International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Performance Evaluation of Lightweight Prefabricated Concrete Wall Panels Incorporating Rice Husk Ash (RHA) and Kenaf Fibre

Nithishkumar S [a], Mr. Nandhakumar P [b]

[a]-*PG Scholar, Kumaraguru College of Technology, Coimbatore*

[b]-*Associate Professor, Kumaraguru College of Technology, Coimbatore.*

ABSTRACT

This study proposes mix designs and testing procedures for lightweight prefabricated concrete wall panels incorporating rice husk ash (RHA) as a cement replacement and kenaf fibre reinforcement. RHA is an agricultural waste pozzolan rich in amorphous silica[1][2], and kenaf is a natural, biodegradable fibre[3][4]. Light Expanded Clay Aggregate (LECA) is used as coarse aggregate to reduce density. A series of trial mixes (R0–R20) are defined with RHA replacing 0–20 % of cement by weight (increments of 5 %) and kenaf fibre fixed at ~0.5 % volume (~6 kg/m³)[5][4]. The binder content (cement+RHA) is held constant at 440 kg/m³, with w/b≈0.41 and 0.8 % superplasticizer to ensure workability[6][7].

Mix proportions and rationale are detailed in Table 1. Standard ASTM methods are adopted for testing: compressive strength (ASTM C39), splitting tensile (C496), flexural (C78), water absorption (C642), sorptivity (C1585), etc. Based on literature, we expect up to ~10–15 % RHA to maintain near-control compressive strength[2][8], while kenaf fibre will enhance tensile/flexural toughness[4][9]. LECA will reduce density (~1800–1900 kg/m³) at the cost of some strength[10][11]. Durability tests should reveal reduced permeability due to RHA densification[12] but increased water absorption from fibre and porous aggregate[6][13].

Overall, the RHA–kenaf–LECA concrete is expected to exhibit moderate strength (20–30 MPa range) with improved ductility and sustainability (reduced cement use, recycled materials)[2][3].

Keywords: Lightweight Concrete, Prefabricated Wall Panels, Rice Husk Ash (RHA), Kenaf Fibre, Supplementary Cementitious Materials (SCMs), Light Expanded Clay Aggregate (LECA), Mechanical Properties, Durability, Sustainable Construction.

Introduction

Lightweight concrete has gained prominence for energy-efficient and low-dead-load structures. Replacing dense aggregates with artificial lightweight aggregates like LECA (Light Expanded Clay Aggregate) can reduce concrete density by up to 30–40 %[10][11], easing structural demands. LECA-based concretes (LWAC) typically achieve 20–35 MPa compressive strength at densities ~1800–1900 kg/m³[10][11]. However, the lower strength of LECA (a highly porous, expanded clay) means LWAC strength is usually lower than normal-weight concrete[14][15]. Additives such as pozzolans and fibres are often used to enhance LWAC properties.

Rice husk ash (RHA) is a siliceous by-product of rice milling. Its utilization addresses the disposal of ~0.5–1.0 billion tons of paddy waste annually[16]. When properly burned (600–800 °C) and ground, RHA is rich in amorphous silica and acts as a pozzolanic supplementary cementitious material[1][17]. At low replacement levels (typically ≤10–15 %), RHA can refine concrete pore structure and yield strengths comparable to plain mixes[2][8].

RHA also reduces permeability and improves durability[12]. However, RHA's porous, fine particles increase water demand and, beyond ~15 % replacement, tend to create more porosity and strength loss[17][18]. Therefore, RHA percentages up to about 10–15 % are common in literature for structural concrete[2][8].

Kenaf (Hibiscus cannabinus) is a fast-growing bast fibre that has emerged as a sustainable concrete reinforcement. Kenaf fibres (typically 20–50 mm long, alkali-treated) are light and biodegradable[3][4]. As a cellulose fibre, kenaf can significantly improve concrete toughness, flexural strength, and crack control[4][9]. Most studies report that adding 0.5–2.0 % kenaf fibre (by volume) reduces workability and may slightly reduce compressive strength, but greatly enhances tensile and flexural capacity[4][5].

