International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 10 Issue: 11 | Nov - 2026 SJIF Rating: 8.659 ISSN: 2582-3930

Sustainability Assessment and Experimental Performance of Concrete Masonry Blocks Incorporating Waste Fine Aggregate Materials

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Abstract

The present study investigates the use of fly ash, quarry dust and jarofix as partial replacements for natural river sand in concrete masonry blocks, with manufactured sand and lateritic waste also included in selected experimental and sustainability comparisons. Concrete mixes were studied at replacement levels of 0–100%, using 1:2:4 and 1:4:8 proportions and a selected water-to-cement ratio of 0.50. the experimental programmeed 28-day cube strength reached 9.41 MPa at 20% fly ash, 9.15 MPa at 30% quarry dust and 11.00 MPa at 30% jarofix. For 1:4:8 masonry blocks, the corresponding reported strengths were 6.62, 6.38 and 7.19 MPa, respectively, compared with 5.18 MPa for the control. Jarofix blocks also achieved a reported masonry prism efficiency of 81.45%. The study further examined density, water absorption, thermal conductivity, chemical exposure and a weighted sustainability index. The results indicate that selected waste-derived fine aggregates can improve block strength and reduce reliance on river sand. However, inconsistencies in mix identification, exposure-test reporting, material scope and sustainability-index calculations require clarification before the findings are treated as definitive.

Keywords: Concrete masonry blocks, fly ash, jarofix, quarry dust, waste fine aggregate, compressive strength, thermal conductivity, sustainability assessment.

I. INTRODUCTION

Concrete masonry units are widely used in building construction because of their modularity, availability and ease of installation. Their production consumes cement, natural aggregates and water, while extraction of river sand can cause river-bed disturbance and depletion of natural resources. At the same time, industrial and quarrying activities generate by-products that require appropriate reuse or disposal routes.

Fly ash, quarry dust and jarofix have been investigated as alternative fine aggregate constituents in cement-based products. Fly ash is a fine aluminosilicate-rich residue from coal combustion; quarry dust is generated during aggregate crushing; and jarofix is a stabilized residue associated with zinc-industry jarosite processing. Their physical and chemical characteristics differ, and their suitability must be assessed through mechanical, physical and environmental testing.

This study evaluates concrete masonry blocks incorporating fly ash, quarry dust and jarofix as partial replacements for natural river sand. The principal comparison is based on the 1:4:8 block series, for which compressive strength, density and water-absorption results are tabulated across replacement levels. Cube, masonry-prism, thermal and sustainability results are also examined, with limitations in the available datasets identified explicitly.

II. MATERIALS AND EXPERIMENTAL PROGRAMME

A. Materials and Mix Proportions

The experimental materials comprised 43-grade ordinary Portland cement, 10 mm nominal-size crushed coarse aggregate and natural river sand as the reference fine aggregate. Fly ash, quarry dust and jarofix were included in the principal tabulated replacement programme. Manufactured sand and lateritic waste were considered in selected descriptions and sustainability comparisons, but complete parallel result datasets are not available for these materials. The physical properties of the three principal alternatives are summarized in Table 1.

Table 1. Physical properties of the alternative fine aggregates.

Property	Fly ash	Quarry dust	Jarofix
Specific gravity	2.503	2.86	2.758
Bulk density (reported)	0.70	0.675	0.949
Porosity (reported)	0.72	0.764	0.656
Void ratio	2.568	3.243	1.907
Colour	Grey	Red	Grey

Two nominal mix proportions, 1:2:4 and 1:4:8 (cement:fine aggregate:coarse aggregate), were considered. Trial water-to-cement ratios of 0.45, 0.48 and 0.50 were examined; 0.50 was selected for the subsequent programme because lower ratios reportedly resulted in inadequate workability for some alternative materials. River sand replacement levels were 0, 10, 20, 30, 40, 50 and 100%. The precise basis of replacement by mass or volume should be confirmed from the original mix-design sheets.

