

An Experimental Investigation On The Production Of Geopolymer Bricks Utilizing Industrial Waste Materials For Sustainable Construction

Aditya¹, Dr. Brijbhushan S²

¹Student, Department of Civil Engineering, VTU Regional Center, Kalaburagi, India
adityachavan888829@gmail.com

²Assistant professor, Department of Civil Engineering, VTU Regional Center, Kalaburagi, India

ABSTRACT

The production of conventional masonry units consumes natural resources and often requires energy-intensive firing or Portland-cement-based binders. This experimental investigation evaluates geopolymer bricks produced from industrial by-products, with particular emphasis on red mud, ground granulated blast-furnace slag (GGBS), lime, fly ash, and waste foundry sand. Preliminary lime-pozzolana cube trials were used to screen material combinations. The finalized brick composition comprised 80% red mud, 10% lime, and 10% GGBS, activated using a 2 M alkaline solution prepared from sodium hydroxide and sodium silicate. The binder-to-filler ratio was maintained at 1:5.5, and the specimens were produced by dry mixing, controlled activator addition, moulding, and moisture-retaining thermal curing. Brick performance was evaluated through dimensional, density, water-absorption, compressive-strength, and flexural-strength tests. X-ray diffraction (XRD) and scanning electron microscopy (SEM) were used for phase and microstructural assessment, while masonry prisms and triplets were tested to examine system-level compression, stiffness, and shear-bond behaviour. The bricks developed average compressive strengths of 5.67, 10.37, and 14.74 MPa at 3, 7, and 28 days, respectively, and average flexural strengths of 0.35, 0.46, and 0.66 MPa. Average dry density was 1620.1 kg/m³, detailed water absorption was 11.12%, prism strength was 3.95 MPa, and mean triplet shear-bond strength was 0.68 MPa. The results demonstrate the technical potential of industrial-waste geopolymer bricks for sustainable masonry construction.

Keywords: Geopolymer bricks; Red mud; GGBS; Industrial waste; Alkaline activation; Compressive strength; Masonry prism; Shear bond strength

I. INTRODUCTION

Masonry remains a fundamental construction system in which individual units and mortar act together to carry load and resist environmental exposure. Conventional fired-clay bricks and cement-based blocks provide reliable performance, but their production depends on high-temperature firing, natural resource extraction, and carbon-intensive binders. Sustainable masonry research therefore increasingly focuses on materials that reduce process energy and convert industrial residues into useful construction products.

Geopolymerization provides a route for chemically activating aluminosilicate-rich materials without relying entirely on Portland cement. Sodium hydroxide promotes dissolution of reactive silica and alumina, while sodium silicate supplies soluble silicate that supports gel formation. Calcium-rich materials such as GGBS and lime can additionally contribute to calcium silicate hydrate and calcium aluminosilicate hydrate phases, supporting early strength and matrix densification.

Red mud, fly ash, GGBS, and waste foundry sand are generated in large quantities by metallurgical, power, steel, and foundry industries. Their use in masonry units can reduce disposal requirements while replacing virgin raw materials. Red mud is particularly challenging because of its fine particle size and alkalinity, but its mineral constituents make it a potential geopolymer precursor when combined with compatible calcium-rich materials and an appropriate activator.

The present investigation develops and evaluates red-mud-based geopolymer bricks and extends the assessment from individual units to masonry prisms and triplets. The proof chain covers preliminary material screening, optimized mix selection, brick manufacture, physical and mechanical testing, microstructural verification, and structural-interface assessment.

II. OBJECTIVES

- To investigate different mix proportions and evaluate their influence on the mechanical behaviour of alternative masonry units.
- To characterize the mineralogical and microstructural properties of the developed geopolymer material using XRD and SEM.

- To assess the performance of individual bricks, masonry prisms, and triplets through physical and mechanical testing.
- To evaluate whether industrial by-products can be converted into masonry units with satisfactory strength, water absorption, stiffness, and bond behaviour.

