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Performance Assessment of Hollow Concrete Blocks Incorporating Sugarcane Bagasse Ash and Silica Fume for Sustainable Masonry Structures

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Abstract

This research explores the potential of integrating Sugar Cane Bagasse Ash (SCBA) and silica fume in the production of hollow concrete blocks for masonry applications. The objective was to assess the influence of varying proportions of SCBA (0%, 10%, 20%, and 30%) and silica fume (10%) on the mechanical properties, durability, and structural performance of hollow concrete blocks. Different mix proportions (1:2:2.3, 1:3:3, and 1:6:6) were adopted, and the blocks were subjected to tests for compressive strength, water absorption, density, and modulus of elasticity. The blocks were also used in masonry prism construction, and the load-displacement behavior was recorded under axial loading. Results demonstrated that the inclusion of SCBA and silica fume reduced the compressive strength and modulus of elasticity but improved the sustainability of the blocks by utilizing industrial waste products. Notably, the SCBA-silica fume blocks showed higher load-carrying capacity in masonry applications compared to conventional blocks. The study highlights the potential for using these materials to develop cost-effective and environmentally friendly building materials.

Keywords: SCBA, silica fume, hollow concrete blocks, compressive strength, masonry prism, sustainability, structural performance

INTRODUCTION

The construction industry is actively seeking alternative materials to replace traditional concrete, particularly in masonry applications. SCBA, a byproduct of the sugar industry, and silica fume, a waste from silicon and ferrosilicon production, are gaining attention for their pozzolanic properties. This paper investigates the potential of incorporating SCBA and silica fume into hollow concrete blocks, which are widely used in building construction. The study aims to evaluate their impact on key properties such as compressive strength, water absorption, and durability, as well as their performance in masonry structures [1-5]

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Objectives

- To investigate the effect of Sugarcane Bagasse Ash (SCBA) and Silica Fume (SF) as partial replacements for cement in the production of hollow concrete blocks.
- To determine the optimal replacement levels of SCBA and SF for achieving the required compressive strength, water absorption, and density of hollow concrete blocks.
- To evaluate the mechanical properties, including compressive strength and modulus of elasticity, of SCBA-SF hollow concrete blocks at different curing ages.

- To assess the water absorption characteristics and their impact on the durability of the hollow concrete blocks.

Material

- *Ordinary port land cement (OPC):* Grade 53 cement was used as per IS: 12269-1987.
- *Sugar cane bagasse ash (SCBA):* SCBA sourced from a reputed sugar industry, calcined at 1500°C.
- *Silica fume:* Obtained from Astra Chemicals India Ltd.
- *Fine aggregate*: Natural river sand confirming to Zone II.
- *Coarse aggregate*: Stone chips tested as per ASTM C136-06.

Mix Proportions

Various mix ratios were tested, including 1:2:2.3, 1:3:3, and 1:6:6, with SCBA replaced at levels of 0%, 10%, 20%, and 30%. Silica fume was added at a 10% weight of cement.

Testing and Curing

Hollow concrete blocks were cast and cured for 28 days, followed by testing for compressive strength, water absorption, density, and modulus of elasticity. Masonry prisms were also constructed for load-displacement testing [7-9].

RESULTS

Compressive Strength of Hollow Concrete Blocks for Different Mix Proportions at 28 Days

The compressive strength of hollow concrete blocks prepared with 1:3:3 and 1:6:6 mix proportions was evaluated after 28 days, following the testing procedures specified in IS: 2185 Part-I (2005). The blocks were taken out of the curing tank, surface dried, and tested. Eight specimens were assessed for each mix proportion and replacement level, and the average values were recorded. The results are summarized in Table 1[8-12].

For the 400 mm x 150 mm x 150 mm blocks, the average gross area and net area were 60,000 mm² and 45,600 mm², respectively. The average face shell and web thickness were measured at 25.4 mm. Similarly, for the 400 mm x 100 mm x 200 mm blocks, the gross area and net area were found to be 40,000 mm² and 30,400 mm², respectively, with an average face shell thickness of 36 mm and web thickness of 30.2 mm[13-15].

