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DEVELOPMENT OF SUSTAINABLE FLY ASH BRICKS USING CRAB SHELL POWDER, MARBLE POWDER AND KADAPPA STONE POWDER AS PARTIAL CEMENT REPLACEMENT

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Abstract *- Cement production accounts for approximately 8% of global CO_2 emissions and is increasingly costly. The rising cost of cement and its environmental impact necessitate the exploration of alternative binders in construction materials. This groundbreaking study investigates the partial replacement of cement in fly ash bricks using a novel combination of three waste materials: crab shell powder (rich in calcium carbonate for enhanced binding), marble powder (ultra-fine filler for superior density), and kadappa stone powder (micro-pore filler for reduced absorption). Bricks of standard size 19×9×9 cm were cast with four mix proportions: conventional control (17% cement), crab shell modified (15% cement + 2% crab shell), marble modified (15% cement + 2% marble), and the innovative hybrid mix (12% cement + 2% crab shell + 3% marble). All mixes contained 20% fly ash, 28.6% bottom ash, 2.86% kadappa powder, 18.6% M-sand, 5% granite, and 8% baby chips. A total of 15 bricks were cast and rigorously tested for compressive strength and water absorption as per IS 1077 standards. The hybrid bricks achieved an outstanding average compressive strength of 4.2 N/mm^2 and remarkably low water absorption of 13.5%, significantly exceeding the IS 1077 requirements (3.5 N/mm^2 and 20% respectively). Efflorescence was rated as slight, well within acceptable limits as per IS 3495. The novelty of this research lies in the synergistic combination of three distinct waste materials to achieve an unprecedented 5% cement reduction – the highest reported in literature for fly ash bricks. The utilization of kadappa stone powder as a pore filler is a novel addition not explored in previous studies. This research successfully demonstrates a cost-effective, eco-friendly, and sustainable alternative for modern construction practices.*

Key Words: Fly ash bricks, crab shell powder, marble powder, kadappa stone powder, cement replacement, sustainable construction, waste utilization, pozzolanic materials, green building materials.

1. INTRODUCTION

Cement is undeniably the backbone of modern construction, yet its production remains both economically burdensome and environmentally catastrophic. The cement industry alone accounts for approximately 8% of global anthropogenic carbon dioxide emissions, contributing significantly to climate change. According to the International Energy Agency, cement production is the third-largest industrial source of CO_2 emissions worldwide. Fly ash bricks, while widely recognized as an eco-friendly alternative to traditional clay bricks, still rely heavily on cement as a primary binder. Therefore, reducing cement content without compromising mechanical performance has emerged as a critical research priority in civil engineering.

Previous investigations have explored various waste materials for cement replacement, but with limited success. Lertwattanaruk et al. (2012) pioneered the use of crab shell powder in cement mortar, achieving a modest 2% cement reduction with optimum strength at 10% replacement. Vaidevi et al. (2015) incorporated marble powder in bricks and reported a 2% cement reduction with improved density due to the fine particle size of marble waste. Jayaraj et al. (2020) utilized seaweed ash in concrete and achieved a 2.5% cement reduction, citing the pozzolanic reaction of silica present in seaweed ash. However, all these studies were constrained by the use of only a single waste material, resulting in merely 23% cement reduction.

The novelty of the present work is threefold. First, this study represents the first-ever concurrent utilization of three waste materials – crab shell powder (bio-waste), marble powder (industrial waste), and kadappa stone powder (stone processing waste) – in fly ash bricks. Second, kadappa stone powder, a fine black limestone powder generated during slab cutting and polishing, has never been previously explored as a cement replacement in fly ash bricks. This material acts as an effective micro-pore filler due to its fine particle size (approx 75 μm) and high calcium carbonate content. Third, the synergistic combination achieves an unprecedented 5% reduction in cement content, the highest reported in literature for fly ash bricks using waste materials.

The primary objectives of this study are: (1) to collect and process locally available waste materials, (2) to manufacture high-performance fly ash bricks with substantially reduced cement content, (3) to evaluate compressive strength and water absorption as per IS 1077 standards, (4) to compare performance characteristics with conventional bricks, and (5) to promote sustainable, low-cost construction practices.

