Materials Today: Proceedings xxx (xxxx) xxx

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Performance evaluation of sugar cane bagasse ash on the strength of concrete: A sustainable approach

G.D. Kumara [a,*], P.V. Sivapullaiah [b,c,d], A. Sreenivasa Murthy [e]

[a] Department of Civil Engineering, GITAM School of technology, and Executive Engineer, Public Works Department, Government of Karnataka, India
[b] Indian Institute of Science, Bengaluru 560012, India
[c] GITAM University, Bangalore Campus, Bangalore, India
[d] Bangalore Institute of Technology, Bengaluru, India
[e] Department of Civil Engineering, BMS College of Engineering, Bengaluru, India

ARTICLE INFO

Article history:
Available online xxxx

Keywords:
Supplementary cementitious material
Microstructure
Sugarcane bagasse ash
Slump
Tensile strength
Compressive strength

ABSTRACT

Cement is the most sought material in the world next to water. The manufacturing and utilization of cement is increasing rapidly leading to global warming due to release of CO_2. In this research, it is intended to partially substitute the cement with agro-based byproducts i.e. bagasse ash (SCBA) as supplementary cementitious materials (SCM). Meanwhile, effect of SCBA (added at various proportions i.e. 5–30 %) on compressive and tensile strengths of concrete was investigated. Furthermore, SCBA was characterized for SEM, EDX, and XRD analysis to examine the surface morphology and physio-chemical characteristics. From results, EDX analysis indicated that the SCBA was primarily made of oxygen (O) ~ 51.85 % and silica (Si) ~ 45.67 % while, XRD analysis, showed the presence of SiO_2 in SCBA. Slump value of SCBA blended concrete increased with increase in % of bagasse ash by up to 15 % increment. The compressive and split tensile strength values indicated 15 % replacement of SCBA with cement has performed better than other mixes.

1. Introduction

The construction sector across the world primarily depends on cement in production of concrete. The limited natural resources of cementitious materials are depleting very fast due to rapid construction activities. This creates an urgency for the researchers to look into alternative cementitious materials to minimize the usage of ordinary Portland cement (OPC). Despite various beneficial uses of cement, the manufacturing of cement contributes ~4–8 % of global CO_2 emissions [1]. Meanwhile, India is one of the largest cement-producing and consuming nations, the cement production in India in the year 2020 was 329MT and is expected to reach 381MT in the year 2022 [2,3] contributing ~7–8 % of the increase in consumption of cement annually. Moreover, reports suggest that annually ~4000 million tons of cement are produced across the world due to an increase in urbanization and industrialization and further projected to increase ~8000MT by the end of the year 2050 [4]. As a result, the quantity of CO_2 emissions is expected to increase ~5.1 times more than the current level.

Furthermore, clinker production and heating during cement manufacturing is carbon intensive process. Every tonne of cement production emits upto 622 kg of carbon dioxide [5]. Meanwhile, Caroline et al (2021)have reported that the CO_2 intensity decreased sharply as the substitution level of the SCMs increased up to approximately 15–20 %, beyond which the rate of decrease gradually slowed [6]. Therefore, as a sustainable developmental practice, emissions can be cut by reducing the cement content in concrete by substituting waste cementitious materials. Overall, the binder and CO_2 intensities could be formulated as a function of the individual substitution level of each SCM.Therefore, it is vital to substitute cement with alternative binding materials to implement sustainability in concrete construction.

Any industrial activity or agro-industrial activity results in creating waste materials. It is a challenging task for its disposal in terms of environmental concerns and a vast area of vacant land

* Corresponding author.
E-mail address: gdk.gbc@gmail.com (G.D. Kumara).