B. Specimen Preparation and Testing

The experimental programme included 150 mm concrete cubes, concrete masonry blocks nominally measuring 400 × 200 × 150 mm, and masonry prisms constructed using 1:6 cement mortar. Specimens were demoulded after approximately 24 h and water-cured. The principal block-strength table reports 28-day results; other experimental sections refer to 14-, 28- and 90-day curing. Tests included compressive strength, prism strength and efficiency, density, water absorption, thermal conductivity using Lee's Disc apparatus, and chemical exposure to 3% H_2SO_4 and 3% NaOH.

Table 2. Details of Sample preparation

Test	Specimen / condition	Reported reference or procedure
Cube compression	150 mm cubes	Compression testing machine
Block compression	400 × 200 × 150 mm blocks	IS 2185 (Part 1):2005
Masonry prism	400 × 200 × 650 mm prism; 1:6 mortar	ASTM C1314-11 cited; IS 1905:1987 also cited
Density	Three blocks, oven-dried to constant mass	IS 2185 (Part 1):2005 cited
Water absorption	24 h immersion; oven drying at 100–115°C	IS 2185 (Part 1):2005 cited
Thermal conductivity	Lee's Disc apparatus	ASTM D7340-07 cited in text; IS 3346 listed in references
Chemical exposure	3% H_2SO_4 and 3% NaOH; up to 120 days stated	Residual mass and strength described

C. Sustainability Index

A Simple Additive Weighting (SAW) method was used to combine material efficiency and embodied energy, assigning an equal weight of 0.5 to each criterion. Normalized scores were calculated using benefit- or cost-type normalization, as applicable. This assessment is restricted to the two stated indicators and should be interpreted as a comparative scoring exercise, not as a comprehensive life-cycle assessment (LCA).

III. RESULTS AND DISCUSSION

A. Cube Compressive Strength

The cube results show a material-dependent optimum replacement level. The control strength was 5.48 MPa. Fly ash reached 9.41 MPa at 20% replacement, quarry dust reached 9.15 MPa at 30%, and jarofix reached 11.00 MPa at 30%. At 100% replacement, strength decreased for all three materials, although the jarofix mixture remained above the control value. These are the maximum values in the experimental programmeed cube dataset.

Table 3. Cube Compressive Strength

Replacement (%)	Fly ash (MPa)	Quarry dust (MPa)	Jarofix (MPa)
0	5.48	5.48	5.48
10	8.43	7.72	9.00
20	9.41	8.67	10.05
30	8.13	9.15	11.00
40	6.90	7.94	10.18
50	6.06	6.44	9.55
100	4.06	5.13	7.72

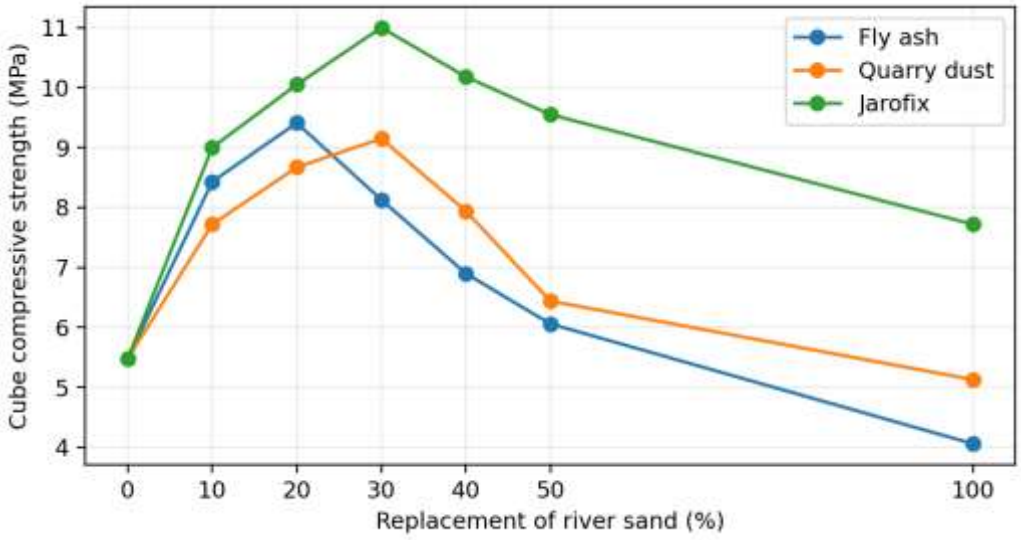


Fig. 1. Cube compressive strength versus river-sand replacement level.

