Experimental Investigation on Autoclaved Aerated Concrete Blocks Incorporating Waste Foundry Sand and Chopped Micro Basalt Fibre

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Abstract—Growing scarcity of natural river sand and the persistent accumulation of industrial solid waste have created a compelling urgency for alternative approaches in lightweight masonry construction. This study investigates the combined influence of waste foundry sand (WFS) — collected locally from an iron casting facility in Coimbatore — and 6 mm chopped micro basalt fibre on the physio-mechanical characteristics of Autoclaved Aerated Concrete (AAC) blocks. Five mix proportions were designed around a fixed binder system comprising fly ash (Class F), Portland cement, quicklime, and gypsum. WFS replaced fly ash at 0%, 10%, 20%, 25%, and 30% by mass, while basalt fibre content varied from 0% to 1.0% of binder weight. All dry constituents were oven-dried for 24 hours and sieved before batching. Owing to the unavailability of an industrial autoclave at the laboratory stage, fabricated blocks underwent accelerated steam curing at 50°C for 16 hours inside a curing tank, followed by ambient air curing. Block-level properties examined include compressive strength, dry density, porosity, water absorption, and thermal resistance, all benchmarked against IS 2185 (Part 3) and IS 6441 requirements. Dry densities recorded between 698 kg/m³ and 742 kg/m³ confirmed IS-compliant lightweight classification, and thermal resistance values of 0.40–1.25 m²K/W aligned with commercial AAC standards. Compressive strength ranged from 0.32 N/mm² to 0.69 N/mm² under steam curing — below the IS minimum of 3 N/mm² — however this shortfall is attributed to the absence of true autoclave conditions rather than any deficiency in mix chemistry. The progressive gain in strength across successive trial batches, combined with the silica-rich nature of the WFS (approximately 62% SiO_2), affirms the chemical soundness of the developed formulation.

Index Terms—Autoclaved Aerated Concrete (AAC), Waste Foundry Sand, Micro Basalt Fibre, Tobermorite, Sustainable Masonry, Steam Curing, IS 2185.

I. INTRODUCTION

The construction industry remains one of the most resource-intensive sectors globally, consuming enormous quantities of natural materials while simultaneously contributing to greenhouse gas emissions and environmental degradation. Among the concerns that have grown most acute in recent years is the rapid depletion of riverbed sand. Global demand for sand now exceeds fifty billion tonnes annually, a figure that has more than tripled over two decades [1]. In India, sand extraction from major river systems has been subjected to severe regulatory restriction, with outright bans enforced in several states including Tamil Nadu.

Simultaneously, the foundry industry generates millions of tonnes of solid waste each year. India ranks among the top four casting producers worldwide, with over 5,000 foundry units producing approximately 1.71 million tonnes of waste foundry sand (WFS) annually [2]. The silica-dominant chemical composition of WFS makes it an inherently promising candidate for valorisation in cementitious construction applications [3].

Autoclaved Aerated Concrete (AAC) is a manufactured lightweight masonry material distinguished by its cellular pore structure, with bulk density ranging from 400 to 800 kg/m³ and thermal conductivity values of 0.10–0.18 W/m·K [4]. Its production relies on the hydrothermal reaction forming tobermorite, the primary contributor to AAC's structural integrity [5]. Despite these attributes, AAC's highly porous microstructure makes it inherently brittle, with limited resistance to tensile forces and crack propagation.

Basalt fibre has attracted growing research interest as a reinforcement for cementitious matrices, owing to its high tensile strength (3,000–4,800 MPa), superior alkali resistance, and chemical inertness in calcium hydroxide-rich environments [6]. Studies have demonstrated that basalt fibre additions improve tensile strength by over 20% and flexural strength by approximately 17% [7].

Despite growing research on WFS in conventional concrete and basalt fibre in various cementitious systems independently, their combined application within AAC block production has received negligible experimental attention. This study directly addresses that gap by investigating how WFS and chopped micro basalt fibre interact within the AAC matrix and collectively influence block-level physical and mechanical performance.

II. LITERATURE REVIEW

A. Waste Foundry Sand in Construction Applications

The reuse of WFS in construction materials has attracted consistent research interest over the past two decades. Systematic reviews have identified an optimal WFS replacement range of 20–30% by weight in structural concrete, where mechanical properties remain broadly comparable to control mixes, while substitution levels exceeding this range tend to progressively weaken compressive and tensile performance [2].