III. LITERATURE SURVEY

Traditional lime-pozzolana systems provide the historical foundation for alternative masonry binders. Lime has been used with reactive siliceous materials to form durable cementitious products, and studies of surkhi-lime and lime-pozzolana systems have documented their strength development and long-term performance [1]-[4]. Research on hydration in lime-pozzolan cement further demonstrates that precursor chemistry and curing conditions strongly influence reaction products and mechanical behaviour [5].

Modern research extends these principles to low-molar alkaline activation and geopolymer composites. Alternative masonry binders incorporating soil, brick powder, pozzolanic materials, and low-molar activators have been investigated as substitutes for conventional cement systems [6]. Strength development in lime-pozzolana cement-soil-brick-powder geopolymer composites has also been reported, supporting the feasibility of waste-derived masonry matrices [7].

The reviewed work indicates that industrial and construction by-products can contribute to compressive strength, durability, ductility, and thermal performance when proportions and activation conditions are controlled. The present study builds on this foundation by combining a red-mud-rich final blend with GGBS, lime, and alkaline activation and by evaluating both unit-level and masonry-system performance.

IV. MATERIALS AND METHODOLOGY

Materials and activation system

The experimental programme considered limestone/lime, fly ash, GGBS, red mud, waste foundry sand, sodium hydroxide, and sodium silicate. Lime supplied calcium and alkalinity; fly ash and red mud contributed aluminosilicate phases; GGBS provided a calcium-rich latent hydraulic precursor; and waste foundry sand served as a fine filler in the broader material programme. The alkaline activator combined sodium hydroxide and sodium silicate.

Table 1. Functional role of the materials used

Material	Role in the experimental programme
Lime	Calcium-rich supplementary activator/binder constituent
Red mud	Principal industrial-waste precursor in the finalized brick
GGBS	Reactive calcium-aluminosilicate precursor
Fly ash	Pozzolanic precursor assessed during material development
Waste foundry sand	Industrial-waste fine filler considered in the masonry matrix
Sodium hydroxide	Provides the alkaline environment for precursor dissolution
Sodium silicate	Supplies soluble silica and supports geopolymer gel formation

Preliminary mixture screening

Preliminary 70 × 70 × 70 mm cube specimens were prepared to compare lime-GGBS and lime-fly-ash binder combinations with red sand or red mud. Three specimens were cast for each combination and tested after three days of wet curing. The binder-to-filler framework was maintained while the precursor composition was varied.

Table 2. Preliminary water-cured cube mixtures and compressive strength

Trial	Binder constituents (%)	Filler (%)	3-day strength (MPa)
Test 1	GGBS 10; Lime 10	Red sand 80	1.28
Test 2	Lime 10; Fly ash 10	Red sand 80	1.20
Test 3	GGBS 10; Lime 15	Red mud 70	1.75
Test 4	Lime 15; Fly ash 10	Red mud 70	1.90

Finalized mix, manufacturing, and curing

The finalized brick blend contained 80% red mud, 10% lime, and 10% GGBS and was activated using a 2 M alkaline solution. The binder-to-filler ratio used for the brick and masonry mortar system was 1:5.5. Sodium hydroxide and sodium silicate were blended approximately 24 hours before use so that the heat of dissolution could dissipate. Dry constituents were mixed for three minutes before gradual introduction of the activator.

The mixed material was placed in moulds in controlled layers, compacted, finished, and demoulded after initial hardening. Moisture-retaining thermal curing was achieved by sealing specimens and exposing them to daytime ambient heat while preventing moisture loss. Masonry prisms and triplets were produced using the same mortar proportion and were cured for 28 days before testing.



Fig. 1. Specimen casting and moisture-retaining thermal curing.

