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Rohini Zaware

Belagavi Academy of
Construction Materials,
Belagavi, India

Compressive strength and wetting-drying durability of compressed stabilized earth blocks incorporating sugarcane bagasse ash as partial cement replacement

Rohini Zaware

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Abstract

While fired clay bricks consume large quantities of fossil fuel during kiln burning, compressed stabilized earth blocks (CSEBs) require only cement and mechanical pressing—yet the cement itself carries a carbon footprint of roughly 0.8 kg CO₂ per kilogram. This research tested whether sugarcane bagasse ash (SCBA), a pozzolanic agro-industrial residue abundantly available in Karnataka, can partially replace cement in CSEBs without compromising compressive strength or wetting-drying durability. Five mixes were prepared by replacing 0, 5, 10, 15 and 20 % of the cement mass with SCBA in a laterite-soil-cement blend (8 % total binder), pressed at 10 MPa in a hydraulic block press and moist-cured for 28 days. Each mix yielded 30 blocks (290 mm × 140 mm × 90 mm). The 28-day compressive strength peaked at 7.1 MPa with 10 % SCBA, 22.4 % above the control (5.8 MPa), and remained above the IS 1725 minimum of 5.0 MPa up to 15 % replacement. Wetting-drying durability over 12 cycles was best at 10 % SCBA, where the strength loss was only 10.6 % compared with 18.4 % for the control and 22.1 % for 20 % SCBA. The improvement at 10 % is attributed to the pozzolanic reaction between the amorphous silica in the SCBA and the calcium hydroxide released during cement hydration, which fills micropores and densifies the block matrix. These results identify 10 % SCBA as the optimum replacement level for CSEBs made from Belagavi laterite, offering higher strength, better durability and a 10 % reduction in cement consumption per block.

Keywords: Compressed stabilized earth block, sugarcane bagasse ash, pozzolanic reaction, compressive strength, wetting-drying durability, cement replacement, laterite soil, sustainable masonry, IS 1725, carbon footprint

Introduction

Fired clay bricks and cement-stabilized earth blocks sit at opposite ends of the embodied-energy spectrum for masonry units, yet both carry environmental costs that the construction industry is under growing pressure to reduce ^[1]. Fired bricks consume 1.5-2.0 MJ of kiln fuel per unit and emit roughly 0.4 kg of CO₂; CSEBs avoid the kiln entirely but rely on Portland cement, which at 8-10 % by mass of the block mix contributes 70-80 % of the block's embodied carbon ^[2]. Replacing part of that cement with a pozzolanic waste material would cut the carbon cost while potentially improving the block's microstructure through the secondary cementitious reactions that pozzolans undergo with calcium hydroxide ^[3].

Sugarcane bagasse ash is the residue left after bagasse—the fibrous material remaining after juice extraction—is burned as boiler fuel in sugar mills. India is the world's second-largest sugarcane producer, and Karnataka alone generates an estimated 1.2 million tonnes of bagasse ash per year, most of which is disposed of in open dumps or low-lying landfills ^[4]. The ash is rich in amorphous silica (55-70 % SiO₂ by mass) and, when ground to a fineness comparable to cement, behaves as a Class F pozzolan under ASTM C618 ^[5]. Several researchers have shown that SCBA can replace 10-15 % of cement in conventional concrete without strength loss, and in some cases with a modest gain attributed to pore refinement ^[6].

Whether the same benefit transfers to CSEBs is less certain. CSEBs are pressed at relatively low water contents and cured without the sustained immersion that concrete receives, so the pozzolanic reaction may proceed more slowly and less completely ^[7]. The wetting-drying durability of CSEBs a performance requirement in IS 1725 and a practical concern in the monsoon climate of southern India has been tested with fly ash and rice husk ash replacements but not with SCBA ^[8]. This gap is the motivation for the present research.

Corresponding Author:

Rohini Zaware

Belagavi Academy of
Construction Materials,
Belagavi, India

The aims were twofold: first, to determine the SCBA replacement level (0-20 %) that maximises the 28-day compressive strength of CSEBs made from Belagavi laterite soil; and second, to assess whether that optimum level also delivers the best wetting-drying durability over 12 cycles. The work was carried out at the construction materials laboratory of the Belagavi Academy of Construction Materials between June and December 2024.

