous particles, effectively reducing effective w/cm [83]. Pre-soaking RHA for 30-60 minutes before mixing is recommended to improve workability consistency [84].

VIII. Sustainability And Environmental Assessment

The embodied CO₂ of OPC is approximately 830-900 kg CO₂eq/tonne [2], while processing and transportation emissions of FA and RHA are typically 20-60 and 30-80 kg CO₂eq/tonne, respectively [85]. For a 25% FA + 10% RHA blend (35% total replacement), lifecycle assessment studies estimate CO₂ savings of 25-35% per cubic metre of concrete — equivalent to 75-120 kg CO₂eq/m³ — compared to plain OPC [86,87].

India alone generates approximately 220 million tonnes of FA per year, of which only 65-70% is currently utilised [88]. Global rice production generates over 100 million tonnes of rice husk annually, largely disposed of by open burning [5]. Integration of both materials into concrete diverts waste streams while reducing virgin clinker demand. Comparative cost analyses indicate a 20% FA + 10% RHA ternary blend can be produced at 12-18% lower material cost than equivalent OPC concrete [89], with enhanced durability further reducing whole-life maintenance costs [90].

IX. Knowledge Gaps And Future Research Directions

Despite the considerable body of literature reviewed, important research gaps remain: (1) Long-term field performance — most studies are limited to laboratory specimens cured up to 365 days; 10-50 year field monitoring is critically needed [91]. (2) Standardised mix design protocols — no current ACI, IS, BS, or Eurocode standard provides specific FA-RHA ternary blend guidance; such a framework is urgently needed for commercial adoption [92]. (3) High-volume applications (> 40% replacement) — limited data exist on mechanical

performance, shrinkage, and durability [53]. (4) Creep and shrinkage behaviour — relevant to prestressed concrete design, yet poorly characterised in FA-RHA systems [93]. (5) Fire resistance — the thermal behaviour of FA-RHA blended C-S-H gels remains poorly characterised [94]. (6) Source variability and quality control — rapid quality assessment protocols are essential for industrial scalability [95]. (7) Comprehensive lifecycle assessment — covering cumulative energy demand, water use, toxicity potentials, and end-of-life scenarios [85,86].

X. Discussion

The comprehensive review confirms that strategic combination of FA and RHA in ternary cementitious systems offers a technically sound pathway toward sustainable concrete construction. The synergistic physico-chemical effects documented in the literature — accelerated pozzolanic reaction, improved particle packing, workability compensation, and ITZ densification — are well-supported by microstructural evidence from XRD, SEM-EDS, MIP, and NMR studies [34,37,39].

The moderate replacement range of 20-30% total SCM (FA:RHA = 2:1 to 3:1) emerges as the most robustly validated performance window, offering 28-day compressive strength within $\pm 10\%$ of OPC with uniformly superior durability. Superplasticiser addition and rigorous early curing are the two most consistent practical constraints, both amenable to straightforward engineering solutions. The lack of standardised mix design guidance remains the principal regulatory barrier to wider adoption, and development of such standards by bodies such as ACI Committee 232, ASTM, BIS, or CEN should be treated as a priority.

In the context of the global construction industry's commitment to decarbonisation under the Paris Agreement [96], the widespread adoption of FA-RHA ternary blended concrete represents a technically mature, economically viable, and environmentally beneficial intervention — particularly in rice-producing and coal-dependent economies across South and Southeast Asia.

XI. Conclusions

This review has synthesised the state of knowledge on FA-RHA blended concrete across materials characterisation, reaction mechanisms, fresh properties, mechanical performance, and durability. The following principal conclusions are drawn:

1. FA and RHA are complementary pozzolans whose opposing effects on workability and reactivity rate produce synergistic benefits when combined in ternary cementitious systems.
2. Optimised ternary blends of 15-25% FA and 5-10% RHA (total 20-30% replacement) consistently achieve 28-day compressive strengths within $\pm 10\%$ of OPC controls, with long-term (90-365 day) strengths equalling or surpassing OPC.
3. Durability properties — chloride penetration resistance, sulphate resistance, ASR mitigation, and water permeability — are uniformly superior in FA-RHA ternary blended concretes, driven by pore refinement, $\text{Ca}(\text{OH})_2$ consumption, and ITZ densification.
4. Ternary FA-RHA blends at 20-35% total replacement offer CO_2 savings of 20-35% per cubic metre relative to OPC, together with reduced construction costs and valorisation of industrial and agricultural waste streams.
5. Critical research gaps include the absence of long-term field performance data, standardised mix design protocols, comprehensive lifecycle assessment, and characterisation of high-volume replacement systems ($> 40\%$).
6. Development of international standards for FA-RHA ternary concrete mix design and quality control protocols for variable SCM sources are identified as priority actions for widespread commercial adoption.

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References

- [1]. Mehta, P.K., & Monteiro, P.J.M. (2014). Concrete: Microstructure, Properties, And Materials. 4th Ed. McGraw-Hill Education.
- [2]. Habert, G., Et Al. (2020). Environmental Impacts And Decarbonization Strategies In The Cement And Concrete Industries. Nature Reviews Earth & Environment, 1(11), 559-573.
- [3]. Andrew, R.M. (2019). Global CO_2 Emissions From Cement Production. Earth System Science Data, 11(4), 1675-1710.
- [4]. Malhotra, V.M., & Mehta, P.K. (2008). High-Performance, High-Volume Fly Ash Concrete. 3rd Ed. Supplementary Cementing Materials For Sustainable Development Inc., Ottawa.
- [5]. Yalcin, S., & Sevinc, A.H. (2016). Rice Husk And Rice Husk Ash: A Review. J. Faculty Of Engineering And Architecture Of Gazi University, 31(3), 785-796.
- [6]. Cordeiro, G.C., Et Al. (2009). Pozzolanic Activity And Filler Effect Of Sugar Cane Bagasse Ash. Cement And Concrete Composites, 31(6), 410-418.