B. Masonry Block Compressive Strength

For the 1:4:8 block series at 28 days, the control strength was 5.18 MPa. The maximum fly-ash result was 6.62 MPa at 20% replacement (FB02), representing an increase of approximately 27.8% over the control. Quarry dust achieved 6.38 MPa at 30% (QB03), an increase of approximately 23.2%. Jarofix achieved the highest value, 7.19 MPa at 30% (JB03), corresponding to an increase of approximately 38.8%. At 100% replacement, the block strengths were below the control for all three materials.

Table 4. Masonry Block Compressive Strength

Replacement (%)	Fly ash (MPa)	Quarry dust (MPa)	Jarofix (MPa)
0	5.18	5.18	5.18
10	5.80	5.46	5.66
20	6.62	5.99	6.41
30	5.52	6.38	7.19
40	4.96	5.36	5.63
50	4.40	4.69	5.12
100	4.01	4.11	4.27

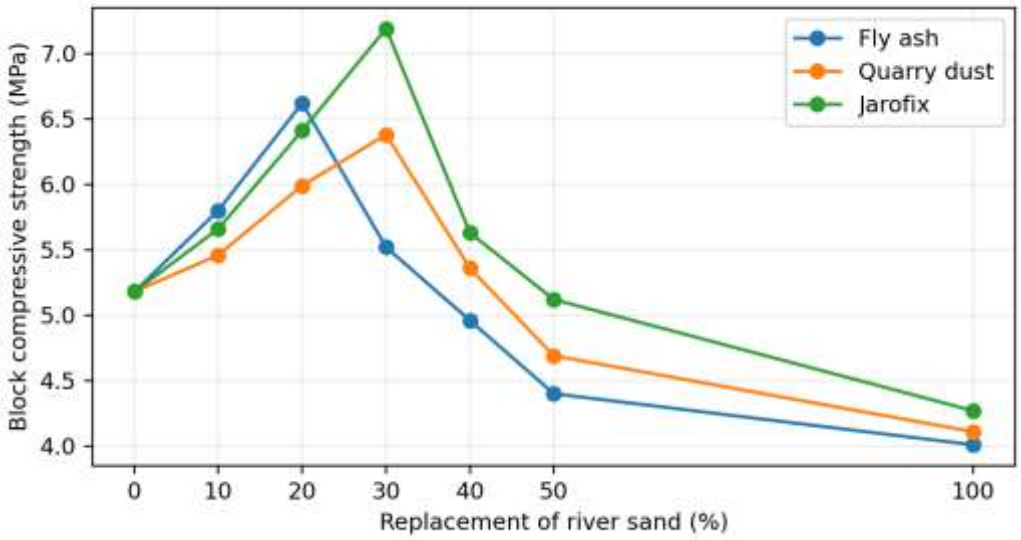


Fig. 2. 28-day compressive strength of 1:4:8 concrete masonry blocks.

The block-strength results indicate that partial replacement was more effective than complete replacement within the investigated mixtures. The maximum values occurred at 20% fly ash and 30% quarry dust and jarofix. Particle packing, grading, surface texture and material-specific chemistry may influence these trends; however, these mechanisms were not independently measured in the experimental programme.

C. Density and Water Absorption

The density data indicate that moderate replacement can increase block density, followed by a reduction at higher replacement levels. Quarry dust reached a maximum reported density of 2,286 kg/m³ at 30% replacement, while fly ash and jarofix reached 2,210 and 2,243 kg/m³ at 20% and 30%, respectively. At 100% replacement, the corresponding densities were 1,907, 2,009 and 1,874 kg/m³.