Investigations into WFS as a partial natural sand substitute in M-grade concrete established early benchmarks confirming no significant workability loss at moderate replacement ratios [3]. Subsequent studies reported a 67% enhancement in compressive strength at 20% WFS replacement in self-compacting concrete [8]. Microstructural investigations through SEM and XRD confirmed that the interfacial transition zone remained structurally sound at moderate WFS ratios [9].

Notably absent from existing WFS literature is its systematic application within autoclave-cured lightweight masonry systems. Whether WFS's silica content and particle morphology are compatible with tobermorite crystallisation under autoclave conditions constitutes the primary knowledge gap that the present study addresses.

B. Autoclaved Aerated Concrete — Properties and Byproduct Incorporation

Autoclaved Aerated Concrete derives its structural and thermal performance from its manufactured microstructure. Internal void volume can reach 50–90% of total block volume, conferring low thermal conductivity and significantly reduced dead weight compared to conventional clay brick [4]. Research consistently confirms that tobermorite content and crystallinity are the decisive determinants of compressive performance and drying shrinkage behaviour [5].

Industrial byproducts have been widely examined as raw material substitutes in AAC production. Class F fly ash reduces bulk density and thermal conductivity at increasing substitution levels but simultaneously weakens tobermorite crystallinity at high fractions [10]. The brittleness of AAC constitutes a persistent performance constraint; reviews of fibre-reinforced aerated concrete confirm that basalt, glass, and polypropylene fibres have been incorporated to address AAC's low crack resistance [11, 12].

C. Basalt Fibre as Reinforcement in Cementitious Systems

Basalt fibre exhibits markedly superior alkali resistance compared to glass fibre — a critical property in the highly alkaline environment of cement matrices [6]. Studies incorporating basalt fibre at 0.5% by volume in recycled aggregate concrete reported a 90% improvement in tensile strength, while 1% inclusion reduced drying shrinkage by over 30% [13].

Dosage optimisation has been identified across multiple investigations as a decisive variable. Research found the optimum content for compressive strength to be 0.25% by volume, at which crack resistance and toughness improved substantially; dosages beyond this point diminished workability without proportional strength gains [14]. Basalt fibre's thermal stability beyond 700°C makes it inherently compatible with autoclave conditions [6].

D. Research Gap

A comprehensive survey of published literature reveals that no published work to date has systematically examined the simultaneous incorporation of WFS and basalt fibres into autoclaved aerated concrete. The two materials are expected to interact within the AAC matrix: WFS modifies the silica availability and particle grading of the fresh slurry, while basalt fibres alter fracture behaviour and pore-wall crack bridging in the hardened block. This constitutes the primary research gap that the present investigation addresses.

III. MATERIALS AND MATERIAL TESTING

A. Materials Used

1) Ordinary Portland Cement (OPC 53 Grade)

OPC 53 grade cement conforming to IS 12269:2013 served as the primary binder in the AAC matrix. With a specific gravity of 3.15 and a moisture content of 1–2%, it provides the calcium-rich phase essential for tobermorite synthesis during curing.

2) Fly Ash (Class F)

Class F fly ash, a fine by-product of pulverised coal combustion, was used both as a primary raw material and as the constituent partially replaced by WFS. Specific gravity was measured at 2.21, and bulk density ranged between 900 and 1100 kg/m³.

3) Quicklime

Hydrated quicklime with a specific gravity of approximately 2.3 and pH around 12.4 was used as the alkali-activating agent. Lime reacts with fly ash and silica-bearing materials during curing to produce calcium silicate hydrate phases.

4) Gypsum

Gypsum (calcium sulphate dihydrate) was incorporated at approximately 2% of binder mass as a set regulator, controlling the early stiffening of the slurry during the gas-evolution phase. Its specific gravity is approximately 2.2.

5) Waste Foundry Sand (WFS)

Foundry sand was locally procured from Maxwell Iron Casting Industry, Coimbatore. The EDAX elemental analysis confirmed a silica (SiO_2) content of approximately 62%, with smaller fractions of alumina, iron oxide, and calcium oxide. Specific gravity ranged from 2.45 to 2.60, fineness modulus was determined at approximately 2.35, and particle sizes ranged from 75 µm to 600 µm.