For example, Lam and Yatim found that at optimal fibre contents and lengths, flexural and indirect tensile strengths exceeded plain concrete, even though compressive strength slightly decreased[4]. Kenaf fibers act as crack bridges in the cement matrix, improving post-cracking ductility and impact resistance[9].

To date, few studies have combined RHA, kenaf, and LECA in concrete. This paper develops mix designs for lightweight precast wall panels using RHA (as SCM) and kenaf fibre, examines standard test methods for evaluating their performance, and discusses expected trends by analogy with existing studies. The objectives are to outline concrete mixes (R0–R20 with RHA) and predict mechanical and durability behavior based on literature, without presenting new experimental data.

Objectives

The specific objectives of this study are:

- To propose mix designs for lightweight concrete wall panels incorporating rice husk ash (RHA) as partial cement replacement and kenaf fibre as reinforcement, using LECA as coarse aggregate.
- To detail material characterization (cement, RHA, kenaf fibre, LECA, sand) and design rationales based on prior findings.
- To outline testing protocols for fresh and hardened properties (workability, density, compressive strength, splitting tensile strength, flexural strength) and durability (water absorption, sorptivity, microstructure) following ASTM/IS standards.
- To discuss expected mechanical performance and durability trends (strength development, toughness, crack behavior, moisture sensitivity) from literature for RHA-kenaf-LECA concretes.
- To evaluate the sustainability implications of using RHA and kenaf in concrete panels.

Materials and Methods

Materials

- **Cement:** Ordinary Portland Cement (Type I, e.g. ASTM C150), Grade 43/53, specific gravity ~3.15. Typical physical and chemical properties can be assumed from standards.
- **Rice Husk Ash (RHA):** RHA is obtained by controlled burning of rice husks at 600–800 °C. Properly processed RHA is gray, highly siliceous (SiO_2 ~60–90 %)[1], with particle sizes in the 1–10 µm range acting as a micro-filler[19]. Its high surface area makes it a reactive pozzolan that can densify the cement paste[19]. Excess carbon (residual char) should be low to avoid negative effects. Chemically, RHA conforms to ASTM C618 Class F requirements.
- **Kenaf Fibre:** Alkaline-treated kenaf bast fibres (approx. 25–50 mm length) are used as reinforcement. Treatment (e.g. 5–10 % NaOH bath, pH≈13) improves fibre–matrix bonding[20]. Fiber density is about 1.2–1.4 g/cm³. Fibre dosage is fixed at ~0.5 % by volume (~6 kg/m³) in all mixes, consistent with studies showing significant toughness gains at low contents[5][4].
- **Fine Aggregate:** Locally available river sand, conforming to ASTM C33 grading (max size ~4.75 mm), saturated surface dry (SSD) condition. Specific gravity ~2.65, fineness modulus ~2.6.
- **Coarse Aggregate (LECA):** Expanded clay (LECA) of 10–20 mm size is used as full coarse aggregate replacement to achieve lightweight concrete. LECA has dry density ~400–600 kg/m³ and high water absorption (~15–20 % by mass)[10][6]. Because of its porosity, preliminary wetting or extra mix water (~20 % of aggregate weight) is needed to saturate LECA and maintain slump[6]. In our design, LECA is used at ~180 kg/m³ to target a fresh concrete density ~2000 kg/m³.
- **Water:** Potable mixing water (pH ~7).
- **Admixture:** Polycarboxylate-based superplasticizer (e.g. meeting ASTM C494 Type F), dosage ~0.8 % by cementitious binder mass (cement+RHA)[7]. This dosage is chosen to offset workability loss from RHA and fibres.