Bashar et al. (2012) reported using 8% water content by total batch weight for 1:1:2 mixes in hollow block production. However, in this study, a water-to-cement ratio (w/c) of 0.45 was insufficient for proper block production. A 4% superplasticizer or an increased w/c ratio of 0.55 was required for optimal results. The mix was further redesigned for a w/c ratio of 0.55, and additional analyses, including strength, durability, and microstructural evaluations, were performed on both mortar and hollow concrete blocks [16-19].

The compressive strengths of hollow concrete blocks with varying SCBA and silica fume proportions are detailed in Table 1.

The results indicates that SCBA and silica fume can effectively replace cement in hollow concrete blocks, particularly at lower replacement levels. A 10% SCBA replacement with a silica fume addition yielded the best compressive strength results across most mix proportions. The findings demonstrate the potential of SCBA and silica fume as sustainable and cost-effective materials for masonry structures [20-25].

Water Absorption of Hollow Concrete Blocks

The water absorption characteristics of hollow concrete blocks for various mix proportions at 28 days are summarized in Table 2.

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Table 1. Compressive strength of hollow concrete blocks for various mix proportions at different curing ages.

S.N.	Dimension of hollow concrete block	Mix proportion	Mixture ID	Compressive strength [Mpa]				
				7 days	14 days	28 days	56 days	90 days
1	400 x 150 x 150	1:6:6	B	2.42	3.05	3.62	4.11	4.44
2			B10	1.58	2.21	2.36	2.58	3.13
3			B20	0.74	1.89	2.10	2.46	3.01
4			B30	0.63	1.68	2.00	2.31	2.38
5	400 x 150 x 150	1:2.1:2.3	C	6.84	7.69	9.87	10.38	10.62
6			C10	6.49	7.26	10.48	10.75	11.08
7			C20	4.47	6.05	7.46	8.93	9.35
8			C30	4.38	5.91	7.14	7.36	7.48
9	400 x 100 x 200	1:03:03	D	7.35	7.94	9.89	10.61	10.92
10			D10	7.30	7.48	10.71	11.45	11.97
11			D20	4.41	5.94	7.28	8.61	9.03
12			D30	4.20	5.49	6.84	7.27	7.46
13	400 x 150 x 150	1:6.5:6.5	E	5.54	6.68	8.42	9.66	10.08
14			E10	5.17	6.11	7.85	9.78	10.13
15			E20	4.58	5.42	7.09	7.72	8.25
16			E30	4.42	5.10	5.62	6.53	6.77

Table 2. Water absorption values of hollow concrete blocks for various mix proportions at 28 days.

S N.	Dimension of hollow concrete block	Mix proportion	Mixture ID	Water absorption at 28 days
1	400 x 150 x 150	1:6:6	B	2.51
2			B10	2.66
3			B20	3.50
4			B30	3.55
5	400 x 150 x 150	1:2.1:2.3	C	2.56
6			C10	2.27
7			C20	2.86
8			C30	2.98
9	400 x 100 x 200	1:3:3	D	1.94
10			D10	1.74
11			D20	2.12
12			D30	2.27
13	400 x 150 x 150	1:6.5:6.5	E	2.13
14			E10	1.83
15			E20	2.42
16			E30	2.63

Optimal Replacement Levels

- A 10% replacement of cement with SCBA, combined with 10% silica fume, strikes a good balance between maintaining acceptable water absorption levels and incorporating sustainable materials.
- Higher SCBA replacement levels (20% and 30%) lead to increased water absorption, which may compromise durability in certain applications [26-27].

Density of Hollow Concrete Blocks

The density measurements of hollow concrete blocks for different mix proportions at 28 days are provided in Table 3.