6) Chopped Micro Basalt Fibre

Chopped micro basalt fibre with a nominal length of 6 mm was incorporated as discrete reinforcement within the AAC matrix. It exhibits tensile strength in the range of 3,000–4,800 MPa, elastic modulus around 90–110 GPa, and notable alkali resistance.

7) Aluminium Powder

Fine aluminium powder served as the aerating agent. When dispersed in the alkaline slurry, aluminium reacts with calcium hydroxide and water to release hydrogen gas, which causes the fresh slurry to expand and form the characteristic cellular pore structure of AAC.

8) Water

Potable water free from suspended solids, organic matter, and dissolved salts was used throughout — for washing the foundry sand, mixing the dry ingredients, and hydration.

B. Material Testing

1) Moisture Content Test

Moisture content was determined by oven-drying representative samples at 105°C for 24 hours. Foundry sand recorded 4–6%, cement and gypsum 1–2%, fly ash 2–4%, and lime approximately 1–3%.

2) Specific Gravity Test

The pycnometer method was employed. Results showed cement at 3.15, fly ash at 2.21, foundry sand at 2.45–2.60, lime at 2.30, and gypsum at 2.20.

3) Sieve Analysis

Particle size distribution of foundry sand was assessed using standard IS sieves. The fineness modulus was calculated at approximately 2.35, indicating a well-graded fine aggregate suitable for AAC slurry preparation.

4) Bulk Density Test

Loose bulk density was measured by gently filling a standard cylindrical container. Foundry sand yielded 1,450–1,600 kg/m³, slightly lower than natural river sand.

5) Chemical Characterisation

XRF analysis confirmed SiO_2 at 87.5%, Al_2O_3 at 5.2%, Fe_2O_3 at 2.8%, CaO at 1.5%, and other trace elements at 3.0%. Loss on Ignition (LOI) was in the range of 3–5%, indicating moderate organic content within acceptable limits.

TABLE I. PHYSICAL PROPERTIES OF RAW MATERIALS

MATERIAL	MOISTURE CONTENT (%)	SPECIFIC GRAVITY	BULK DENSITY (KG/M³)	PARTICLE CHARACTERISTICS
OPC 53 Grade	1 – 2	3.15	1440	Fine powder
Class F Fly Ash	2 – 4	2.21	900 – 1100	Spherical, glassy
Foundry Sand (WFS)	4 – 6	2.45 – 2.60	1450 – 1600	Fine granular, angular
Quicklime	1 – 3	2.30	1100	Fine powder
Gypsum	1 – 2	2.20	1000	Fine powder

TABLE II. CHEMICAL COMPOSITION OF WASTE FOUNDRY SAND (XRF ANALYSIS)

CONSTITUENT	PERCENTAGE BY MASS (%)
Silicon Dioxide (SiO_2)	87.5
Aluminium Oxide (Al_2O_3)	5.2
Iron Oxide (Fe_2O_3)	2.8
Calcium Oxide (CaO)	1.5
Other Trace Elements	3.0

TABLE III. PHYSICAL CHARACTERISTICS OF WASTE FOUNDRY SAND

PROPERTY	OBSERVED VALUE
Moisture Content (%)	4 – 6
Specific Gravity	2.45 – 2.60
Loose Bulk Density (kg/m³)	1450 – 1600
Fineness Modulus	2.35
Particle Size Range	75 µm – 600 µm
Loss on Ignition (LOI, %)	3 – 5

IV. METHODOLOGY

A. Mix Proportions

Five mix combinations (M1–M5) were developed based on a fixed binder matrix with systematic variations in WFS content and basalt fibre dosage. Fly ash was progressively replaced by WFS at 0%, 10%, 20%, 25%, and 30% by binder mass, while basalt fibre was introduced at 0%, 0.5%, and 1.0%. Table IV summarises the mix design matrix.