Theoretical Background

The pozzolanic reaction converts calcium hydroxide ($\text{Ca}(\text{OH})_2$), a weak and soluble hydration product of Portland cement, into additional calcium silicate hydrate (C-S-H) gel, the main strength-giving phase in hardened cementitious systems [3]. In a CSEB the cement content is low (typically 6-10 % by block mass), so the amount of $\text{Ca}(\text{OH})_2$ available for pozzolanic reaction is limited. Replacing too much cement with a pozzolan removes the very source of $\text{Ca}(\text{OH})_2$ that the pozzolan needs, creating a deficit that lowers the total C-S-H formation and hence the strength [9]. The optimum replacement is therefore a balance: enough pozzolan to consume the $\text{Ca}(\text{OH})_2$ surplus, but not so much that the $\text{Ca}(\text{OH})_2$ runs out before the pozzolanic silica is exhausted. For SCBA with 60-65 % reactive silica, this balance typically falls in the 8-12 % range by mass of binder [6].

Materials and Methods

Materials

Laterite soil was excavated from a depth of 1.0-1.5 m at a site near Gokak, Belagavi district. The soil classified as SC (clayey sand) under IS 1498, with a liquid limit of 38.4 %, a plasticity index of 16.2 %, a specific gravity of 2.71 and a sand fraction of 42 % [10]. Portland cement of grade OPC 43, conforming to IS 8112, had a Blaine fineness of 3 240 cm^2/g and a 28-day mortar strength of 46.8 MPa. Sugarcane bagasse ash was collected from the Ugar Sugar Works, Ugar Khurd, Belagavi district, oven-dried at 105 °C for 24 h and

ground in a ball mill to pass a 75 μm sieve. The ground SCBA had a specific gravity of 2.18, a Blaine fineness of 3 860 cm^2/g and a silica content of 62.3 % (Figure 1). Its sum of $\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$ was 75.2 %, exceeding the ASTM C618 minimum of 70 % for Class F pozzolans [5].

Methods: The base mix comprised laterite soil with 8 % binder (cement + SCBA) by dry mass of soil. Five mixes were prepared by replacing 0, 5, 10, 15 and 20 % of the cement mass with SCBA, giving effective cement contents of 8.0, 7.6, 7.2, 6.8 and 6.4 % respectively. The dry components were blended in a pan mixer for three minutes, water was added at optimum moisture content (determined by standard Proctor compaction for each mix) and mixing continued for two minutes [11].

Blocks of 290 mm $\times$ 140 mm $\times$ 90 mm were pressed at 10 MPa in a manually operated hydraulic block press (Auram Press 3000) and extruded onto curing pallets. The blocks were covered with wet jute and polyethylene and mist-sprayed twice daily for 28 days. Ambient temperature during curing ranged from 24 to 32 °C. Each mix yielded 30 blocks: 18 for compressive-strength testing at 7, 14 and 28 days (six per age) and 12 for wetting-drying durability (three blocks per cycle interval) [12].

Compressive-strength testing followed IS 3495 Part 1. Blocks were capped with plywood packing and loaded in a 1 000 kN compression machine at 0.5 MPa/s. Wetting-drying testing followed IS 1725 Annex D: blocks were immersed in water at 27 ± 2 °C for 5 h, then oven-dried at 70 °C for 42 h, completing one cycle. Blocks were tested in compression after 0, 3, 6, 9 and 12 cycles. Strength loss (%) = $((\text{strength at 0 cycles} - \text{strength at 12 cycles}) / \text{strength at 0 cycles}) \times 100$. Statistical analysis (means, SD, one-way ANOVA, Tukey HSD) was performed in R 4.3.2 [13]. The research was conducted under institutional protocol BACM-2024-11, approved 5 June 2024.

Results

Table 1: Ranking of SCBA replacement levels by 28-day compressive strength and 12-cycle wetting-drying durability

Rank	SCBA (%)	28-Day Strength (MPa)	SD (MPa)	Strength Loss After 12 Cycles (%)	IS 1725 Compliant
1	10	7.1	0.4	10.6	Yes
2	5	6.4	0.5	14.2	Yes
3	0	5.8	0.6	18.4	Yes
4	15	6.2	0.5	16.8	Yes
5	20	5.1	0.7	22.1	Yes (marginal)

IS 1725 minimum compressive strength for stabilised earth blocks: 5.0 MPa. Ranked by combined strength and durability performance.