Table 5. Density

Replacement (%)	Fly ash (kg/m³)	Quarry dust (kg/m³)	Jarofix (kg/m³)
0	2168	2168	2168
10	2193	2238	2177
20	2210	2271	2189
30	2157	2286	2243
40	2113	2223	2099
50	2058	2140	2022
100	1907	2009	1874

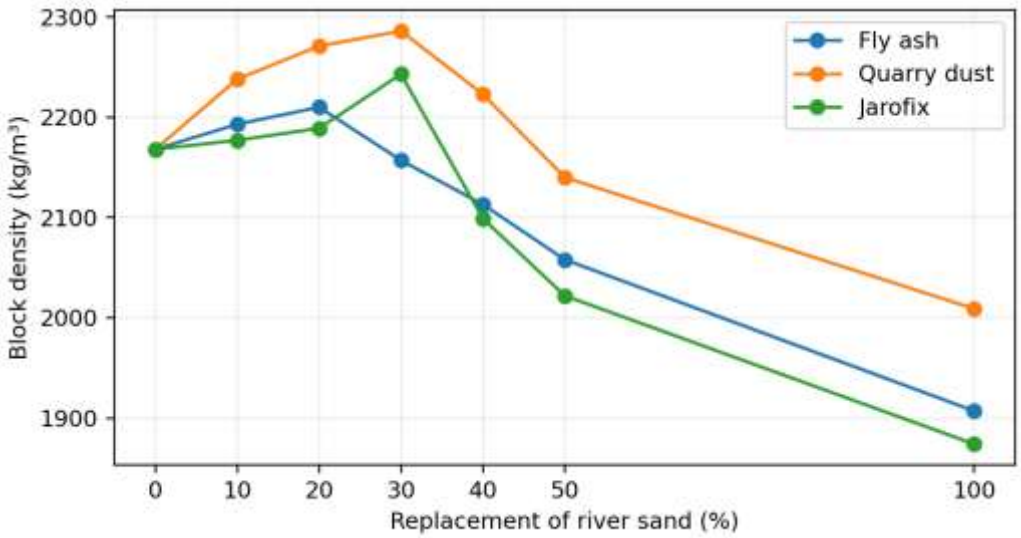


Fig. 3. Density variation of 1:4:8 masonry blocks.

Water absorption increased with replacement level in all three material series. The control value was 7.81%. At 100% replacement, absorption was 10.94% for fly ash, 9.97% for quarry dust and 10.73% for jarofix. Thus, although selected partial-replacement mixtures improved compressive strength, the absorption results do not demonstrate a general reduction in water uptake relative to the control.

Table. 6. Water Absorption

Replacement (%)	Fly ash (%)	Quarry dust (%)	Jarofix (%)
0	7.81	7.81	7.81
10	7.92	7.87	8.57
20	8.58	8.13	8.81
30	9.61	9.15	9.23
40	9.89	9.72	9.65
50	9.96	9.85	9.85
100	10.94	9.97	10.73

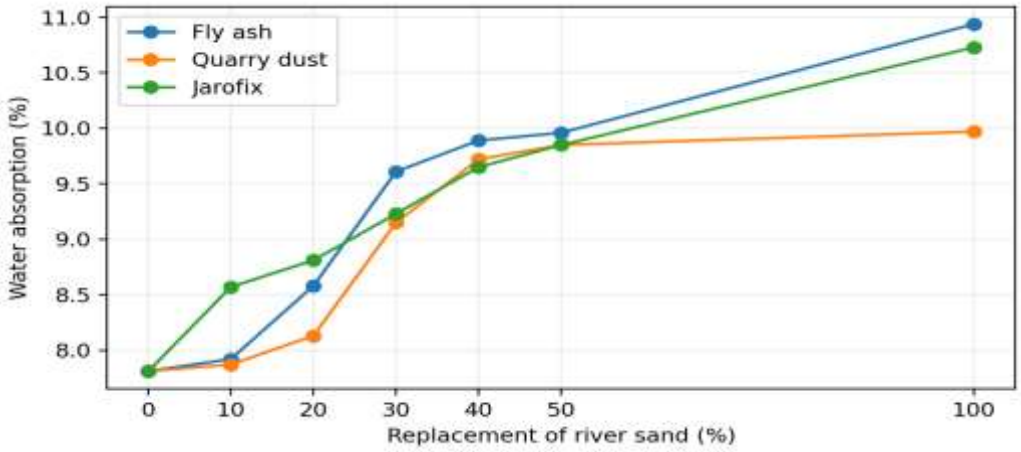


Fig. 4. Water absorption of 1:4:8 masonry blocks at different replacement levels.