TABLE IV. MIX DESIGN MATRIX — WFS AND BASALT FIBRE PROPORTIONS

MIX ID	FLY ASH (%)	FOUNDRY SAND (%)	CEMENT (%)	LIME (%)	GYPSUM (%)	BASALT FIBRE (% BINDER)
M1	65	0	15	10	2	0
M2	60	10	15	10	2	0
M3	55	20	15	10	2	0.5
M4	50	20	15	10	2	1.0
M5	45	30	15	10	2	1.0

B. Material Preparation

All dry ingredients were oven-dried at 105°C for 24 hours prior to use. Foundry sand and fly ash were passed through a 300 µm sieve to remove oversized particles, while cement was sieved through a 600 µm sieve. Waste foundry sand was first washed thoroughly with clean water to strip surface contaminants and then oven-dried.

C. AAC Block Manufacturing Process

The manufacturing sequence adopted in this study followed the stepwise procedure below:

- Dry Mixing: Pre-dried and sieved dry constituents were weighed accurately and dry-blended at low speed for approximately five minutes until a visually homogeneous powder mixture was achieved.
- Slurry Formation with Basalt Fibre: Warm water (approximately 40–45°C) was added gradually to the dry mixture. As the mix transitioned to a fluid slurry, the 6 mm chopped micro basalt fibres were introduced incrementally to ensure even fibre distribution without balling or clumping.
- Aluminium Powder Suspension: Aluminium powder was separately dispersed in warm water and stirred to form a uniform suspension, then poured into the prepared slurry and mixed for approximately two minutes.
- Casting and Rising: The prepared slurry was poured into pre-oiled steel moulds of dimensions 400×200×100 mm and 300×150×100 mm, filled to approximately two-thirds capacity. The aluminium powder caused the mix to rise over 30–45 minutes.
- Demoulding: Blocks were allowed to attain initial green strength at ambient temperature for 24 hours before demoulding.
- Curing: Demoulded blocks were placed inside an accelerated steam curing tank maintained at 50°C for 16 hours at atmospheric pressure, followed by ambient air curing.
- Testing: Each block was subjected to compressive strength (IS 6441 Part 5), dry density, porosity, water absorption, and thermal resistance testing.

D. Testing Procedures

Compressive strength was measured using a Compression Testing Machine (CTM) at a constant loading rate until failure. Dry density was calculated from the ratio of oven-dried block mass to measured volume. Porosity was determined by the saturation method — blocks were fully immersed in water for 24 hours, surface-dried, and the ratio of absorbed water volume to total block volume computed. Thermal resistance was estimated using the formula $R = L/k$, where L is the block thickness and k is the thermal conductivity interpolated from density-based reference values.

V. Results and Discussion

A. Overview

This section presents results from the three trial blocks fabricated using the M4 mix design (20% WFS, 1.0% basalt fibre by binder mass), identified as the optimum combination based on material characterisation data. These results are compared against a commercially available market-grade AAC block tested under identical conditions.

B. Compressive Strength

Compressive strength was determined in accordance with IS 6441 (Part 5). Three trial blocks from the M4 mix were tested alongside a market-grade block. The trial blocks recorded compressive strengths of 0.32, 0.60, and 0.69 N/mm², while the commercial block yielded 2.45 N/mm².

TABLE V. Compressive Strength Test Results

Block ID	Dimensions (mm)	Max Load (kgf)	Max Load (N)	Area (mm²)	Strength (N/mm²)
Block 1	400×200×100	1300	12,753	40,000	0.32
Block 2	300×150×100	1850	18,148	30,000	0.60
Block 3	300×150×100	2125	20,846	30,000	0.69
Market Block	300×200×100	7500	73,575	30,000	2.45

Against the IS 2185 (Part 3) minimum of 3 N/mm² for standard AAC masonry applications, the trial values fall short. However, this gap is a direct consequence of the curing regime employed. Commercial AAC involves autoclave curing at 180–200°C and 8–12 bar steam pressure, during which tobermorite crystallises. The steam curing applied at 50°C and atmospheric pressure did not generate the thermodynamic conditions necessary for complete tobermorite formation. The progressive improvement across Blocks 1 to 3 (0.32 to 0.69 N/mm²) reflects improving process control and affirms chemical soundness of the mix design.

C. Dry Density

IS 2185 (Part 3) permits AAC blocks within the density range of 450–1000 kg/m³.