Testing programme

Table 3. Physical, mechanical, and microstructural tests

Assessment	Specimen / method	Reference stated in the study
Dimensional tolerance	Ten aligned bricks	IS 1077:1977
Dry density	Oven-dried brick mass and measured volume	IS 3495:1976
Water absorption	Oven-dry and saturated mass	IS 3495 (Part 2):1992
Brick compression	Axial loading to failure	IS 3495 (Part 1):1992
Brick flexure	Centre-point bending; effective length 170 mm	ASTM C348:2014
Phase identification	X-ray diffraction	XRD
Microstructure	Scanning electron microscopy	SEM
Prism compression/stiffness	28-day masonry prisms	Experimental evaluation
Triplet shear bond	Three-unit masonry triplets	Experimental evaluation

V. RESULTS AND DISCUSSION

Brick dimensions, density, and water absorption

Table 4. Physical characteristics of the geopolymer bricks

Property	Individual / measured values	Reported result
Dimensional tolerance	Ten-unit totals correspond to about $231 \times 105 \times 88$ mm per brick	Nominal summary: $230 \times 115 \times 90$ mm
Dry density	1621.17; 1639.13; 1600 kg/m ³	Average: 1620.1 kg/m ³
Water absorption	11.11%; 11.19%; 11.08%	Detailed average: 11.12%

The dimensional-tolerance measurements and the consolidated nominal dimensions are not identical: the ten-brick measurements correspond to approximately $231 \times 105 \times 88$ mm per unit, whereas the consolidated result table lists $230 \times 115 \times 90$ mm. Both are reported without substituting one dataset for the other. The density values were closely grouped around 1620.1 kg/m³, indicating reasonably consistent specimen compactness.

Water absorption ranged from 11.08% to 11.19%, producing a detailed average of 11.12%, below the stated 20% tolerance. A later consolidated result table lists 11.21%; the discussion uses the detailed specimen calculation while preserving the summary-table difference.

Brick compressive and flexural strength

Table 5. Compressive-strength development of geopolymer bricks

Age	Specimen strengths (MPa)	Average strength (MPa)
3 days	6.05; 5.29	5.67
7 days	10.24; 10.50	10.37
28 days	13.91; 15.57	14.74

Table 6. Flexural-strength development of geopolymer bricks

Age	Specimen strengths (MPa)	Average strength (MPa)
3 days	0.34; 0.36	0.35
7 days	0.45; 0.47	0.46
28 days	0.64; 0.68	0.66



Fig. 2. Experimental arrangements for brick compression and flexural testing.

Compressive strength increased substantially with curing age, rising from 5.67 MPa at three days to 14.74 MPa at 28 days. Flexural strength followed the same progressive trend and reached 0.66 MPa at 28 days. The gain is consistent with continuing alkaline activation and development of a denser geopolymer and calcium-bearing reaction network. The red-mud-rich matrix therefore developed both load-bearing capacity and measurable resistance to bending.