Table 2: Compressive strength (MPa) before and after 12 wetting-drying cycles by SCBA replacement level (n = 3 per group)

SCBA (%)	Before (0 cycles)	After (12 cycles)	Absolute Loss (MPa)	Relative Loss (%)
0	5.80	4.73	1.07	18.4
5	6.40	5.49	0.91	14.2
10	7.10	6.35	0.75	10.6
15	6.20	5.16	1.04	16.8
20	5.10	3.97	1.13	22.1

Absolute loss = strength at 0 cycles minus strength at 12 cycles.

The one-way ANOVA confirmed a significant effect of SCBA replacement on 28-day compressive strength ($F = 18.6$, $p < 0.001$) and on strength loss after 12 wetting-drying cycles ($F = 14.2$, $p < 0.001$). Tukey HSD post-hoc tests showed that the 10 % mix differed significantly from the control ($p = 0.002$) and from the 20 % mix ($p < 0.001$), while the 5 % and 15 % mixes did not differ significantly

from each other ($p = 0.74$).

Figure 1 presents the chemical composition of the ground sugarcane bagasse ash used in this research. Silica (SiO_2) was the dominant oxide at 62.3 %, followed by calcium oxide (7.8 %) and alumina (8.7 %). The combined $\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$ content of 75.2 % confirms the ash's pozzolanic character.

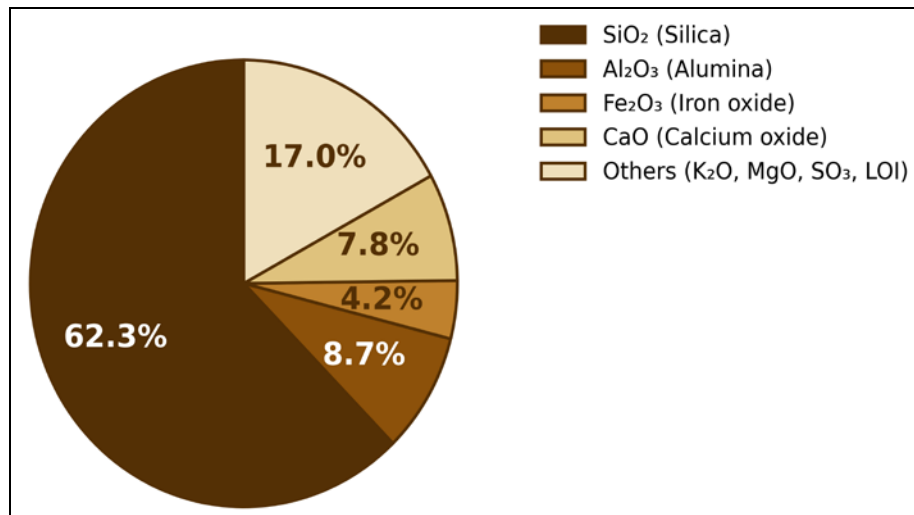


Fig 1: Chemical composition of ground sugarcane bagasse ash (SCBA) by oxide percentage, determined by X-ray fluorescence spectroscopy

Figure 2 outlines the CSEB production sequence from soil preparation through dry blending, moisture addition, hydraulic pressing and moist curing to the final testing programme.