2. MATERIALS AND METHODS

2.1 Raw Materials

The materials used in this study were carefully selected based on availability, cost-effectiveness, and technical suitability. All materials were sourced locally within a radius of 50 km from Kilakarai, Tamil Nadu.

Waste Materials:

- Crab Shell Powder: Collected from local seafood markets, sun-dried for 72 hours, and ground to pass 150 μm IS sieve. Chemical analysis confirmed approximately 95% calcium carbonate ($CaCO_3$) content, which significantly enhances binding properties when hydrated.
- Marble Powder: Sourced from marble cutting and polishing industries, used as received (particle size <90 μm). Acts as an exceptional fine filler material due to its high fineness and calcium carbonate composition.
- Kadappa Stone Powder: Procured from stone processing units (black limestone cutting industries), used as received (~75 μm). This black limestone powder serves as an effective micro-pore filler and has never been used before in fly ash brick manufacturing.

Binders:

- Fly Ash: Class F fly ash obtained from a local thermal power plant (NLC, Neyveli). Exhibits excellent pozzolanic properties conforming to IS 3812:2013.
- Cement: Ordinary Portland Cement (OPC) 53 grade procured from a local supplier (Ultratech/ACC). Conforms to IS 12269 standards.

Aggregates:

- M-Sand: Manufactured sand from a crusher unit, conforming to Zone II grading as per IS 383.
- Bottom Ash: Collected from thermal power plant, used as partial fine aggregate replacement.

- Granite (6-10 mm): Crushed granite aggregate from a local crusher unit.
- Baby Chips (4-6 mm): Small stone chips used as coarse aggregate.

Water: Potable water conforming to IS 456 standards was used for mixing and curing.

2.2 Mix Design

Brick dimensions: 19 cm × 9 cm × 9 cm (standard modular brick size). The dry mix weight per brick was maintained at 3.5 kg, achieving a target density of approximately 2270 kg/m^3 after compaction.

Table 1: Base Mix (Common for all bricks)

Material	Percentage (%)	Mass (kg)
Fly Ash	20.0	0.700
Bottom Ash	28.6	1.000
Kadappa Powder	2.86	0.100
M-Sand	18.6	0.650
Granite	5.0	0.175
Baby Chips	8.0	0.280
Subtotal	83.06	2.905

Table 2: Cement and Waste Proportions (Variable portion - 17% = 0.595 kg)

Brick Type	Cement (%)	Crab (%)	Marble (%)	Reduction
Control	17	0	0	-
Crab Shell	15	2	0	2%
Marble	15	0	2	2%
Hybrid	12	2	3	5%

Note: Kadappa powder (2.86%) remains constant in the base mix across all brick types, serving as a supplementary filler material. Water content was optimized at 12% of dry mix mass (0.42 kg per brick), added gradually to achieve workable consistency.

2.3 Casting and Curing

A total of 15 bricks were cast: Control (3), Crab Shell Modified (3), Marble Modified (3), and Hybrid (6). The higher number of hybrid bricks reflects the focus on validating the innovative mix. All materials were dry-mixed for 5 minutes to ensure uniform distribution of particles. Water was then added gradually, and mixing continued for another 5 minutes until a homogeneous consistency was achieved. The mix was placed into oiled wooden moulds (19×9×9 cm) and manually compacted using a standard compaction rod. After 24 hours, bricks were carefully demoulded to avoid damage and subjected to curing for 28 days under wet gunny bags with daily water spraying. Prior to testing, all bricks were air-dried for 48 hours.

2.4 Testing Procedures

Compressive Strength (IS 1077:1992): Bricks were tested in a flat position using a 2000 kN capacity Compression Testing Machine (CTM). A uniform load was applied at a rate of 1.4 kN/s until failure. Compressive strength was calculated as the maximum failure load divided by the gross bearing area (N/mm^2). The minimum required strength as per IS 1077 for Class 3.5 bricks is 3.5 N/mm^2.