XRD and SEM observations

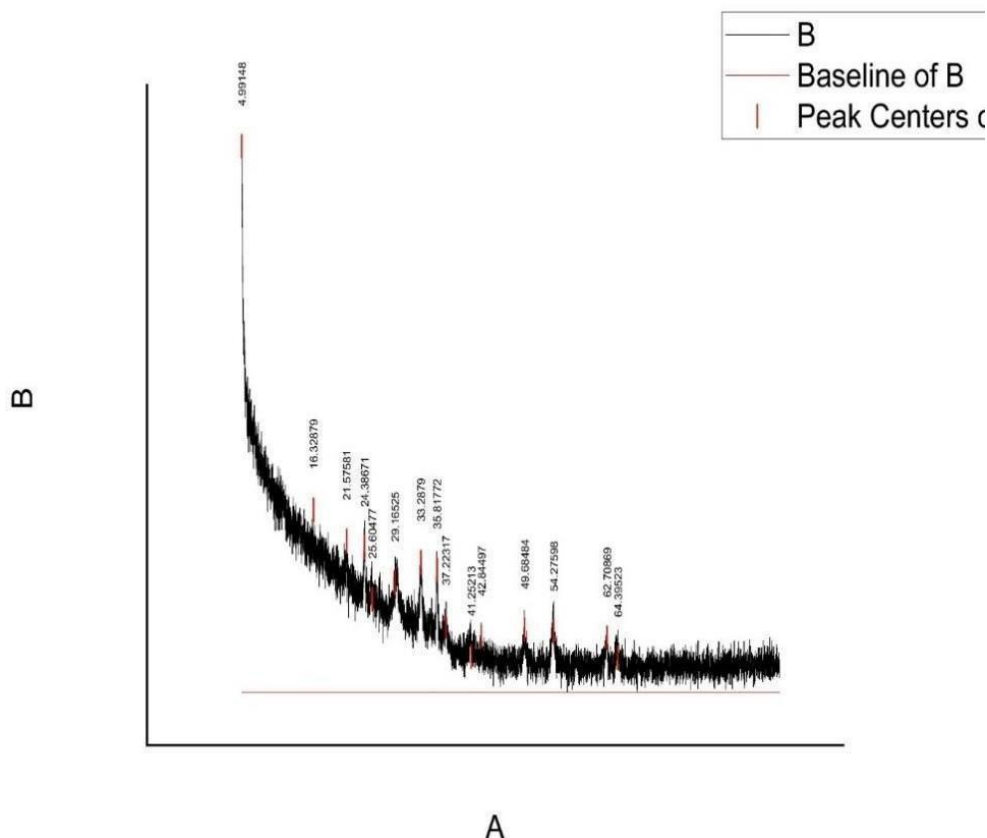


Fig. 3. X-ray diffraction pattern of the red-mud-GGBS-lime geopolymer brick.

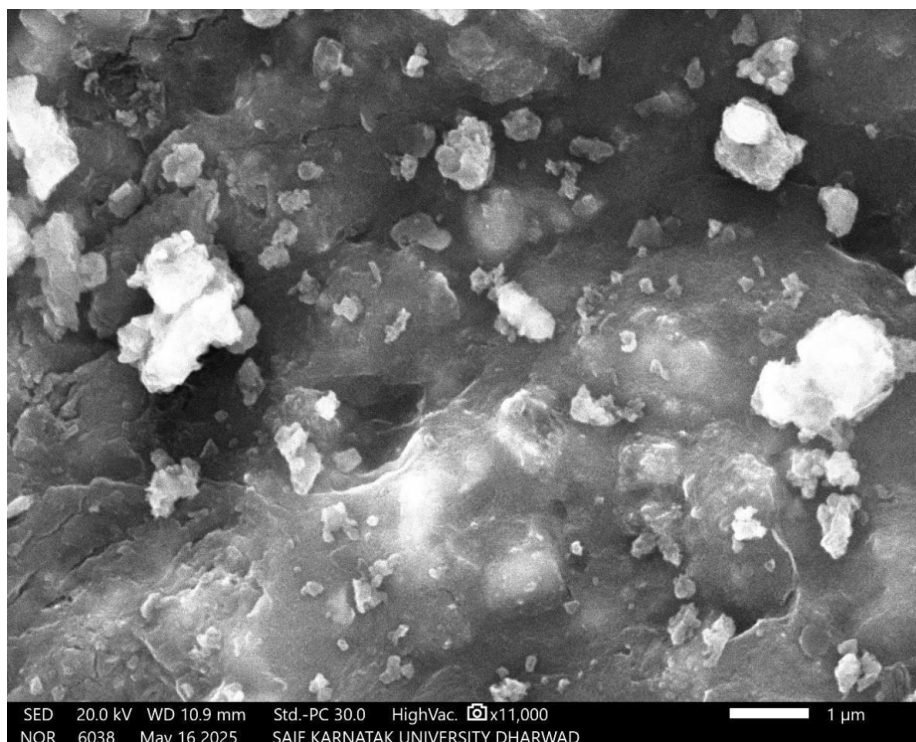


Fig. 4. Scanning electron micrograph of the geopolymer brick matrix.

The XRD interpretation identified a hydrated sodium aluminosilicate phase, confirming that the aluminosilicate precursors participated in geopolymerization. The diffractogram also contained multiple crystalline features superimposed on the broader reaction background. SEM examination showed a cohesive matrix containing embedded particles and geopolymer reaction products. Together, the phase and morphological observations support the mechanical strength development measured at later curing ages.