Mix Proportions (Mix Design)

Five trial mixes (R0, R5, R10, R15, R20) are defined with RHA replacing 0, 5, 10, 15, and 20 % of cement by weight, respectively. Kenaf fibre content is constant (0.5 % vol, ~6 kg/m³). The total binder (cement + RHA) is kept constant at 440 kg/m³ for all mixes (Table 1). This ensures that w/b and workability can be maintained across mixes. The water-to-binder ratio is fixed at ~0.41 (w/(C+RHA) ≈0.41), based on preliminary trial aiming at moderate strength. Superplasticizer (SP) is 0.8 % of binder mass (3.5 kg/m³) in all mixes[7]. Fine aggregate (sand) is ~930 kg/m³, and LECA is ~180 kg/m³. The extra mix water supplied accounts for LECA absorption (as noted above). The mixes and rationale are:

- **Mix R0 (Control):** 100 % OPC (440 kg/m³), no RHA. Provides baseline strength. W / (C + RHA) = 0.41.
- **Mix R5:** 5 % RHA (22 kg) replaces cement (418 kg cement + 22 kg RHA). A small RHA content; literature indicates up to ~10 % RHA yields similar strength to plain[2].

- **Mix R10:** 10 % RHA (44 kg). At this level, pozzolanic benefits are maximized without major strength loss[2][8]. Many studies use 10 % as optimum.
- **Mix R15:** 15 % RHA (66 kg). This may begin to reduce early strength but can improve long-term strength and durability; still within structural range[8].
- **Mix R20:** 20 % RHA (88 kg). A high replacement level, likely showing noticeable strength reduction and higher porosity[18][8], but tested for completeness.

Kenaf fibre (6 kg/m³) is added to all mixes after 30–50 s of dry mixing to ensure dispersion. The mix proportions (per m³) are given in Table 1.

Table 1. Mix proportions (kg/m³) for lightweight RHA–kenaf concrete mixes (fibre content ~0.5% vol, SP = 0.8% binder). W/B = water/(cement+RHA).

Mix	Cement	RHA	Sand	LECA	Water	Kenaf fibre	SP (0.8%)	W/B
R0	440	0	930	180	180	6.0	3.5	0.41
R5	418	22	930	180	180	6.0	3.5	0.41
R10	396	44	930	180	180	6.0	3.5	0.41
R15	374	66	930	180	180	6.0	3.5	0.41
R20	352	88	930	180	180	6.0	3.5	0.41

Note: Binder mass (cement+RHA) is 440 kg/m³ in all mixes. Superplasticizer (SP) is 0.8 % of binder. Kenaf fibre content is ~0.5% by volume (~6.0 kg/m³ assuming 1.2 g/cm³ density)[5][4].

The binder content was chosen to target a 28-day compressive strength on the order of 20–30 MPa (typical for structural lightweight concrete[10][21]). The sand-to-binder ratio (~2.12) and LECA content were derived from literature proportions for similar LWAC[22]. Trial mixtures would be adjusted (e.g. water or SP) in practice to achieve slump ~75±25 mm.

Specimen Preparation

Concrete was mixed in a pan mixer: first dry-mix cement, RHA, and sand; then add ~50% of water and mix 1 minute; add LECA (pre-soaked), remaining water, superplasticizer; mix 2 minutes. Kenaf fibres are dispersed gradually to prevent clumping. Fresh concrete is cast into molds for cubes (150×150×150 mm) and cylinders (150×300 mm) and prisms (100×100×500 mm) following ASTM procedures. Specimens are covered for 24 h, then demolded and cured in water at ~23 °C until testing. At least three specimens per mix per test/age are prepared to ensure statistical significance.

Testing Procedures

Fresh concrete tests include slump (ASTM C143) and unit weight. Hardened tests are conducted after 7 and 28 days of curing (unless otherwise noted). Testing matrix is outlined in Table 2.

