

Investigation on the Manufacturing of Red Bricks Using Pozzolan Materials: Fly Ash, Gypsum, Lime Powder and Coconut Shell Powder

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Abstract - The construction industry is increasingly exploring sustainable alternatives to clay bricks to reduce environmental impact while maintaining structural performance. This study investigates manufacturing red bricks using red soil blended with pozzolanic and waste materials: fly ash, gypsum, lime powder and coconut shell powder (CSP), an agricultural waste product used as a partial fine aggregate replacement. Red soil from Kudthini, Ballari district, Karnataka, was characterized for specific gravity, moisture content, Atterberg limits, particle size distribution, Proctor compaction and unconfined compressive strength. Three brick mixes were prepared with a constant proportion of fly ash (32%), gypsum (16%) and lime powder (3%), while CSP was varied at 4%, 7% and 10% by weight, with red soil making up the remainder. Bricks were tested for compressive strength using a compression testing machine. The mix with 4% CSP achieved the highest average compressive strength of 8.585 N/mm², decreasing to 7.595 N/mm² and 5.585 N/mm² as CSP increased to 7% and 10%, indicating an inverse relationship between CSP content and strength, with a corresponding reduction in brick weight. The findings demonstrate that red bricks made with fly ash, gypsum, lime powder and moderate coconut shell powder offer a technically viable, low-cost, sustainable alternative to clay bricks.

Key Words: Pozzolan materials, red bricks, fly ash, coconut shell powder, compressive strength, sustainable construction.

1. INTRODUCTION

The construction industry has witnessed a significant shift towards sustainability in recent years, as conventional building materials such as clay bricks and cement concrete are associated with substantial carbon emissions, energy-intensive firing processes and depletion of natural topsoil. Researchers and practitioners are therefore exploring alternative raw materials, particularly industrial by-products and agricultural waste, that can reduce the environmental footprint of brick manufacturing without compromising structural performance.

Pozzolan materials are siliceous and aluminous substances that, in finely divided form and in the presence of moisture, react chemically with calcium hydroxide to form compounds possessing cementitious properties. This reaction, historically exploited by the Romans in structures such as the Pantheon and the aqueducts, forms the basis of many modern supplementary cementitious materials. In brick manufacturing, incorporating pozzolan by-products such as fly ash, gypsum and lime can improve compressive strength,

reduce permeability and enhance durability, while simultaneously providing a productive outlet for industrial waste.

Fly ash, a by-product of coal combustion in thermal power plants, is rich in silica and alumina and contributes to strength gain through pozzolan reaction. Gypsum, a by-product of the phosphate fertilizer industry, offers useful binding properties, while lime powder improves the workability and cementitious behaviour of the mix. Coconut shell powder (CSP), an abundant agricultural waste in tropical regions, has been explored as a lightweight aggregate in concrete, but its performance as a partial soil replacement in brick manufacturing remains comparatively less studied.

The present study investigates the manufacture of red bricks using red soil blended with fly ash, gypsum, lime powder and varying proportions of coconut shell powder, with the aim of developing an eco-friendly, cost-effective brick that utilizes industrial and agricultural waste while meeting the minimum compressive strength requirements for structural masonry.

The specific objectives of the present investigation are:

- To develop a sustainable, eco-friendly brick using red soil blended with fly ash, gypsum, lime powder and coconut shell powder.
- To evaluate the index and engineering properties of the red soil used as the base material.
- To determine the compressive strength of bricks manufactured with varying coconut shell powder content and compare performance across mixes.
- To assess the influence of coconut shell powder content on brick weight and strength, and to identify a suitable proportion for structural application.

2. STUDY AREA

The red soil used in this investigation was collected from an open site at Kudthini, Ballari district, Karnataka, a semi-arid region of the Deccan Plateau underlain predominantly by lateritic and red soils formed from the in-situ weathering of granite-gneiss and associated basement rocks. Red soils of this region are typically granular to loamy in texture, well-drained, and derive their characteristic reddish-brown colour from the presence of iron oxides.

Soil samples were collected from an undisturbed patch of land free from vegetation and construction debris, so as to be representative of the naturally occurring red soil available in the locality. The material was air-dried and processed in the laboratory prior to characterization and use in brick

manufacturing. The other constituents used in the study — fly ash, gypsum and lime powder — were procured from local industrial suppliers, while coconut shell powder was obtained by grinding waste coconut shells, an agricultural residue generated abundantly in the coastal and semi-urban markets of the region.