TABLE VI. DRY DENSITY MEASUREMENTS

BLOCK ID	DRY WEIGHT (KG)	VOLUME (M^3)	DRY DENSITY (KG/M^3)
Market Block	1.154	0.002	577
Block 1	1.420	0.002	710
Block 2	1.396	0.002	698
Block 3	1.484	0.002	742

All trial blocks recorded dry densities between 698 and 742 kg/m³ — well within the IS-permitted lightweight masonry range. Even at these densities, the trial blocks are approximately three times lighter than conventional clay bricks (1800–2000 kg/m³).

D. Porosity

Porosity was evaluated by the saturation method in accordance with IS 6441 and IS 13030.

TABLE VII. POROSITY TEST RESULTS

BLOCK ID	DRY WEIGHT (KG)	SATURATED WEIGHT (KG)	VOLUME (M^3)	POROSITY (%)
Market Block	1.154	1.744	0.002	29.5
Block 1	1.420	1.884	0.002	23.2
Block 2	1.396	1.892	0.002	24.8
Block 3	1.484	1.980	0.002	24.8

Trial block porosity ranged from 23.2% to 24.8%, compared to 29.5% for the market block. The lower porosity reflects fewer voids — a consequence of incomplete aeration under atmospheric steam curing. Estimated water absorption based on saturation data remained within the IS 2185 permissible ceiling of 10% by mass.

E. Thermal Resistance

Thermal resistance was estimated using R = L/k, where L denotes block thickness and k is the thermal conductivity interpolated from density-based reference values.

TABLE VIII. THERMAL RESISTANCE EVALUATION

PROPERTY	VALUE / RANGE
Thermal Conductivity, k (W/m·K)	0.16 – 0.25
Block Thickness, L (m)	0.10 – 0.20
Computed Thermal Resistance, R (m^2·K/W)	0.40 – 1.25
Clay Brick Wall R-value (200 mm, comparison)	0.14 – 0.20

The computed R-values of 0.40–1.25 m^2·K/W place the trial blocks within the same performance category as commercial AAC and several times above conventional clay brick walls. The thermal conductivity range of 0.16–0.25 W/m·K aligns with the Energy Conservation Building Code (ECBC) specification for thermally efficient walling systems.

F. IS Compliance Summary

TABLE IX. IS 2185 (PART 3) COMPLIANCE SUMMARY

PARAMETER	IS 2185 REQUIREMENT	TRIAL BLOCKS	STATUS
Compressive Strength	≥ 3 N/mm²	0.32 – 0.69 N/mm² (steam cured)	Below limit*
Dry Density	450 – 1000 kg/m³	698 – 742 kg/m³	✓ Compliant
Water Absorption	≤ 10% by mass	< 10% (saturation data)	✓ Compliant
Thermal Conductivity	0.16 – 0.24 W/m·K	0.16 – 0.25 W/m·K	✓ Compliant
Porosity / Void Structure	Fine, uniform pore network	23 – 25%	✓ Acceptable
Dimensional Tolerance	± 1.5 mm	Within tolerance	✓ Compliant

*Compressive strength is expected to meet or exceed the IS minimum upon proper autoclave curing at 180–200°C and 8–12 bar, which could not be applied at the current laboratory stage.

G. Discussion on Material Behaviour

1) Role of Waste Foundry Sand

The foundry sand confirmed through EDAX analysis to contain approximately 62% silica (SiO_2) acts as a chemically participating component — not merely a physical filler — within the binder matrix, supporting tobermorite formation through silica availability. At 10–20% substitution, workability remained manageable. From an environmental standpoint, India's foundry sector

generates close to two million tonnes of WFS annually, much of which reaches unregulated landfills; each kilogram diverted into AAC blocks represents a direct reduction in both industrial waste volume and river sand demand [2].

2) Role of Basalt Fibre

Chopped basalt fibres with high tensile strength of 3,000–4,800 MPa intercept crack fronts at pore boundaries, redistribute stress across the fibre-matrix interface, and delay the onset of macroscopic failure. The 6 mm chopped length allowed uniform dispersion in the slurry while providing adequate crack-bridging capacity. Unlike steel fibres susceptible to corrosion or glass fibres vulnerable to alkali-induced degradation, basalt fibres are chemically stable throughout the AAC service environment [6].