- **Compressive Strength:** ASTM C39/C39M on concrete cubes (150×150×150 mm) or cylinders (150×300 mm). Three specimens per mix per age (7, 28 days). A compression machine is used, and peak load recorded to compute strength. For example, similar studies used 100 mm cubes and 150×300 mm cylinders[23].
- **Splitting Tensile Strength:** ASTM C496 on 150×300 mm cylinders at 28 days. Three specimens per mix.
- **Flexural Strength (Modulus of Rupture):** ASTM C78 on prismatic beams (100×100×500 mm) with 3-point loading at 28 days. Three prisms per mix. (Lam et al. cast 100×100×500 mm prisms to measure flexural strength[24].)
- **Density:** ASTM C642 on 28-day specimens (cube or cylinder), by measuring mass in air and in water. Three specimens per mix.
- **Water Absorption:** ASTM C642 on dried 28-day cubes. Percentage absorption after 24 h immersion. Three specimens per mix.
- **Sorptivity:** ASTM C1585 on 50×50×100 mm specimens (sawn from cubes) at 28 days. Measures capillary absorption rate (mm/√min). Three specimens per mix.
- **Microstructure (SEM/XRD):** Small fragments of the crushed specimen (e.g. from broken flexure beams) are collected at 28 days. Scanning electron microscopy (SEM) examines the interfacial transition zone (ITZ) around fibres and RHA particles. X-ray diffraction (XRD) on powdered samples can identify hydration products and any residual unreacted RHA.

Table 2. Proposed test matrix for each mix (specimens per test per age).

Test	Specimen Size	Standard	Specimens (per mix)
Slump	Fresh mix (Ø100×200 mm cone)	ASTM C143/C143M	1
Density (unit weight)	Cube/Cylinder (150 mm)	ASTM C642	3 (28 d)
Compressive strength	Cube (150×150×150 mm)	ASTM C39/C39M	3 (7 d), 3 (28 d)
Splitting tensile	Cylinder (150×300 mm)	ASTM C496/C496M	3 (28 d)
Flexural (modulus of rupture)	Prism (100×100×500 mm)	ASTM C78/C78M	3 (28 d)
Water absorption	Cube/Cylinder (150 mm)	ASTM C642	3 (28 d)
Sorptivity	Beam (50×50×100 mm)	ASTM C1585	3 (28 d)
SEM/EDS imaging	Fragments (broken)	–	1–2 (28 d)
XRD (powder)	Paste powder (from 28 d)	–	1–2 (28 d)

This testing suite conforms to IS/ASTM standards for mechanical and durability characterization of concrete. For instance, Agboola and Shabi used similar specimen sizes in assessing fiber–RHA foamed concretes[23].

Discussion of Expected Behaviors

Compressive Strength

Based on literature, we anticipate that mixes with moderate RHA will achieve compressive strengths close to the control, while high RHA and fibre will reduce strength. Up to ~10–15 % RHA replacement often yields 28-day strengths statistically similar to plain concrete[2][8]. The frontiers study noted that "up to 10% substitution of RHA with cement is allowed … without a notable effect" on compressive strength[18]. Similarly, Agboola et al. found foamed concrete with 0–10 % RHA (sealed cure) did not significantly differ from control (15.2 MPa at 28 d)[8]. Beyond 15 %, however, strength drops – RHA's high porosity and fineness increase water demand and entrain pores[17][25]. Thus, R15 and R20 mixes may show modest compressive reductions (perhaps 10–20 % lower than R0).

Kenaf fibre also tends to slightly lower compressive strength. Lam and Yatim observed that increasing kenaf content (0.5–2.0 % by vol) reduced compressive strength[4]. The exact drop depends on dosage and workability; at 0.5 % fiber, the loss is modest. In contrast, one study found a 3 % KF mix had *higher* compressive strength in saltwater exposure[3], but this is atypical. Overall, we expect compressive strength to gradually decline with higher RHA and fibre content. However, since LECA concretes are designed for 20–30 MPa, the reductions will likely keep strengths within this range[10][21]. The 28-day compressive strength of R0 (control) is expected around 25–30 MPa, with R10 perhaps 5–10 % lower, and R20 up to 15–20 % lower, consistent with previous LWAC results. The early (7-day) strength of RHA mixes may lag behind control due to slower pozzolanic reaction, while at 28+ days the RHA can contribute to C–S–H formation. LECA's use inherently lowers strength compared to normal aggregate (as reported in numerous studies[14][15]), but this tradeoff is acceptable for lightweight panels.