Fig -1: Collection of red soil sample at the study site, Kudthini, Ballari district, Karnataka

3. LITERATURE REVIEW

Utilization of pozzolanic and agro-industrial waste materials in brick and concrete manufacturing has been widely investigated as a means of improving sustainability and reducing dependence on virgin raw materials.

Coconut shells, a major agricultural waste in tropical regions, pose significant disposal challenges owing to their abundance [1]. Prior studies have explored their potential as a lightweight aggregate in concrete: Gunasekaran et al. reported that replacing conventional coarse aggregate with coconut shell aggregate in concrete met ASTM strength requirements while offering long-term durability and reduced material cost [2], and subsequently demonstrated favourable mechanical and bond properties of coconut shell concrete [4]. Osei similarly reported promising compressive strength characteristics for coconut-shell-aggregate concrete [5], while Reddy et al. and Tukiman and Mohd examined coconut shell (and, in combination, palm kernel shell) as coarse aggregate replacements, reporting acceptable structural performance alongside the associated environmental and economic benefits of utilizing this waste stream [6], [7]. Osei and Jackson further extended this line of investigation to palm kernel shells as a coarse aggregate in concrete, corroborating the broader viability of agricultural shell wastes as construction aggregates [8]. Bamgboye and Jekayinfa examined the energy consumption pattern of coconut processing operations, providing useful context on the availability and processing energy of coconut shell waste as a by-product stream [3].

Collectively, this body of literature indicates that shell-based agricultural wastes such as coconut shell can be successfully incorporated into cementitious and clay-based construction materials, generally at the cost of some reduction in strength with increasing replacement level, but with clear benefits in terms of weight reduction, waste utilization and cost. Most previous work, however, has focused on coconut shell as a coarse aggregate in concrete rather than as a fine constituent in fired or unfired brick manufacturing blended with other pozzolanic by-products such as fly ash, gypsum and lime. The

present study addresses this gap by evaluating red soil bricks incorporating fly ash, gypsum and lime powder together with varying proportions of coconut shell powder.

4. DATA AND METHODOLOGY

The materials used in the present investigation, their properties, the brick mix proportions, and the test methods followed are described in this section.

4.1 Materials

Red soil collected from Kudthini, as described in Section 2, was air-dried and used as the primary base material for brick manufacturing. The soil is granular to sandy in texture (particle size approximately 50–2000 microns), red to brownish-red in colour due to the presence of iron oxides, and exhibits low inherent pozzolanic activity and low binding capacity on its own; binding occurs only when the soil is combined with lime and other pozzolanic constituents. The index and engineering properties of the soil, determined as per relevant IS codes, are summarized in Table 2.

Coconut shell powder (CSP), an agricultural waste product, is granular in texture (particle size approximately 50–2000 microns) and exhibits moderate-to-high pozzolanic reactivity when combined with lime, although it does not show significant pozzolanic activity on its own; its main functional contribution in the brick mix is as a lightweight filler that reduces overall brick weight and improves thermal insulation. Fly ash, a by-product of coal combustion, is rich in silica and alumina and imparts good pozzolanic reactivity, contributing to strength gain, reduced permeability and improved thermal resistance. Gypsum contributes useful binding characteristics and, combined with lime, assists in the formation of cementitious calcium-silicate-hydrate (C–S–H) products that densify the brick microstructure. Lime powder acts primarily as a binder that reacts with the pozzolanic constituents to improve overall workability and strength development. A qualitative summary of the properties of these constituents is presented in Table 1.



Fig -2: Raw materials used in brick manufacturing — (a) coconut shell powder, (b) fly ash, (c) lime powder, (d) gypsum

Table -1: Qualitative properties of pozzolanic constituents used in the brick mix

Material	Appearance	Pozzolanic activity	Primary role
Red soil	Granular/sandy, red-brown, 50–2000µm	Low	Base material
CSP	Fine granular, brown, 50–2000µm	Mod.–high (w/ lime)	Lightweight filler
Fly ash	Fine powder, rich in silica/alumina	High	Pozzolanic binder
Gypsum	Fine powder	Moderate	Binder
Lime powder	Fine powder	Activator/binder	Binder