D. Masonry Prism Strength and Efficiency

Masonry prisms were constructed using 1:6 mortar and tested under compression. the experimental programmeed masonry-efficiency values were 81.63% for the control, 81.09% for fly ash, 78.66% for quarry dust and 81.45% for jarofix. The jarofix prism recorded the highest reported failure load (430 kN) and masonry strength (5.375 MPa); applying the stated correction factor of 1.09 gives a normalized strength of 5.859 MPa.

Table 7.Masonry Prism Strength and Efficiency

Prism type	Failure load (kN)	Masonry strength (MPa)	Normalized strength (MPa)	Efficiency (%)
Control (SB)	310.33	3.874	4.228	81.63
Fly ash (FB)	394.00	4.925	5.368	81.09
Quarry dust (QB)	368.33	4.604	5.018	78.66
Jarofix (JB)	430.00	5.375	5.859	81.45

The tabulated results show a relatively narrow masonry-efficiency range of 78.66–81.63%. This differs from the wider range of 73.6–81.6% stated in the accompanying narrative. The four tabulated values are retained here, but the discrepancy should be checked against the original prism calculations and test records.

E. Thermal Conductivity

Thermal conductivity was measured for four selected block types. the experimental programmeed values were 0.263 W/(m·K) for the control, 0.207 W/(m·K) for FB02, 0.283 W/(m·K) for QB03 and 0.212 W/(m·K) for JB03. The fly-ash and jarofix specimens therefore had lower reported conductivity than the control, whereas the quarry-dust

specimen had a higher value. Because only four block types were tested, these results should not be generalized to all replacement levels.

Table 8. Thermal Conductivity

Block designation	Thermal conductivity (W/m·K)
SB00 (control)	0.263
FB02 (20% fly ash)	0.207
QB03 (30% quarry dust)	0.283
JB03 (30% jarofix)	0.212

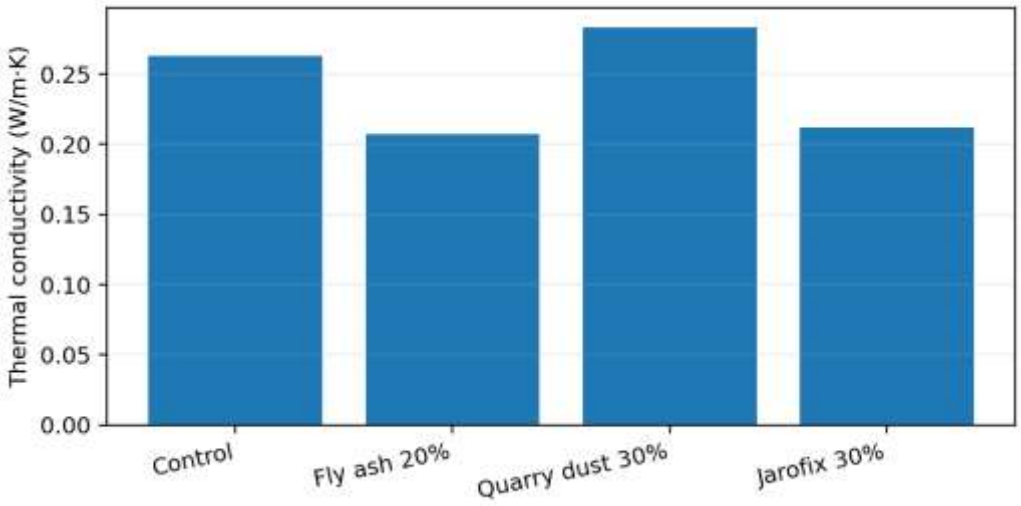


Fig. 5. Thermal conductivity of selected concrete masonry block specimens.