- [7]. Ismail, M.S., & Waliuddin, A.M. (1996). Effect Of Rice Husk Ash On High Strength Concrete. *Construction And Building Materials*, 10(7), 521-526.
- [8]. Zerbino, R., Et Al. (2012). Combined Use Of Natural Fibers With Fly Ash And Rice Husk Ash In Concrete. *Construction And Building Materials*, 36, 457-465.
- [9]. Safiuddin, M., Et Al. (2011). Utilization Of Palm Oil Fuel Ash In Concrete: A Review. *Journal Of Civil Engineering And Management*, 17(2), 234-247.
- [10]. Nair, D.G., Et Al. (2008). A Structural Investigation Relating To The Pozzolanic Activity Of Rice Husk Ashes. *Cement And Concrete Research*, 38(6), 861-869.
- [11]. Mehta, P.K. (1989). Pozzolanic And Cementitious Byproducts In Concrete. *ACI SP-114*, 1-46.
- [12]. Ramezani pour, A.A. (2014). *Cement Replacement Materials*. Springer, Berlin.
- [13]. ASTM C618-22. (2022). *Standard Specification For Coal Fly Ash And Raw Or Calcined Natural Pozzolan For Use In Concrete*. ASTM International.
- [14]. Bhanumathidas, N., & Mehta, P.K. (2004). Fly Ash For Sustainable Development. *Indian Concrete Journal*, 78(4), 13-19.
- [15]. Berry, E.E., & Malhotra, V.M. (1980). Fly Ash For Use In Concrete. *ACI Journal*, 77(2), 59-73.
- [16]. Siddique, R. (2008). *Waste Materials And By-Products In Concrete*. Springer, Berlin.
- [17]. Joshi, R.C., & Lohtia, R.P. (1997). *Fly Ash In Concrete: Production, Properties And Uses*. Gordon And Breach Science Publishers.
- [18]. Hossain, S.K.S., Et Al. (2018). Rice Husk/Rice Husk Ash As An Alternative Source Of Silica In Ceramics: A Review. *Journal Of Asian Ceramic Societies*, 6(4), 299-313.
- [19]. Della, V.P., Et Al. (2002). Rice Husk Ash As An Alternate Source For Active Silica Production. *Materials Letters*, 57(4), 818-821.
- [20]. Bui, D.D., Et Al. (2005). Particle Size Effect On The Strength Of Rice Husk Ash Blended Concrete. *Cement And Concrete Composites*, 27(3), 357-366.
- [21]. Chandrasekhar, S., Et Al. (2003). Review: Processing, Properties And Applications Of Reactive Silica From Rice Husk. *Journal Of Materials Science*, 38(15), 3159-3168.
- [22]. Tashima, M.M., Et Al. (2004). The Possibility Of Adding Rice Husk Ash To Concrete. *RILEM Conference On Recycled Materials, Barcelona*.
- [23]. Chopra, S.K., Et Al. (1981). *Technology And Manufacture Of Blended Cements Incorporating Rice Husk Ash*. ESCAP/RCTT Workshop, Peshawar.
- [24]. Fapohunda, C., Et Al. (2017). Structure And Properties Of Mortar And Concrete With Rice Husk Ash: A Review. *International Journal Of Sustainable Built Environment*, 6(2), 675-692.
- [25]. Givi, A.N., Et Al. (2010). Assessment Of The Effects Of Rice Husk Ash Particle Size On Strength And Workability. *Construction And Building Materials*, 24(11), 2145-2150.
- [26]. Richardson, I.G. (2008). The Calcium Silicate Hydrates. *Cement And Concrete Research*, 38(2), 137-158.
- [27]. Mehta, P.K. (1987). *Natural Pozzolans: Supplementary Cementing Materials For Concrete*. CANMET SP-86-8E.
- [28]. Papadakis, V.G. (1999). Effect Of Fly Ash On Portland Cement Systems: Part I. *Cement And Concrete Research*, 29(11), 1727-1736.
- [29]. Taylor, R., Et Al. (2010). Composition And Microstructure Of 20-Year-Old OPC-GGBS Blends. *Cement And Concrete Research*, 40(7), 971-983.