Masonry prism behaviour

Table 7. Compressive strength of 28-day masonry prisms

Specimen	Dimensions (mm)	Applied load (kN)	Measured strength (MPa)	Adjusted strength (MPa)
LGR 1	384 × 230 × 115	125.0	4.73	4.707
LGR 2	388 × 230 × 115	85.0	3.22	3.22

Table 8. Reported masonry-prism stiffness ranges

Parameter	LGR 1 (MPa)	LGR 2 (MPa)
Ultimate stress	4.74	3.23
Initial tangent modulus	900-1100	700-900
Secant modulus	180-230	140-190
Chord modulus	300-400	220-320

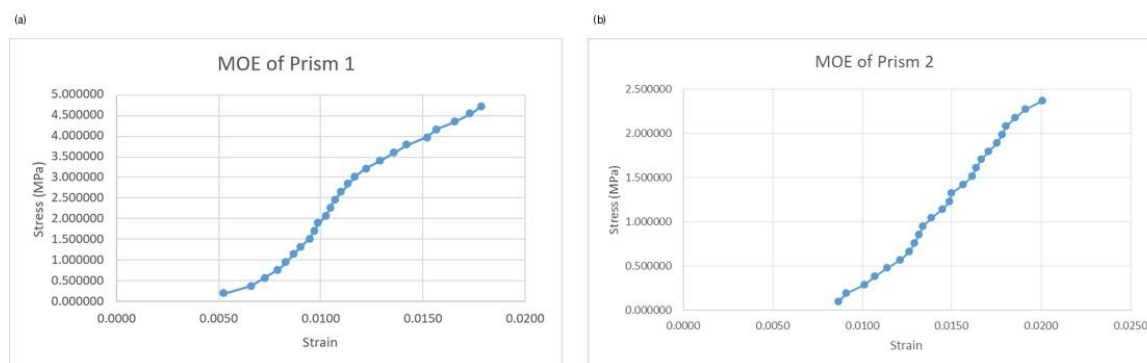


Fig. 5. Stress-strain responses of masonry prism specimens LGR 1 and LGR 2.

The adjusted prism strengths were 4.707 and 3.22 MPa, giving a reported mean compressive strength of 3.95 MPa. LGR 1 also exhibited higher tangent, secant, and chord-modulus ranges than LGR 2. The two stress-strain curves demonstrate the variability expected in masonry assemblies, where unit properties, mortar, interfaces, alignment, and local compaction collectively influence deformation.

Triplet shear-bond behaviour

Table 9. Triplet shear-bond-strength results

Specimen	Applied load (kN)	Shearing area (mm)	Shear adhesion strength (MPa)
LGR-1	13	230 × 115	0.51
LGR-2	23	230 × 115	0.85
LGR-3	19	230 × 115	0.69