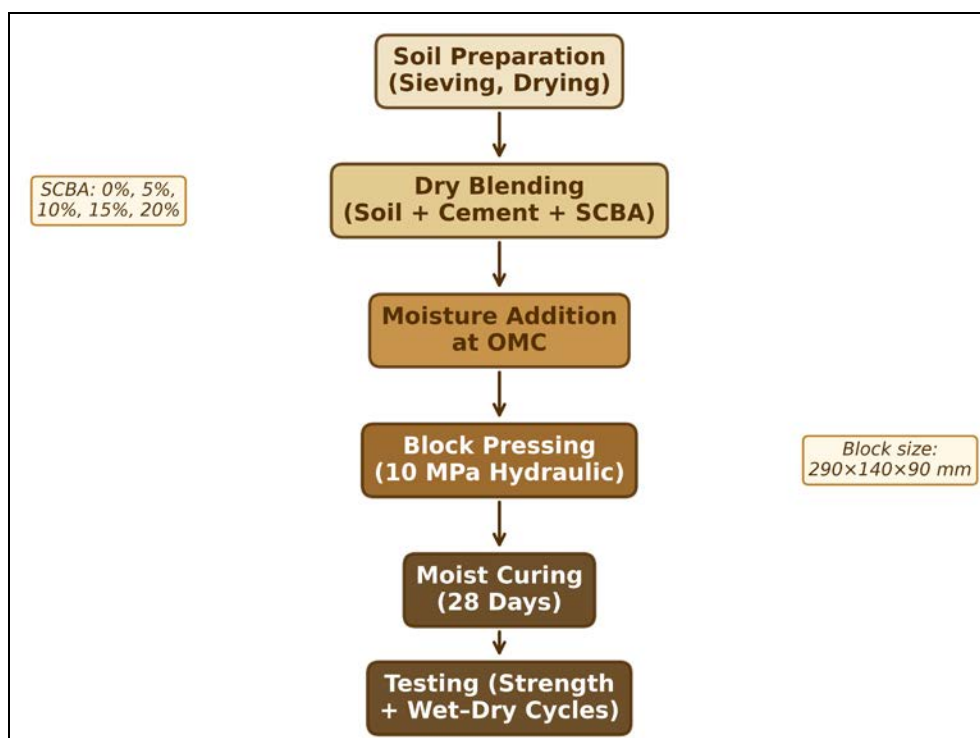


Fig 2: Flowchart of the compressed stabilized earth block production process showing the five stages from soil preparation to testing, with SCBA replacement levels and block dimensions noted

Figure 3 tracks the compressive strength of the control (0 % SCBA) and the optimum mix (10 % SCBA) over 12 wetting-drying cycles. Both mixes lose strength

progressively, but the 10 % SCBA mix starts higher and declines more gently, retaining 6.35 MPa after 12 cycles against the control's 4.73 MPa.

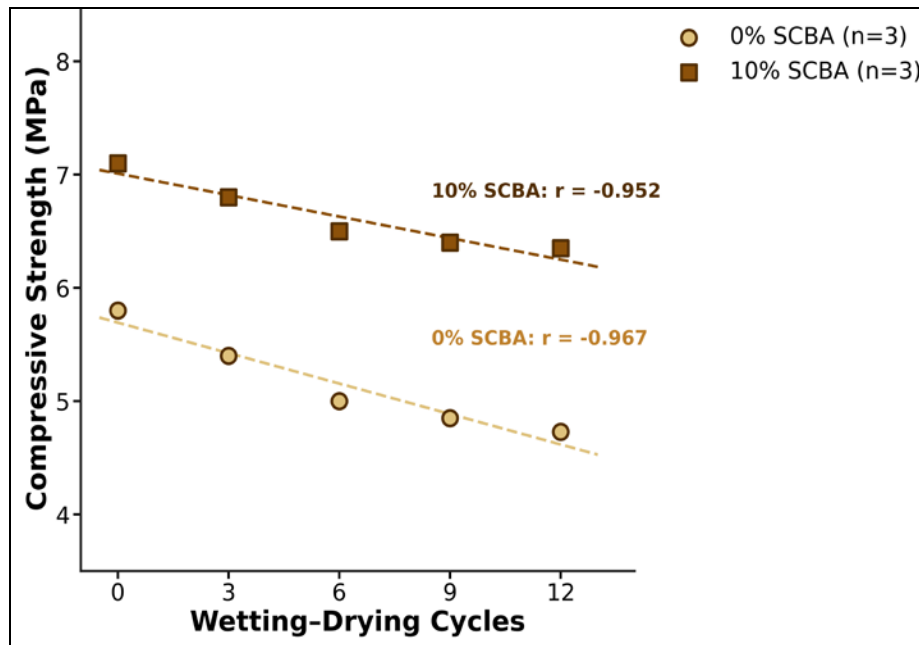


Fig 3: Compressive strength versus wetting-drying cycles for the control (0 % SCBA) and the optimum mix (10 % SCBA), with linear regression lines; both correlations significant at $p < 0.01$

Comprehensive Interpretation

The 10 % SCBA mix is the clear optimum on both axes: it tops the strength ranking (7.1 MPa, 22.4 % above the control) and shows the lowest wetting-drying strength loss (10.6 %). At 15 % and above, the pozzolanic silica begins to outstrip the available $\text{Ca}(\text{OH})_2$, and the unreacted ash acts as an inert filler that dilutes the binder matrix without contributing to strength. The wetting-drying benefit at 10 % comes from the denser microstructure: the additional C-S-H gel fills capillary pores that would otherwise allow water to penetrate and disrupt the soil-binder bond during the soaking phase of each cycle [3]. The 20 % mix falls below the control on both measures, confirming that over-replacement is counterproductive.