Tensile and Flexural Behavior

Kenaf fibres are expected to significantly enhance the tensile and flexural performance of the panels. Natural fibres bridge cracks and increase post-peak toughness[9]. Lam and Yatim found that with appropriate fibre content and length, KFRC's flexural and indirect tensile strengths *increased* over plain concrete, even as compressive strength remained similar[4].

Agboola et al. reported that 0.5 % kenaf fibre in foamed concrete maximized split tensile strength (2.41 MPa vs control 1.68 MPa)[5]. Likewise, research on similar biomass fibres (e.g. hemp, sisal) consistently shows higher energy absorption and tensile capacity[9]. The RHA in these mixes will also act as a fine filler, refining the matrix; this can improve bond and allow fibres to work more effectively. Therefore, RHA+KF mixes (especially R5–R15) should exhibit higher flexural strength and toughness than the control R0 mix, up to the fibre's limit. The stress–strain response in bending is anticipated to show multiple cracking and greater deformation at peak load. In practical terms, cracks in panels with kenaf fiber will be finer and better controlled, which is beneficial for wall panels requiring ductility.

The tensile-to-compressive strength ratio is expected to increase with fibre addition. For R0 (no fibre), typical LWAC shows splitting/compressive ratios around 0.10–0.13[26]. With 0.5 % kenaf, this ratio could approach ~0.15. Overall, toughness (area under stress–strain) will be higher in fibrous mixes.

Durability and Moisture Behavior

RHA generally refines the pore structure and reduces permeability[12]. A dense C–S–H gel forms as RHA reacts with CH, closing capillary pores. Consequently, RHA mixes often show lower chloride ion penetration and better sulfate resistance (where tested). We expect the R5–R15 mixes to have reduced water absorption and sorptivity relative to R0 due to this refinement[12]. However, RHA itself is porous; if replacement is too high, micro-voids from unfilled pores could slightly increase absorption[17].

Kenaf fibres, on the other hand, are hygroscopic and can increase water uptake. Agboola et al. found that adding 0.25–1.0 % kenaf fibres raised water absorption of foamed concrete: control was 2.46 % (at 28d), while 1 % KF mix absorbed 2.72 %[13]. Similarly, sorptivity (capillary absorption rate) increased with fibre content[27]. The fibres create micro-channels, and their lumen can draw water by capillarity. Thus, RHA-fibre mixes may show higher initial absorption than plain LWAC, offsetting some RHA benefits. LECA itself also contributes to absorption: it can hold internal water (hence the extra mixing water needed[6]) and may release it under drying.

In summary, we expect:

- **Water absorption:** Slight increase with kenaf content[13], somewhat mitigated by RHA densification[12]. Overall values likely in the low single digits (%) for 28-day cured specimens.

- **Sorptivity:** Likely higher in mixes with fibre (e.g. 0.5–1.0 % KF mixes)[27], following Agboola's trend of sorptivity ∝ fibre%. RHA's effect is too slow sorptivity, but fibre likely dominates in our case.

- **Moisture sensitivity:** Drying may significantly stiffen LWAC. Buildings et al. found oven-dried LECA concrete had ~26% higher modulus than moist[10]. Thus, panels must be properly cured and possibly sealed.

Overall durability is judged acceptable for wall panels, but we anticipate recommending protective coatings or admixtures if exposure is severe. RHA's pozzolanic action should improve long-term durability (reduced CH, refined pore size)[12]. Fibre degradation in alkaline concrete is a potential issue; thus, alkaline treatment of kenaf[20] and thorough mixing are employed to mitigate this.

Microstructure

SEM imaging of fractured surfaces is expected to show good bond between treated kenaf fibers and the cementitious matrix. The fibers act as crack bridges: micrographs from related studies show fibres spanning microcracks[9]. RHA particles should be largely consumed by 28 days, integrated into the C–S–H network; unreacted RHA would appear as remnants. The interfacial transition zone (ITZ) around LECA might still be slightly porous but improved by RHA filling. XRD may reveal a reduction in portlandite (CH) peaks in RHA mixes, indicating pozzolanic consumption. Qualitatively, the matrix of RHA mixes should be denser than R0.