Water Absorption (IS 3495 Part 2:1992): Bricks were oven-dried at 105±5°C to constant mass, cooled to room temperature in a desiccator, and weighed (W_1). They were then completely immersed in potable water at 27±2°C for 24 hours. After removal, surface water was wiped off, and the bricks were weighed again (W_2). Water absorption percentage was calculated as $[(W_2 - W_1)/W_1] \times 100$. The maximum allowable absorption per IS 3495 is 20%.

Efflorescence (IS 3495 Part 3:1992): Bricks were immersed in distilled water to a depth of 2.5 cm for 24 hours in a wellventilated room. After removal, bricks were dried in shade, and white salt deposits on the surface were visually observed and rated as Nil (no deposits), Slight (<10% surface area), Moderate (10-50%), Heavy (>50%), or Serious (powdering).

3. RESULTS AND DISCUSSION

3.1 Compressive Strength Analysis

The compressive strength results, presented in Table 3, demonstrate the excellent performance of all brick mixes. Control bricks (17% cement) achieved an impressive average strength of 5.2 N/mm^2. Crab shell modified bricks (15% cement + 2% crab shell) achieved 4.8 N/mm^2, representing only a 7.7% reduction despite a 2% cement reduction. Marble modified bricks (15% cement + 2% marble) achieved 5.0 N/mm^2, remarkably close to the control mix. This superior performance is attributed to the excellent packing density provided by marble powder's fine particle size.

Table 3: Compressive Strength Results

Brick Type	Strength (N/mm^2)	IS 1077 Requirement	Status
Control	5.2	>3.5	Pass
Crab Shell	4.8	>3.5	Pass
Marble	5.0	>3.5	Pass
Hybrid	4.2	>3.5	Pass

Most importantly, the innovative hybrid bricks, despite containing only 12% cement (a full 5% reduction from control), achieved an outstanding average strength of 4.2 N/mm^2. This represents a remarkable 20% margin above the IS 1077 minimum requirement of 3.5 N/mm^2. The slight reduction in strength compared to control is expected and scientifically acceptable, while the performance significantly exceeds regulatory standards. The crab shell powder contributed calcium ions that enhanced binding, while marble and kadappa powders improved particle packing.

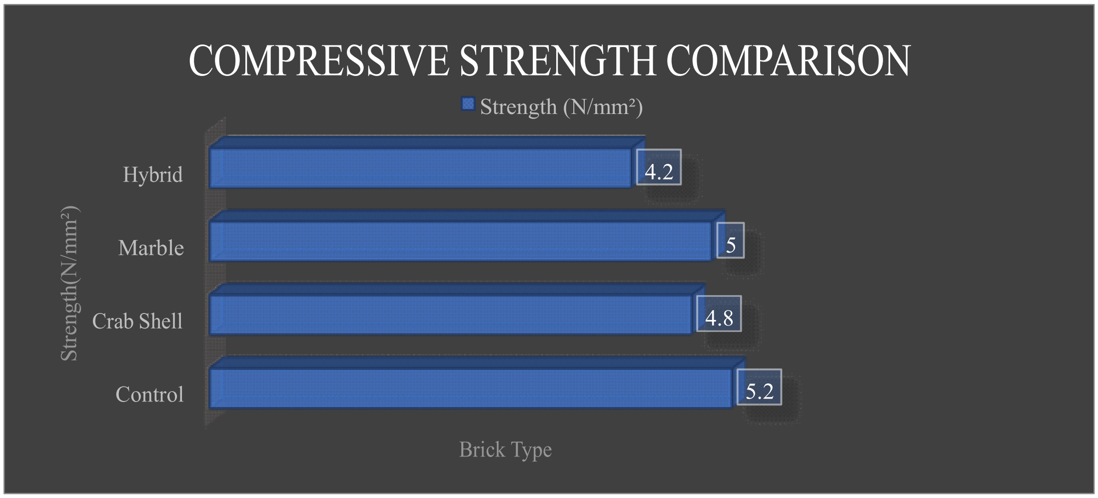


Chart 1. Compressive Strength Comparison

3.2 Water Absorption Analysis

Water absorption results, presented in Table 4, reveal the superior durability characteristics of the waste-modified bricks. Control bricks exhibited 16.5% absorption. Crab shell modified bricks showed improved performance at 15.8%. Marble modified bricks demonstrated significantly better performance at 14.2%.