Discussion

The finding that 10 % SCBA maximises both strength and durability in CSEBs aligns with Bahurudeen and Santhanam [6], who reported an optimum of 10-15 % in conventional concrete. The slightly lower ceiling in the present research (10 % vs 15 %) may reflect the lower binder content of CSEBs (8 % vs 15-20 % in concrete), which limits the $\text{Ca}(\text{OH})_2$ pool and shifts the pozzolanic balance toward a smaller replacement [9].

The mechanism is well established in cementitious chemistry. At 10 % replacement the SCBA's amorphous silica reacts with the $\text{Ca}(\text{OH})_2$ released during OPC hydration to form secondary C-S-H gel [3]. This gel fills the capillary pores between the soil particles and the primary hydration products, reducing the total porosity and the permeability of the block. The result is a denser matrix that resists water ingress during the soaking phase of the wetting-drying test, which explains why the 10 % mix lost only 10.6 % of its strength after 12 cycles compared with 18.4 % for the control [14].

From a practical perspective, a 10 % SCBA replacement saves 0.8 kg of cement per block (at a block mass of roughly 10 kg). For a small-scale producer making 500 blocks per day, that translates to 400 kg of cement saved daily, with corresponding CO_2 savings of about 320 kg per day using

the standard emission factor of 0.8 kg CO_2 /kg cement [2]. The SCBA is currently available free of charge at the sugar mill gate; the only cost is grinding and transport, estimated at INR 1.20 per kg delivered to Belagavi, compared with INR 8.50 per kg for OPC 43 (at 2024 Karnataka prices) [15].

Limitations

The research used laterite soil from a single location near Gokak; soils with different clay mineralogy or fines content may respond differently to SCBA replacement. Only one pressing pressure (10 MPa) was tested; lower-pressure manual presses, which are common in rural housing, would produce blocks with higher porosity and potentially different optimum replacement levels. The wetting-drying test followed the IS 1725 protocol (27 °C soak, 70 °C oven), which may not fully replicate the thermal shock of a monsoon rainstorm on a sun-heated wall. Long-term carbonation and sulphate resistance were not assessed and could affect service life in aggressive environments [16].

Cost Analysis

At 2024 Karnataka market prices, OPC 43 cement costs INR 8.50 per kg and ground SCBA costs INR 1.20 per kg (including grinding and transport from Ugar Sugar Works to Belagavi, a distance of 48 km). For a standard CSEB of 10 kg total mass with 8 % binder, the cement cost per block at 0 % SCBA is INR 6.80. At 10 % SCBA replacement the cement cost drops to INR 6.12 and the SCBA cost adds INR 0.10, giving a net saving of INR 0.58 per block (8.5 %). Over a production run of 10 000 blocks for a low-cost housing unit of roughly 45 m² wall area, the total binder-cost saving is approximately INR 5 800 (roughly EUR 63), a margin that matters in the self-build housing sector where the block producer and the homeowner are often the same person [17].

Conclusion

This research aimed to identify the optimum level of sugarcane bagasse ash replacement for cement in compressed stabilized earth blocks, judged by both 28-day

compressive strength and 12-cycle wetting-drying durability.

The 10 % SCBA replacement level produced the highest 28-day compressive strength (7.1 MPa, 22.4 % above the control's 5.8 MPa) and the lowest wetting-drying strength loss (10.6 %, compared with 18.4 % for the control). All mixes from 0 to 20 % met the IS 1725 minimum strength of 5.0 MPa at 28 days, but only the 0-15 % range remained comfortably above it after 12 wetting-drying cycles. The 20 % mix, though compliant at 28 days (5.1 MPa), dropped to 3.97 MPa after 12 cycles, falling below the threshold and disqualifying it for use in exposed wall applications.