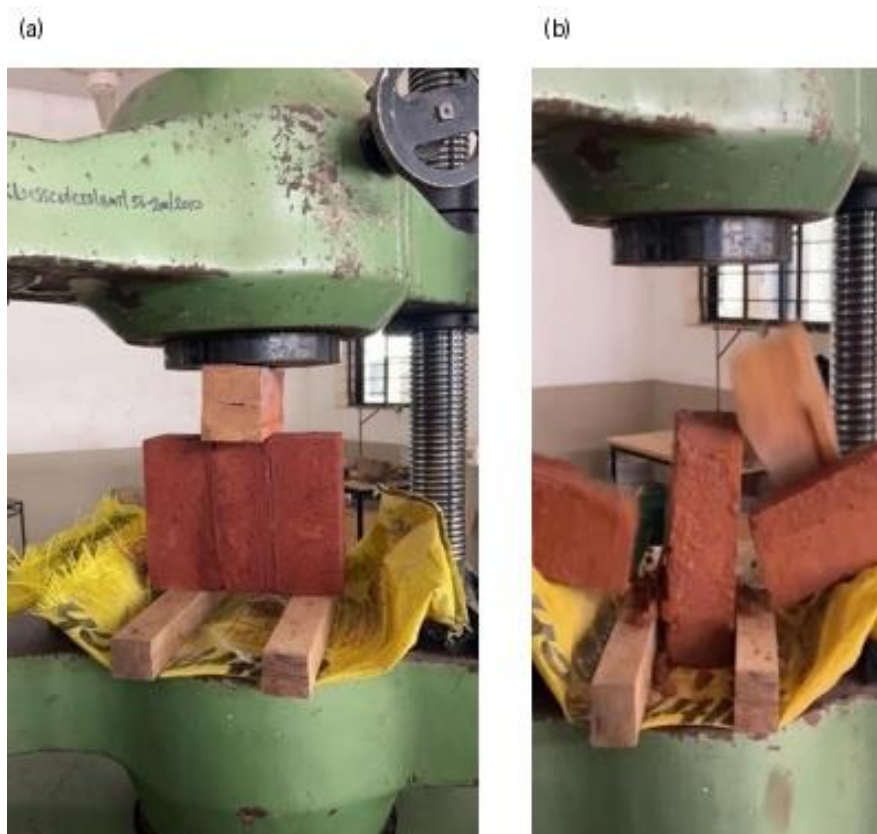


Fig. 6. Triplet specimens during shear-bond testing.

The triplet shear strengths ranged from 0.51 to 0.85 MPa. The mean value is stated as approximately 0.68-0.69 MPa and falls within the cited recommended range of 0.4-0.8 MPa. These results show that the geopolymer brick and compatible mortar developed a functional interface capable of transferring shear across masonry joints.

VI. CONCLUSION

- Industrial by-products were successfully incorporated into alkali-activated masonry materials, reducing dependence on conventional fired-clay or Portland-cement-based brick production.
- The finalized composition of 80% red mud, 10% lime, and 10% GGBS activated with a 2 M sodium-hydroxide/sodium-silicate solution developed progressive strength under thermal curing.
- Average brick compressive strength increased from 5.67 MPa at 3 days to 14.74 MPa at 28 days, while average flexural strength increased from 0.35 to 0.66 MPa.
- The bricks achieved an average dry density of 1620.1 kg/m³ and a detailed average water absorption of 11.12%, below the stated 20% tolerance.
- XRD indicated hydrated sodium aluminosilicate reaction products, and SEM showed a cohesive reaction matrix supporting the observed mechanical behaviour.
- The masonry prisms achieved a mean compressive strength of 3.95 MPa, and the triplets achieved a mean shear-bond strength of approximately 0.68-0.69 MPa.

- The combined unit, prism, triplet, and microstructural results support the use of red-mud-based geopolymer bricks as a technically viable sustainable masonry material.

REFERENCES

- [1] K. S. Jagadish, Sustainable Building Technologies. I. K. International Publishing House, 2019.
- [2] R. N. Iyengar, "Strength characteristics of surkhi lime mortar and concrete," Master's thesis, WRDM, 1972.
- [3] R. J. S. Spence and J. H. Sakula, "Lime-pozzolana as an alternative cementing material," in *Appropriate Technology in Civil Engineering*, pp. 117-119, Institution of Civil Engineers, London, 1981.
- [4] C. Shi, "Studies on several factors affecting hydration and properties of lime-pozzolan cements," *Journal of Materials in Civil Engineering*, vol. 13, no. 6, pp. 441-445, 2001.
- [5] F. M. Wegian, H. M. AlSaeid, and A. A. Alnaki, "Effect of lime and fly ash on the strength of cement composite mortars," *Australian Journal of Structural Engineering*, vol. 12, no. 1, pp. 59-67, 2011.
- [6] P. Revagond and S. Raghunath, "Alternative masonry binders and units using LP cement-soil-brick powder blend and low-molar alkaline solution," in *Calcined Clays for Sustainable Concrete*, pp. 849-859, Springer, 2020.
- [7] T. K. Jyothi, P. T. Jitha, S. Karthik Pattaje, K. S. Jagadish, R. V. Ranganath, and S. Raghunath, "Studies on the strength development of lime-pozzolana cement-soil-brick powder based geopolymer composites," *Journal of The Institution of Engineers (India): Series A*, vol. 99, no. 1, pp. 1-8, 2018.
- [8] K. S. Jagadish, *Structural Masonry*. I. K. International Publishing House, 2015.
- [9] Bureau of Indian Standards, IS 1077:1977.
- [10] Bureau of Indian Standards, IS 3495:1976.
- [11] Bureau of Indian Standards, IS 3495 (Part 1 and Part 2):1992.
- [12] ASTM International, ASTM C348:2014.