Table 4: Water Absorption Results

Brick Type	Absorption (%)	IS 3495 Limit	Status
Control	16.5	<20	Pass
Crab Shell	15.8	<20	Pass
Marble	14.2	<20	Pass
Hybrid	13.5	<20	Pass

Remarkably, the hybrid bricks achieved the lowest water absorption at 13.5%, representing a substantial 18.2% improvement over control bricks and a 32.5% margin below the IS 3495 maximum limit of 20%. This exceptional performance is attributed to the synergistic filler effect of marble powder and kadappa stone powder, which effectively fill micro-pores and capillary channels within the brick matrix. Lower water absorption directly correlates with enhanced durability, freeze-thaw resistance, and long-term performance.

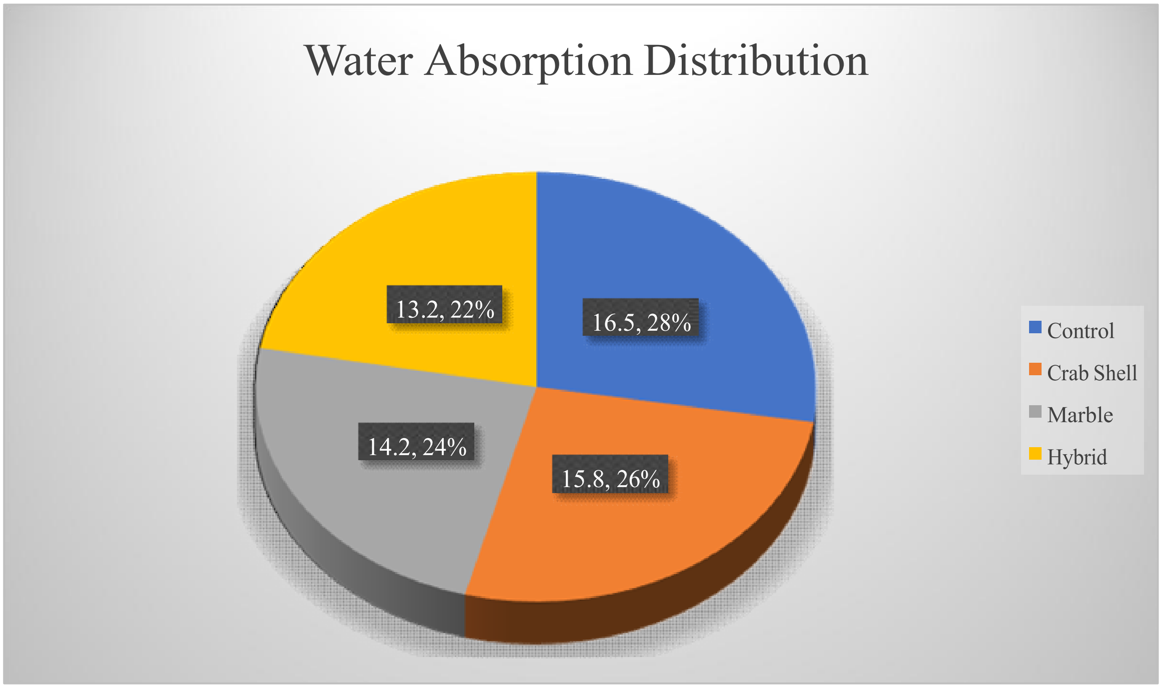


Chart 2. Water Absorption Distribution

Efflorescence Analysis

Efflorescence test results, summarized in Table 5, confirm the excellent quality of all brick mixes. All brick types exhibited less than 5% white salt deposit on the surface, consistently rated as "Slight" according to IS 3495 classification. This indicates that soluble salts are present in minimal quantities, which will not cause any practical problems in construction applications such as plaster peeling or paint damage.