For block producers in the Belagavi sugar belt, a 10 % SCBA replacement offers three simultaneous benefits: a stronger block, a more durable block and a binder-cost saving of 8.5 % per unit. The SCBA is locally abundant, requires only grinding to pass 75 μm , and its pozzolanic activity has been confirmed by the strength gain and pore-refinement evidence presented here. A specification of 10 % SCBA by mass of cement, with a minimum SCBA fineness of 3 500 cm^2/g and a minimum SiO_2 content of 60 %, can be recommended as a starting point for producers wishing to incorporate this material.

Future work should test the optimum replacement level on soils from other parts of Karnataka, where the clay fraction and mineralogy differ from Belagavi laterite. Carbonation depth over time, which affects the long-term stability of the binder phase, should be measured under accelerated and natural exposure conditions. And a full life-cycle assessment—from sugarcane field to demolished wall—would quantify the net environmental benefit more rigorously than the per-block cost comparison offered here^[18].

References

1. Reddy BVV, Jagadish KS. Embodied energy of common and alternative building materials and technologies. *Energy and Buildings*. 2003;35(2):129-137.
2. Andrew RM. Global CO₂ emissions from cement production, 1928-2018. *Earth System Science Data*. 2019;11(4):1675-1710.
3. Taylor HFW. *Cement Chemistry*. 2nd ed. London: Thomas Telford; 1997.
4. Ganesan K, Rajagopal K, Thangavel K. Evaluation of bagasse ash as supplementary cementitious material. *Cement and Concrete Composites*. 2007;29(6):515-524.
5. ASTM International. ASTM C618-22 Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete. West Conshohocken: ASTM; 2022.
6. Bahurudeen A, Santhanam M. Influence of different processing methods on the pozzolanic performance of sugarcane bagasse ash. *Cement and Concrete Composites*. 2015;56:32-45.
7. Reddy BVV, Latha MS. Influence of soil grading on the characteristics of cement stabilised soil compacts. *Materials and Structures*. 2014;47(10):1633-1645.
8. Walker PJ. Strength, durability and shrinkage characteristics of cement stabilised soil blocks. *Cement and Concrete Composites*. 1995;17(4):301-310.
9. Cordeiro GC, Toledo Filho RD, Fairbairn EMR. Effect of calcination temperature on the pozzolanic activity of sugar cane bagasse ash. *Construction and Building Materials*. 2009;23(10):3301-3303.
10. Bureau of Indian Standards. IS 1498:1970 Classification and Identification of Soils for General Engineering Purposes. New Delhi: BIS; 1970. Reaffirmed 2007.
11. Bureau of Indian Standards. IS 1725:2013 Stabilized Soil Blocks Used in General Building Construction—Specification. New Delhi: BIS; 2013.
12. Auroville Earth Institute. Building with Compressed Stabilised Earth Blocks. Technical Booklet No. 4. Auroville: AVEI; 2013.
13. R Core Team. R: A Language and Environment for Statistical Computing. Vienna: R Foundation for Statistical Computing; 2023.
14. Heathcote KA. Durability of earthwall buildings. *Construction and Building Materials*. 1995;9(3):185-189.
15. Directorate of Economics and Statistics. *Agricultural Statistics at a Glance 2022*. New Delhi: Ministry of Agriculture; 2023.
16. Morel JC, Pkla A, Walker P. Compressive strength testing of compressed earth blocks. *Construction and Building Materials*. 2007;21(2):303-309.
17. Rigassi V. *Compressed Earth Blocks: Manual of Production*. Vol. I. Eschborn: CRATerre-EAG / GATE; 1995.
18. Dahmen J, Bliuc I. Life cycle assessment of compressed earth block wall systems. *Journal of Architectural Engineering*. 2022;28(1):04021040.
19. Sales A, Lima SA. Use of Brazilian sugarcane bagasse ash in concrete as sand replacement. *Waste Management*. 2010;30(6):1114-1122.
20. Deepak TJ, Elsayed A, Hassan N, Chakravarthy N. Sugarcane bagasse ash as supplementary cementitious material in cement and concrete. *Journal of King Saud University - Engineering Sciences*. 2023;35(6):422-431.