Table -2: Index and engineering properties of red soil

Property	Value	Test standard (IS code)
Specific gravity, G	2.56	IS 2720 (Pt.III/Sec.1):1980
Natural moisture content (%)	6.37	Oven-drying method
Liquid limit, w _L (%)	38.0	IS 2720 (Pt.V):1985
Plastic limit, w _P (%)	9.38	IS 2720 (Pt.V):1985
Plasticity index, IP (%)	28.62	—
Coefficient of uniformity, Cu	22.5	IS 2720 (Pt.IV):1985
Fines (silt + clay) (%)	1.37	IS 2720 (Pt.IV):1985
Max. dry density (g/cm ³)	2.00	IS 2720 (Pt.VII):1983
OMC (%)	10.07	IS 2720 (Pt.VII):1983
UCS (kg/cm ²)	1.20	IS 2720 (Pt.X):1991

4.2 Mix Design

Three brick mixes were prepared, each containing a constant proportion of fly ash (32%), gypsum (16%) and lime powder (3%) by weight, while the coconut shell powder content was varied at 4%, 7% and 10%, with red soil making up the balance of each mix (45%, 42% and 39%, respectively). Two trial batches were prepared for each mix. The complete mix proportions, expressed both as percentage and as weight per batch (total batch weight of approximately 2.3–2.9 kg), are summarized in Table 3. The constituents were dry-mixed thoroughly, moistened to the required consistency, moulded into standard brick dimensions, air-dried, and thereafter tested for compressive strength.

Table -3: Mix proportions of brick samples (percentage and weight per batch)

Constituent	S1 (%)	S1 (kg)	S2 (%)	S2 (kg)	S3 (%)	S3 (kg)
Red soil	45	1.314	42	1.054	39	0.902
Fly ash	32	0.934	32	0.803	32	0.740
Gypsum	16	0.467	16	0.401	16	0.371
Lime powder	3	0.088	3	0.075	3	0.069
CSP	4	0.117	7	0.176	10	0.231
Total batch wt.	100	2.920	100	2.510	100	2.313

4.3 Test Methods

Specific gravity of the red soil was determined by the density-bottle method as per IS 2720 (Part III/Sec.1)–1980. Natural moisture content was determined by the oven-drying method. Atterberg limits (liquid limit and plastic limit) were determined using the Casagrande apparatus and the thread-rolling method, respectively, in accordance with IS 2720 (Part V)–1985. Dry sieve analysis was carried out as per IS 2720 (Part IV)–1985 to obtain the particle size distribution and the coefficient of uniformity (Cu) and coefficient of curvature (Cc) of the soil.

Standard Proctor compaction tests were performed as per IS 2720 (Part VII/VIII)–1980/83 to determine the maximum dry density (MDD) and optimum moisture content (OMC) of the red soil. Unconfined compressive strength (UCS) of the soil was determined as per IS 2720 (Part X)–1991, with load applied axially at a constant rate of strain until failure, and the corresponding stress recorded at each strain increment.

Compression tests on the manufactured bricks were carried out using a compression testing machine (CTM) as per IS 3495. Prior to testing, each brick was soaked in water for 24 hours and then surface-dried; its dimensions were measured to compute the loaded cross-sectional area, and the brick was placed between plywood packing sheets to ensure uniform

load distribution. Load was applied gradually until failure, and the compressive strength was calculated as the maximum load divided by the loaded cross-sectional area, expressed in N/mm².

5. RESULTS AND DISCUSSION

5.1 Properties of Red Soil

The properties of the red soil determined in the present study are summarized in Table 2. The soil exhibited a specific gravity of 2.56, indicating the absence of significant organic matter (specific gravity greater than 2) and the absence of unusually heavy mineral content (specific gravity less than 3). The natural moisture content was found to be 6.37%. The liquid limit and plastic limit were determined as 38% and 9.38%, respectively, giving a plasticity index of about 28.6%; since the natural moisture content is well below the liquid limit and the toughness index exceeds unity, the soil behaves as a relatively stiff, cohesive material that does not crumble easily.

Table -4: Dry sieve analysis of red soil

Sieve (mm)	Wt. Ret. (g)	% Ret.	Cum. % Ret.	% Finer
4.75	285.74	28.57	28.57	71.43
2.36	176.96	17.70	46.27	53.73
1.18	233.16	23.32	69.59	30.41
0.6	76.62	7.66	77.25	22.75
0.425	90.82	9.08	86.33	13.67
0.3	32.00	3.20	89.53	10.47
0.15	57.00	5.71	95.24	4.76
0.075	33.92	3.39	98.63	1.37
Pan	13.72	1.37	100.00	0.00



Fig -3: Particle size distribution (grain size) curve of red soil

Figure 3 presents the particle size distribution (grain size) curve of the red soil obtained from dry sieve analysis (Table 4). From the curve, D₁₀, D₃₀ and D₆₀ were found to be 0.12 mm, 1.1 mm and 2.7 mm, respectively, giving a coefficient of uniformity (Cu) of about 22.5, indicating a well-graded soil. The percentage of fines (silt and clay fraction passing the 0.075 mm sieve) was found to be about 1.4%, confirming the predominantly granular, sandy nature of the red soil.