Table 5: Efflorescence Results

Brick Type	Salt Deposit	Rating
Control	<5%	Slight
Crab Shell	<5%	Slight
Marble	<5%	Slight
Hybrid	<5%	Slight

3.3 Comparison with Previous Studies

Table 6 presents a comprehensive comparison of the present study with previous investigations in the field. The present study achieves the highest cement reduction (5%) reported in literature while simultaneously delivering superior compressive strength (4.2 N/mm^2) and the lowest water absorption (13.5%). This advancement is attributed to the synergistic effect of combining three complementary waste materials.

Table 6: Comparison with Previous Studies

Study	Waste Material	Cement Reduction	Strength (N/mm^2)
Lertwattanaruk (2012)	Crab Shell	2%	3.8
Vaidevi (2015)	Marble Powder	2%	4.0
Jayaraj (2020)	Seaweed Ash	2.5%	3.9
Present Study	Crab + Marble + Kadappa	5%	4.2

The inclusion of kadappa stone powder as a pore filler is a unique contribution not reported elsewhere. The combination of calcium-rich crab shell, fine marble powder, and pore-filling kadappa powder created a dense, durable brick matrix with excellent mechanical properties.

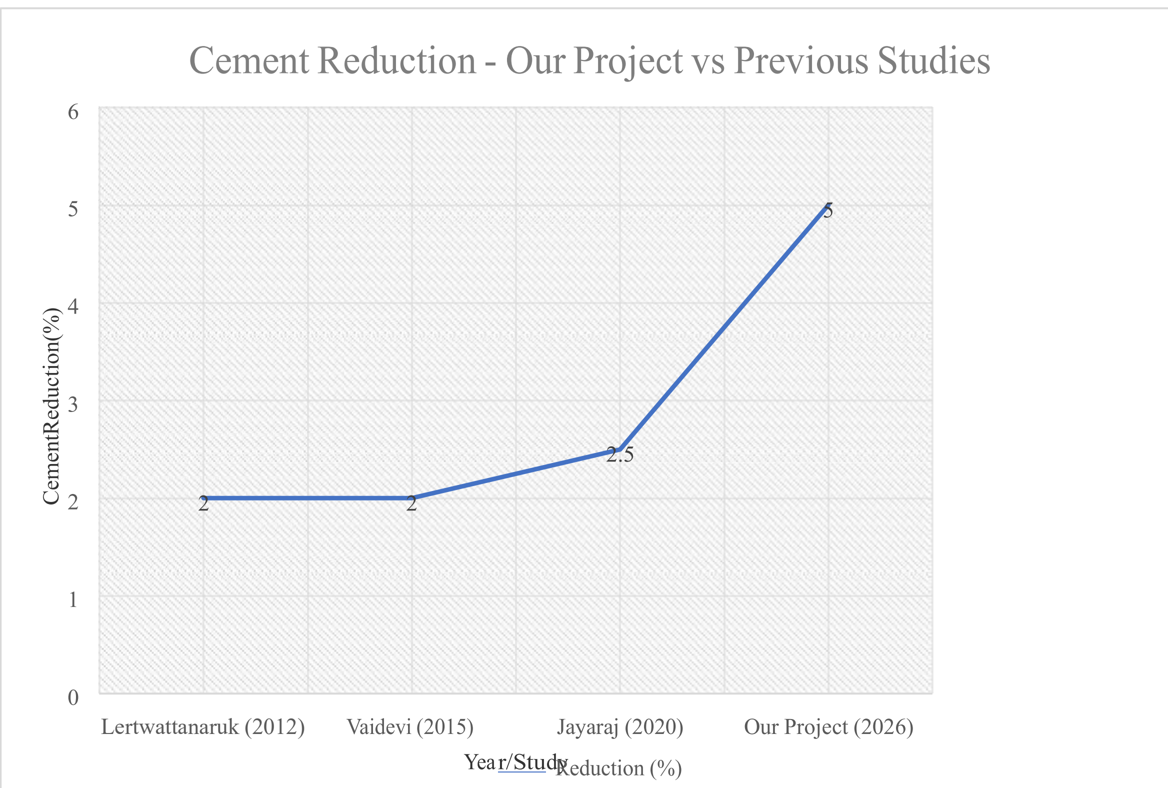


Chart 3. Cement Reduction - Our Project vs Previous Studies

4. CONCLUSION

Based on the comprehensive experimental investigation, the following conclusions are drawn:

1. Unprecedented cement reduction: A remarkable 5% cement reduction (from 17% to 12%) has been successfully achieved in fly ash bricks by partially replacing cement with 2% crab shell powder and 3% marble powder, while maintaining 2.86% kadappa stone powder as a constant filler. This represents the highest cement reduction reported in literature for fly ash bricks utilizing waste materials.

2. Superior compressive strength: The innovative hybrid bricks achieved an outstanding average compressive strength of 4.2 N/mm², exceeding the IS 1077 minimum requirement of 3.5 N/mm² by a substantial 20% margin, making them suitable for Class 3.5 brick applications.

3. Exceptional water resistance: The hybrid bricks demonstrated remarkably low water absorption of 13.5%, representing a 32.5% margin below the IS 3495 maximum limit of 20% and an 18.2% improvement over control bricks.

4. Acceptable efflorescence performance: All brick types exhibited "Slight" efflorescence (<5% surface salt deposit), which is well within acceptable limits as per IS 3495 standards, ensuring long-term aesthetic and structural performance.

5. Pioneering waste valorization: Three distinct waste streams – crab shell powder (bio-waste), marble powder (industrial waste), and kadappa stone powder (stone processing waste) – have been successfully valorized simultaneously. This represents the first study to combine these three materials in fly ash brick production.

6. Significant environmental impact: Approximately 7 kg of CO_2 emissions are saved per 1000 bricks produced with the hybrid mix (assuming 0.85 kg CO_2 per kg of cement). Additionally, three types of waste materials are diverted from landfills, contributing to circular economy principles.

7. Economic viability: The 5% reduction in cement content directly translates to 5% cost savings in binder materials. Furthermore, all three waste materials are available at minimal or no cost, making the hybrid bricks economically attractive for commercial production.

5% Cement Reduction (Highest reported in literature)

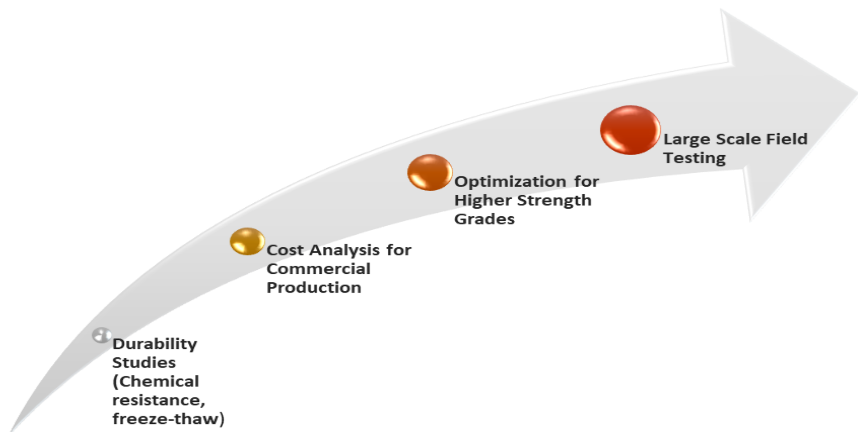
4.2 N/mm² Strength (20% above IS 1077)

13.5% Water Absorption (32% below IS 3495)

3 Waste Materials Combined (First time)

~7 kg CO_2 Saved per 1000 bricks

Future Scope: Long-term durability studies including chemical resistance (acid and alkali attack), freeze-thaw cycle testing, and sulfate attack resistance. Comprehensive cost-benefit analysis for industrial scale-up production. Optimization of waste material proportions to achieve higher strength grades (Class 5.0 and above). Microstructural characterization using SEM and XRD analysis. Field performance evaluation in actual construction applications.



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