Sustainability Considerations

Using RHA and kenaf fibre greatly enhances sustainability. RHA is an abundant agricultural waste; its use "solves the problem of agricultural waste disposal"[16]. Every ton of RHA replacing cement reduces embodied CO_2 (cement produces ~0.9 tCO_2 per ton). Kenaf is renewable and biodegradable[3], with low production energy. LECA is manufactured by heating clay, but its use as an aggregate can reduce overall concrete volume: building with LECA-concrete can lower structural weight and material demands (e.g. up to 20% savings in reinforcement steel[28]). Collectively, RHA–kenaf–LECA concrete panels have a lower carbon footprint than normal concrete: less cement, less dense aggregate (reducing transport and embodied energy), and bio-based fibres. The trade-off (slightly lower strength) is offset by these environmental benefits[16][3][28].

Conclusions

This paper outlines an original research style experimental program for lightweight concrete wall panels with RHA and kenaf fibre. Mix designs (R0–R20) have been proposed with detailed rationale: RHA is varied 0–20% as cement replacement, kenaf fibre fixed at 0.5% vol, LECA as coarse aggregate, and water/binder ≈0.41 with SP. Standard tests (ASTM/IS) are planned for mechanical (compressive, tensile, flexural) and durability (absorption, sorptivity, microstructure). Based on literature, we expect that moderate RHA additions (up to ~10–15%) will maintain compressive strength similar to control[2][8], while fiber reinforcement will enhance ductility and crack resistance[4][9]. High RHA (15–20%) and fiber may reduce strength but improve toughness and durability through pore refinement. Durability tests are anticipated to show lower permeability due to RHA[12], but increased water absorption from the fibrous and porous aggregates[6][13]. In sum, RHA–kenaf–LECA concrete is expected to be a low-density, moderately strong, and tougher material with enhanced sustainability. These insights—fully backed by prior studies—provide a basis for future experimentation and optimization of eco-friendly concrete panels.

References:

[1] [2] [7] [12] [16] [17] [18] [19] Frontiers | Effect of Incorporation of Rice Husk Ash Instead of Cement on the Performance of Steel Fibers Reinforced Concrete

https://www.frontiersin.org/journals/materials/articles/10.3389/fmats.2021.665625/full

[3] Strength and Durability of Kenaf Fiber Reinforced Concrete for Marine Structures | Request PDF

https://www.researchgate.net/publication/357165228_Strength_and_Durability_of_Kenaf_Fiber_Reinforced_Concrete_for_Marine_Structures

[4] [20] (PDF) Mechanical properties of kenaf fiber reinforced concrete with different fiber content and fiber length

https://www.researchgate.net/publication/287402647_Mechanical_properties_of_kenaf_fiber_reinforced_concrete_with_different_fiber_content_and_fiber_length

[5] [8] [13] [23] [25] [27] (PDF) Durability Performance of Kenaf Fibre Foamed Concrete Produced with Rice Husk Ash as Partial Replacement for Cement

https://www.researchgate.net/publication/390411866_Durability_Performance_of_Kenaf_Fibre_Foamed_Concrete_Produced_with_Rice_Husk_Ash_as_Partial_Replacement_for_Cement

[6] [14] [21] [22] [24] [26] (PDF) Mechanical properties of lightweight expanded clay aggregate (LECA) concrete

https://www.researchgate.net/publication/364169565_Mechanical_properties_of_lightweight_expanded_clay_aggregate_LECA_concrete

[9] (PDF) Assessment of Impact Resistance Properties of Rice Husk Ash Based Kenaf Fibrous Concrete for Sustainable Construction

https://www.researchgate.net/publication/363837463_Assessment_of_Impact_Resistance_Properties_of_Rice_Husk_Ash_Based_Kenaf_Fibrous_Concrete_for_Sustainable_Construction

[10] [28] Physical and Mechanical Properties of Lightweight Expanded Clay Aggregate Concrete

https://www.mdpi.com/2075-5309/14/6/1871

[11] [15] imanagerpublications.com

https://imanagerpublications.com/assets/htmlfiles/JSTE7(4)December-February201915473.html