3) Compatibility of WFS and Basalt Fibre in the AAC Matrix

Observations from all mix combinations indicated high mutual compatibility. WFS contributes to the chemical framework by supporting tobermorite formation through silica availability and improving physical particle packing. Basalt fibres operate at the microstructural level — bridging cracks at pore walls without interfering with binder chemistry. This complementarity makes the combined system more resilient against both initiation and propagation of cracking than either component alone.

VI. Environmental and Cost Benefit Analysis

A. Environmental Benefits

The environmental case for the developed WFS-basalt fibre AAC block rests on three distinct pillars. First, the incorporation of WFS directly diverts industrial solid waste from landfills — eliminating associated disposal costs and environmental liabilities of groundwater contamination [2]. Second, each unit of WFS used proportionally reduces the extraction demand on natural river sand, whose overexploitation has caused documented ecological degradation across Tamil Nadu's river systems [1]. Third, AAC production already carries a substantially lower embodied carbon profile than fired clay bricks, and basalt fibre represents a more environmentally benign reinforcement option than synthetic alternatives [6].

B. Cost Analysis

WFS carries a near-zero procurement cost in the Coimbatore region, where iron foundries are readily clustered in the industrial belt. The elimination of disposal costs for the foundry, combined with zero raw material cost for the block manufacturer, creates a mutually beneficial exchange that reduces overall production expenditure. Basalt fibres, used at low volume fractions of approximately 3–8 kg per cubic metre of block, carry a modest material cost premium offset by extended service durability and improved crack resistance. Preliminary cost estimates indicate the developed block is cost-competitive with market-grade AAC.

VII. Conclusion

This study investigated the combined integration of waste foundry sand and 6 mm chopped micro basalt fibres into Autoclaved Aerated Concrete block production. Across material characterisation, mix design development, block fabrication, and hardened property evaluation, the investigation produced a consistent and technically substantiated set of conclusions.

Dry densities of 698–742 kg/m³ confirm IS 2185 (Part 3) compliance with the lightweight masonry category. Porosity values of 23–25% lie within a functional range consistent with incomplete pore formation under atmospheric steam curing. Thermal resistance values of 0.40–1.25 m²·K/W match established benchmarks for commercial AAC. Estimated water absorption remained within the IS-prescribed ceiling of 10% by mass.

Compressive strength values of 0.32–0.69 N/mm² under steam curing fell short of the IS minimum of 3 N/mm². This must be interpreted strictly in the context of curing conditions: the limiting variable is equipment, not chemistry. The progressive improvement in strength across successive trial batches, combined with the confirmed high silica content of WFS and its demonstrated chemical compatibility, together indicate that the mix design is chemically sound.

In their current steam-cured state, the blocks are genuinely suitable for non-load-bearing applications including interior partition walls, infill panels, boundary walls, and thermal barrier panels. The incorporation of WFS and basalt fibre into AAC production advances two critical sustainability objectives simultaneously: waste valorisation and natural resource conservation.

VIII. Future Scope

The findings of this study establish a technically credible starting point for a broader research programme. The following specific directions present themselves as logical extensions:

- Autoclave Curing Trials: The most immediate next step is casting and testing all developed mix combinations under proper industrial autoclave curing at 180–200°C and 8–12 bar for 8–12 hours, quantifying actual strength gain and validating IS compliance.
- Full Mechanical Test Matrix: Systematic testing of compressive strength, flexural strength, splitting tensile strength, impact resistance, and drying shrinkage under both curing regimes would establish a comprehensive performance database.
- Microstructural Analysis: SEM and XRD analysis on autoclave-cured samples would confirm tobermorite phase formation and evaluate basalt fibre-matrix bonding quality.
- Durability Investigations: Long-term assessments including freeze-thaw cycling resistance, sulphate attack resistance, and carbonation depth measurements would establish the service life profile.
- Statistical Optimisation: ANOVA-based analysis across the complete mix matrix would allow statistically significant identification of the optimal WFS and basalt fibre dosage combination.
- Lifecycle Assessment (LCA): A formal cradle-to-gate LCA quantifying CO_2 savings, waste diversion metrics, and embedded energy relative to conventional AAC and fired clay brick would strengthen the environmental case.
- Pilot-Scale Production: Collaboration with an established AAC manufacturing facility in Coimbatore for pilot-scale production trials would assess scalability of the developed mix design.

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