5.2 Compaction Behaviour

Table -5: Standard Proctor compaction test results for red soil

Trial no.	1	2	3	4	5	6
Water content (%)	7.07	8.47	9.56	9.74	10.07	15.29
Dry density (g/cm ³)	1.78	1.87	1.94	1.97	2.00	1.84

The standard Proctor compaction test results (Table 5) indicate a maximum dry density of 2.00 g/cm³ at an optimum moisture content of about 10.1%, beyond which the dry density reduced with further increase in water content. The unconfined compressive strength of the untreated red soil was found to be about 1.20 kg/cm² (approximately 0.6 kg/cm² shear strength), indicating a soil of medium consistency, consistent with its classification as a granular, low-plasticity material.

5.3 Compressive Strength of Manufactured Bricks



Fig -4: Manufactured brick specimen prepared from red soil, fly ash, gypsum, lime powder and coconut shell powder



Fig -5: Compressive strength testing of brick specimen using a compression testing machine

Table -6: Mix proportions and compressive strength of manufactured brick samples

Sample	Red soil (%)	Fly ash (%)	Gypsum (%)	Lime (%)	CSP (%)	Avg. strength (N/mm ²)
1	45	32	16	3	4	8.585
2	42	32	16	3	7	7.595
3	39	32	16	3	10	5.585

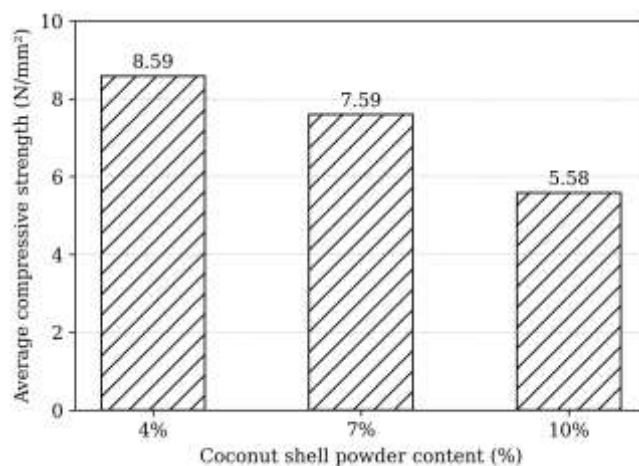


Fig -6: Variation of average compressive strength of manufactured bricks with coconut shell powder (CSP) content

Table 6 summarizes the mix proportions and average compressive strengths obtained for the three brick mixes tested. The mix containing 4% coconut shell powder (and 45% red soil) achieved the highest average compressive strength of 8.585 N/mm², comfortably exceeding the IS 3495 minimum requirement of 3.5 N/mm² for common building bricks and approaching the 10 N/mm² threshold specified for first-class bricks. As the coconut shell powder content was increased to 7% and 10% (with a corresponding reduction in red soil content to 42% and 39%), the average compressive strength decreased to 7.595 N/mm² and 5.585 N/mm², respectively (Fig. 6).

This trend indicates an inverse relationship between coconut shell powder content and compressive strength, attributable to the lower inherent strength and binding capacity of the lightweight, fibrous CSP particles compared with the red soil matrix; as CSP content increases, the proportion of the stronger soil-pozzolan matrix correspondingly decreases, reducing the overall load-bearing capacity of the brick. At the same time, the substitution of denser soil with lightweight CSP reduces the overall weight of the brick and is expected to improve its thermal insulation behaviour, though this was outside the scope of the physical tests performed. Even at the highest CSP content investigated (10%), the average compressive strength of 5.585 N/mm² remained well above the minimum requirement for common building bricks, suggesting that CSP contents in the range of 4–10% can be used to proportion bricks for different structural grades depending on the strength required, with lower CSP content favouring higher-grade structural applications and higher CSP content favouring lightweight, non-load-bearing applications.