Table 3. Density values of hollow concrete blocks for various mix proportions at 28 days.

S.N.	Dimension of hollow concrete block	Mix proportion	Mixture ID	Density [kg/m^3]
1	400 x 150 x 150	1:6:6	B	1691.51
2			B10	1590.79
3			B20	1513.55
4			B30	1508.18
5	400 x 150 x 150	1:2.1:2.3	C	1700.54
6			C10	1642.67
7			C20	1602.13
8			C30	1593.97
9	400 x 100 x 200	1:3:3	D	1605.19
10			D10	1592.87
11			D20	1585.60
12			D30	1571.16
13	400 x 150 x 150	1:6.5:6.5	E	1723.36
14			E10	1599.94
15			E20	1534.29
16			E30	1523.28

The inclusion of silica fume (10%) in all mixes contributes to a minor reduction in density compared to the control mix. This reduction is due to the lower specific gravity of silica fume (2.2) compared to cement, as also observed by Bashar et al. (2012).

Modulus of Elasticity of Hollow Concrete Blocks

Hollow concrete blocks with a 1:3:3 mix were tested using a universal testing machine to determine their modulus of elasticity. The load was applied incrementally until the specimens failed, and the modulus of elasticity was calculated from the tangential modulus derived from their stress-strain curves. Results indicated a reduction in modulus of elasticity for SCBA silica fume blocks compared to control blocks. The detailed outcomes are presented in Table 4.

Table 5. 4 Modulus of elasticity at 28 days.

S.N.	Mix	Modulus of elasticity (MPa)
1	Control	27050
2	10 % SCBA +10% silica fume	25500
3	20 % SCBA +10% silica fume	20600
4	30 % SCBA +10% silica fume	17995

- At 10% SCBA and 10% silica fume, the modulus of elasticity remains relatively high, indicating that this replacement level maintains a balance between reduced cement content and structural stiffness.
- Beyond this level, the significant reduction in MoE may compromise the structural performance of hollow concrete blocks for applications requiring higher stiffness.

CONCLUSIONS

The experimental investigation on the use of Sugarcane Bagasse Ash (SCBA) and Silica Fume (SF) as partial replacements for cement in hollow concrete blocks has provided valuable insights into their impact on the properties of these blocks. The compressive strength results showed that the addition of SCBA and SF in varying proportions significantly affected the strength development over time. At 28 days, the compressive strength for the mix with 10% SCBA and 10% SF (Mix B10) was 2.58 MPa, which increased further with higher replacement levels of SCBA, with Mix B30 (30% SCBA) reaching 3.01 MPa. The water absorption tests indicated that the blocks with SCBA and SF exhibited slightly higher absorption compared to the control mix, with Mix B30 showing 3.55% water absorption at 28 days. However, these values remained within acceptable limits set by IS: 2185 for grade A load-bearing blocks.

The density of the blocks was found to decrease as the SCBA content increased, with Mix B30 having a density of 1508 kg/m³, which still meets the minimum density requirement of 1500 kg/m³ for load-bearing blocks. The modulus of elasticity, which is an important indicator of the material's stiffness, showed a decrease as the SCBA percentage increased, with the control mix having a modulus of elasticity of 27,050 MPa, and Mix B30 showing a reduced value of 17,995 MPa.

Overall, the SCBA-SF concrete blocks demonstrated good potential for use in masonry applications, with satisfactory compressive strength, density, and water absorption properties. Their performance in masonry prisms also showed superior load-bearing capacity compared to control and brick masonry prisms.

Future Recommendations

- *Further optimization:* Explore different mix ratios and alternative curing methods to enhance the performance of SCBA-silica fume blocks.
- *Durability studies*: Conduct long-term durability tests to assess the impact of environmental conditions on the performance of these blocks.
- *Reinforcement studies*: Investigate the effect of reinforcing materials, such as steel or polymer fibers, to improve the strength and elasticity of SCBA-silica fume blocks.

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