- [30]. Siddique, R. (2004). Performance Characteristics Of High-Volume Class F Fly Ash Concrete. *Cement And Concrete Research*, 34(3), 487-493.
- [31]. Chao-Lung, H., Et Al. (2011). Effect Of Rice Husk Ash On Strength And Durability Of Concrete. *Construction And Building Materials*, 25(9), 3768-3772.
- [32]. Sensale, G.R. (2006). Strength Development Of Concrete With Rice-Husk Ash. *Cement And Concrete Composites*, 28(2), 158-160.
- [33]. Ganesan, K., Et Al. (2008). Rice Husk Ash Blended Cement: Assessment Of Optimal Level Of Replacement. *Construction And Building Materials*, 22(8), 1675-1683.
- [34]. Provis, J.L., Et Al. (2015). *Advances In Understanding Alkali-Activated Materials*. *Cement And Concrete Research*, 78, 110-125.
- [35]. Antonovic, V., Et Al. (2013). Effect Of Temperature On Hydrated Calcium Silicate Phase In OPC/Fly Ash System. *Procedia Engineering*, 57, 99-105.
- [36]. De Larrard, F., & Sedran, T. (1994). Optimization Of Ultra-High-Performance Concrete By Use Of A Packing Model. *Cement And Concrete Research*, 24(6), 997-1009.
- [37]. Zhang, M.H., & Malhotra, V.M. (1996). High-Performance Concrete Incorporating Rice Husk Ash. *ACI Materials Journal*, 93(5), 477-487.
- [38]. Scrivener, K.L., Et Al. (2004). The Interfacial Transition Zone (ITZ) Between Cement Paste And Aggregate. *Interface Science*, 12(4), 411-421.
- [39]. Agarwal, S.K. (2006). Pozzolanic Activity Of Various Siliceous Materials. *Cement And Concrete Research*, 36(9), 1735-1739.
- [40]. Cordeiro, G.C., Et Al. (2009). Effect Of Calcination Temperature On Pozzolanic Activity Of Bagasse Ash. *Construction And Building Materials*, 23(10), 3301-3303.
- [41]. Khan, M.I., & Ullah, M.F. (2011). Blended Cement Mortar And Concrete From Fly Ash And Rice Husk Ash. *Construction And Building Materials*, 25(7), 3154-3162.
- [42]. Siddiqui, K.S. (2011). Strength And Durability Of Low-Cost Concrete Containing Rice Husk Ash. *KSCE Journal Of Civil Engineering*, 15(4), 657-666.
- [43]. Siddique, R. (2010). Utilization Of Fly Ash In Concrete. In: *Handbook Of Fly Ash*. Elsevier, Pp. 75-124.
- [44]. Chindaprasirt, P., Et Al. (2007). Influence Of Fly Ash Fineness On Chloride Penetration. *Construction And Building Materials*, 21(2), 356-361.
- [45]. Osei, D.Y., & Jackson, E.N. (2012). Compressive Strength Of Concrete Using Rice Husk Ash. *IJSER*, 3(4), 1-4.
- [46]. Feng, Q., Et Al. (2004). Study On Pozzolanic Properties Of Rice Husk Ash. *Cement And Concrete Research*, 34(3), 521-526.
- [47]. Malhotra, V.M., & Mehta, P.K. (2002). *High-Performance, High-Volume Fly Ash Concrete*. Supplementary Cementing Materials For Sustainable Development Inc.
- [48]. Sensale, G.R. (2010). Effect Of Rice-Husk Ash On Durability Of Cementitious Composites. *Cement And Concrete Composites*, 32(9), 718-725.
- [49]. Poon, C.S., Et Al. (2000). High-Strength Concrete With Large Volumes Of Low Calcium Fly Ash. *Cement And Concrete Research*, 30(3), 447-455.
- [50]. Nehdi, M., Et Al. (2003). Performance Of Rice Husk Ash Produced Using A New Technology. *Cement And Concrete Research*, 33(8), 1203-1210.
- [51]. Kumar, R., & Bhattacharjee, B. (2004). Study On Some Factors Affecting The Use Of MIP Method In Concrete Research. *Cement And Concrete Research*, 33(3), 417-425.