6. CONCLUSIONS

The following conclusions are drawn from the experimental investigation on manufacturing red bricks using red soil from Kudthini, Ballari district, blended with fly ash, gypsum, lime powder and coconut shell powder:

- The red soil used in the study is a granular, low-plasticity material (specific gravity 2.56, liquid limit 38%, plasticity index about 28.6%, Cu about 22.5) with a maximum dry density of 2.00 g/cm³ at an optimum moisture content of about 10.1%, and is suitable as a base material for brick manufacturing when combined with pozzolanic additives.

- Bricks manufactured with a constant proportion of fly ash (32%), gypsum (16%) and lime powder (3%), together with red soil and coconut shell powder, achieved compressive strengths in the range of 5.585–8.585 N/mm², satisfying the IS 3495 requirement for common building bricks (≥ 3.5 N/mm²) across all mixes tested, and approaching first-class brick strength (≥ 10 N/mm²) at the lowest CSP content investigated.
- Compressive strength decreases progressively with increasing coconut shell powder content, from 8.585 N/mm² at 4% CSP to 7.595 N/mm² at 7% CSP and 5.585 N/mm² at 10% CSP, while brick weight decreases correspondingly, indicating a trade-off between strength and weight reduction that can be tuned to suit the intended structural or non-structural application.
- Utilizing fly ash, gypsum and lime powder as pozzolanic binders together with coconut shell powder as a lightweight agricultural-waste filler offers a technically viable, low-cost and environmentally sustainable alternative to conventional clay bricks, simultaneously addressing industrial by-product and agricultural waste disposal.
- Further studies involving water absorption, efflorescence, durability under wetting–drying cycles, and thermal insulation testing are recommended to fully characterize these bricks prior to large-scale field adoption.

Relation Using Light Compaction, IS 2720 (Part VII):1983. New Delhi, India: BIS, 1983.

- [13] Bureau of Indian Standards, Methods of Test for Soils, Part X: Determination of Unconfined Compressive Strength, IS 2720 (Part X):1991. New Delhi, India: BIS, 1991.
- [14] Bureau of Indian Standards, Specification for Burnt Clay Building Bricks, IS 3495 (Parts 1–4):1992. New Delhi, India: BIS, 1992.

REFERENCES

- [1] Coconut Development Board, Annual Report 2012–13. New Delhi, India: Government of India, 2013.
- [2] K. Gunasekaran, R. Annadurai, and P. S. Kumar, “Long term study on compressive and bond strength of coconut shell aggregate concrete,” *Constr. Build. Mater.*, vol. 28, no. 1, pp. 208–215, 2012.
- [3] A. I. Bamgboye and S. O. Jekayinfa, “Energy consumption pattern in coconut processing operations,” *Agric. Eng. Int.: CIGR J.*, n.d.
- [4] K. Gunasekaran and P. S. Kumar, “Mechanical and bond properties of coconut shell concrete,” *Constr. Build. Mater.*, vol. 25, no. 1, pp. 92–98, 2011.
- [5] D. Y. Osei, “Experimental assessment on coconut shells as aggregate in concrete,” *Int. J. Eng. Sci. Invention*, vol. 2, no. 5, 2013.
- [6] B. Damodhara Reddy, S. Aruna Jyothy, and F. Shaik, “Experimental analysis of the use of coconut shell as coarse aggregate,” *IOSR J. Mech. Civil Eng. (IOSR-JMCE)*, vol. 10, no. 6, Jan. 2014.
- [7] S. A. B. Tukiman and S. B. Mohd, “Investigate the combination of coconut shell and grind palm kernel to replace aggregate in concrete: a technical review,” in *Proc. Nat. Conf. Postgrad. Res. (NCON-PGR)*, 2009.
- [8] D. Y. Osei and E. N. Jackson, “Experimental study of palm kernel shells as coarse aggregate in concrete,” *Int. J. Sci. Eng. Res.*, vol. 3, no. 8, 2012.
- [9] Bureau of Indian Standards, Methods of Test for Soils, Part III/Sec.1: Determination of Specific Gravity, IS 2720 (Part III/Sec.1):1980. New Delhi, India: BIS, 1980.
- [10] Bureau of Indian Standards, Methods of Test for Soils, Part IV: Grain Size Analysis, IS 2720 (Part IV):1985. New Delhi, India: BIS, 1985.
- [11] Bureau of Indian Standards, Methods of Test for Soils, Part V: Determination of Liquid and Plastic Limit, IS 2720 (Part V):1985. New Delhi, India: BIS, 1985.
- [12] Bureau of Indian Standards, Methods of Test for Soils, Part VII: Determination of Water Content–Dry Density