F. Chemical Exposure Performance

The experimental procedure describes immersion in 3% sulphuric acid and 3% sodium hydroxide, with solution renewal every two weeks and observations planned at 30, 60, 90 and 120 days. The H_2SO_4 residual-strength table, however, presents only three residual observations for each of fly ash, quarry dust and jarofix, without clearly identifying the exposure duration associated with each value. The stated residual-strength percentages are 94.61% for fly ash, 91.68% for quarry dust and 71.17% for jarofix, corresponding to reported strength losses of approximately 5.39%, 8.32% and 28.83%. The tabulated results suggest a substantially greater loss for the jarofix series, but the exposure-time mapping and calculations require verification.

Although exposure to NaOH is described, a complete numerical table of residual strength after alkali exposure is not provided. A quantitative comparison of alkali resistance therefore cannot be made from the available results.

G. Sustainability Assessment

the experimental programmeed embodied-energy values for selected block types lie between approximately 12.38 and 12.66, and the associated graph appears to use an energy-per-mass unit. The unit, system boundary, inventory, energy factors and calculation procedure are not sufficiently documented. The SAW table gives indices of 0.829 for FB02, 0.996 for QB03 and 1.000 for JB03, compared with 0.489 for the control. Manufactured-sand and lateritic-waste blocks also appear in selected comparisons, but a complete numerical index dataset is not provided. These indices should be interpreted only as comparative scores within the stated two-criterion framework, not as comprehensive environmental performance or LCA results.

Table 9. Sustainability Assessment

Block	Reported sustainability index
Control (SB00)	0.489
FB02 – 20% fly ash	0.829
QB03 – 30% quarry dust	0.996
JB03 – 30% jarofix	1.000

IV. PRINCIPAL FINDINGS

1. Maximum cube strengths were 9.41 MPa for 20% fly ash, 9.15 MPa for 30% quarry dust and 11.00 MPa for 30% jarofix, compared with 5.48 MPa for the control.
2. For 1:4:8 masonry blocks, the best reported 28-day strengths were 6.62 MPa (20% fly ash), 6.38 MPa (30% quarry dust) and 7.19 MPa (30% jarofix), compared with 5.18 MPa for the control.
3. Jarofix at 30% produced the highest reported block and prism strengths; its masonry efficiency was 81.45%.
4. Density increased at selected intermediate replacement levels and decreased at high replacement levels.
5. Water absorption increased with replacement level in all three tabulated material series; the control showed 7.81% absorption.
6. Selected fly ash and jarofix blocks showed lower thermal conductivity than the control; quarry dust showed a higher value.
7. the experimental programmeed H_2SO_4 residual-strength percentages were highest for fly ash (94.61%) and lowest for jarofix (71.17%), subject to uncertainty in exposure-time mapping.
8. the experimental programmeed SAW indices favour jarofix and quarry dust, but the calculation is limited to material efficiency and embodied energy.

V. CONCLUSION

The experimental results indicate that partial replacement of natural river sand with selected waste-derived fine aggregates can improve the compressive strength of concrete masonry blocks. Among the alternatives with complete tabulated results, jarofix at 30% replacement produced the highest reported 28-day block strength (7.19 MPa), prism failure load (430 kN) and masonry strength (5.375 MPa). Fly ash at 20% and quarry dust at 30% also improved block strength relative to the control. These findings indicate the potential of selected industrial and quarry by-products for masonry-unit production, subject to material characterization and environmental-safety assessment.

Mechanical performance and other physical properties did not improve uniformly. Water absorption increased with replacement level, while thermal conductivity depended on the alternative material. The sustainability indices favoured selected mixtures but were derived from a restricted two-criterion scoring method and should not be interpreted as an LCA. Before publication, the mix-design details, chemical-exposure records, applicable standards, embodied-energy calculations and statistical variability should be verified. Further work should include leaching and contaminant-mobility testing, particularly for jarofix-containing blocks, together with longer-term durability and field validation.

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