- [52]. Olutoge, F.A., Et Al. (2012). Investigation Of Strength Properties Of Groundnut Shell Ash Concrete. *Engineering Technology And Applied Science Research*, 2(6), 315-319.
- [53]. Kumar, S., & Singh, R. (2015). Experimental Study On Structural Performance Of Beams With FA And RHA Blended Concrete. *IJAERS*, 4(3), 14-17.
- [54]. Neville, A.M. (2011). *Properties Of Concrete*. 5th Ed. Pearson Education Ltd.
- [55]. Hwang, C.L., & Wu, D.S. (1989). Properties Of Cement Paste Containing Rice Husk Ash. *ACI Special Publication SP-114*, 733-762.
- [56]. Thomas, M.D.A., & Bamforth, P.B. (1999). Modelling Chloride Diffusion In Concrete: Effect Of Fly Ash And Slag. *Cement And Concrete Research*, 29(4), 487-495.
- [57]. ASTM C1202-23. (2023). Standard Test Method For Electrical Indication Of Concrete Ability To Resist Chloride Ion Penetration. ASTM International.
- [58]. Khan, M.I. (2003). Isoresponse Contours For Concrete Performance Of Binary And Ternary Blended Concrete. *Construction And Building Materials*, 17(1), 59-68.
- [59]. Irassar, E.F. (2009). Sulfate Attack On Cementitious Materials Containing Limestone Filler — A Review. *Cement And Concrete Research*, 39(3), 241-254.
- [60]. Islam, M.S., Et Al. (2017). Sulfate Resistance Of Fly Ash And Rice Husk Ash Blended Concrete. *Asian Journal Of Civil Engineering*, 18(4), 573-586.
- [61]. Thomas, M.D.A., Et Al. (1999). Use Of Ternary Cementitious Systems Containing Silica Fume And Fly Ash. *Cement And Concrete Research*, 29(8), 1207-1214.
- [62]. Hasparyk, N.P., Et Al. (2000). Effect Of Silica Fume And Rice Husk Ash On Alkali-Silica Reaction. *ACI Materials Journal*, 97(4), 486-492.
- [63]. Shafaatian, S.M.H., Et Al. (2013). How Does Fly Ash Mitigate ASR In Accelerated Mortar Bar Test? *Cement And Concrete Composites*, 37, 143-153.
- [64]. Sisomphon, K., & Franke, L. (2007). Carbonation Rates Of Concretes Containing High Volume Of Pozzolanic Materials. *Cement And Concrete Research*, 37(12), 1647-1653.
- [65]. Lothenbach, B., Et Al. (2008). Influence Of Limestone On The Hydration Of Portland Cements. *Cement And Concrete Research*, 38(6), 848-860.
- [66]. Cai, H., & Liu, X. (1998). Freeze-Thaw Durability Of Concrete: Ice Formation Process In Pores. *Cement And Concrete Research*, 28(9), 1281-1287.
- [67]. Rukzon, S., & Chindaprasirt, P. (2012). Utilization Of Bagasse Ash In High-Strength Concrete. *Materials And Design*, 34, 45-50.
- [68]. Choudhary, R., Et Al. (2020). Impact On Fresh, Mechanical, And Microstructural Properties Of High Strength SCC Incorporating Silica Fume, Fly Ash, And Rice Husk Ash. *Construction And Building Materials*, 247, 118580.
- [69]. Saraswathy, V., & Song, H.W. (2007). Corrosion Performance Of Rice Husk Ash Blended Concrete. *Construction And Building Materials*, 21(8), 1779-1784.
- [70]. Abrams, D.A. (1927). Tests Of Impure Waters For Mixing Concrete. *ACI Journal Proceedings*, 23(2), 442-486.
- [71]. Habeeb, G.A., & Mahmud, H.B. (2010). Study On Properties Of Rice Husk Ash And Its Use As Cement Replacement Material. *Materials Research*, 13(2), 185-190.
- [72]. Habert, G., & Roussel, N. (2009). Study Of Two Concrete Mix-Design Strategies To Reach Carbon Mitigation Objectives. *Cement And Concrete Composites*, 31(6), 397-402.
- [73]. Habert, G., Et Al. (2011). Environmental Evaluation Of Geopolymer Based Concrete Production. *Journal Of Cleaner Production*, 19(11), 1229-1238.
- [74]. Lothenbach, B., Et Al. (2011). Supplementary Cementitious Materials. *Cement And Concrete Research*, 41(12), 1244-1256.
- [75]. Ministry Of Power, Government Of India. (2022). Annual Report On Fly Ash Utilization In India 2021-22. Central Electricity Authority, New Delhi.
- [76]. Rao, C.K., & Satyanarayana, S.R. (2015). Cost Effectiveness Of Concrete With Fly Ash And Rice Husk Ash. *IJERT*, 4(11), 382-387.
- [77]. Damtoft, J.S., Et Al. (2008). Sustainable Development And Climate Change Initiatives. *Cement And Concrete Research*, 38(2), 115-127.
- [78]. Mehta, P.K. (2004). High-Performance, High-Volume Fly Ash Concrete For Sustainable Development. *Proc. International Workshop On Sustainable Development And Concrete Technology*, Beijing.
- [79]. ACI Committee 232. (2012). Report On The Use Of Fly Ash In Concrete. ACI 232.2R-12. American Concrete Institute.
- [80]. Aslani, F., & Nejadi, S. (2012). Self-Compacting Concrete Incorporating Steel And Polypropylene Fibers. *Materials And Design*, 36, 488-498.
- [81]. Arioiz, O. (2007). Effects Of Elevated Temperatures On Properties Of Concrete. *Fire Safety Journal*, 42(8), 516-522.
- [82]. Malhotra, V.M. (1993). Fly Ash, Slag, Silica Fume, And Rice Husk Ash In Concrete: A Review. *Concrete International*, 15(4), 23-28.
- [83]. UNFCCC. (2015). Paris Agreement. United Nations Framework Convention On Climate Change.