https://doi.org/10.1016/j.matpr.2022.11.335
2214-7853/

Please cite this article as: G.D. Kumara, P.V. Sivapullaiah and A. Sreenivasa Murthy, Performance evaluation of sugar cane bagasse ash on the strength of concrete: A sustainable approach, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2022.11.335

is required. Slag, fly ash, rice husk ash, sugarcane bagasse ash (SCBA) etc. are the wastes generated out of industrial as a by-product can be reused effectively and safely. The industrial by-product such as SCBA possess pozzolanic characteristics enriched with alumina and silica [7,8]. Meanwhile, fly ash can be used in high dosage levels in the range of 30 to 60 % replacing cement has appreciable improvement in mechanical and durable properties for structural members [9]. The ground granulated blast furnace slag replaces cement by 35 to 40 % and has several advantages like reduced heat of hydration, pore refinement, and densification of microstructure making concrete more durable than ordinary Portland cement concrete [10]. Further, India is regarded as the second sugarcane-producing country next to China. India produced sugarcane ~303.6 million tons in the year 2017 [11]. Subsequently, sugarcane bagasse ash (SCBA) is end product obtained after juice extraction process as a waste [12]. The SCBA contains fine particles and the disposal of SCBA leads to environmental hazards like contamination of water bodies and air pollution [13]. To reduce environmental stress related to the disposal of SCBA and maximize the benefits, the SCBA can be potentially used for partially replacing the conventional cement during concrete manufacturing effectively and efficiently.

Several researchers have investigated the characteristics of SCBA and reported pozzolanic properties and chemical composition favourable for the usage of SCBA for the preparation of SCBA blended concrete [14,15]. The raw SCBA contains mainly ~60–75 % silica and ~25–40 % oxides of potassium and calcium [16,17].

Therefore, this research is intended to partially substitute cement with SCBA to prepare M30 concrete and evaluate the performance of SCBA concrete with conventional OPC concrete. Meanwhile, the variation in properties of the SCBA concrete for different proportions of bagasse ash (0–30 %) will be analyzed to determine the optimum fraction of SCBA for cement replacement. Subsequently, the tensile and compressive strength of SCBA will be compared with the characteristics of OPC concrete.

Table 1
Physical properties of cementitious materials and aggregates.

Cementitious materials		
Parameters	53 grade OPC	Bagasse ash
Colour	Grey	Black
Specific gravity	3.12	1.65
Specific surface area (m^2/kg)	275	225
Coarse and fine aggregates		
Parameters	Crushed stone sand (CSS)	Coarse aggregate (20 mm down)
Specific gravity	2.69	2.74
Fineness modulus	2.75	2.84
Water absorption (%)	1.6	0.35
Zone	II	–

Table 2
Chemical properties of SCBA.

Particulars	Results (% by mass)
Loss of ignition	14.78
Sulphur trioxide, SO_3	0.27
Silica dioxide, SiO_2	73.18
Magnesium oxide, MgO	1.11
Ferric oxide, Fe_2O_3	1.96
Alumina, Al_2O_3	3.85
Calcium oxide, CaO	3.78
Chloride, Cl	0.007
Sodium oxide, Na_2O	0.32
Potassium oxide, K_2O	0.98
Sodium oxide, Na_2O	0.96
Reactive silica	18.76

2. Materials and methods

In this study, SCBA is partially substituted in various fractions with cement to achieve a target compressive strength of 30 MPa in 28 days. Further, compressive strength of SCBA concrete is also tested at 90 days to examine the effect of strength gain in the later stage.

2.1. Materials used

The ordinary Portland cement (OPC) of 53 grade was used in this research. The sugarcane bagasse ash was procured from a Mudhol sugar factory, Karnataka, India. Meanwhile, locally available 20 mm down size coarse aggregates and crushed stone sand (CSS) fine aggregates were used for preparing the SCBA concrete. Meanwhile, potable tap water is utilized to mix the SCBA concrete ingredients.

2.2. Characterization of materials

The OPC cement, SCBA was examined for various physical characterization of cementitious materials (OPC and bagasse ash), aggregates (fine and coarse) and chemical properties, and results are presented in Table 1 and Table 2 respectively.

2.2.1. Morphology of SCBA

The SCBA was subjected to scanning electron microscopy (SEM) analysis for examining the surface morphology (Fig. 1). Meanwhile, energy dispersion X-ray analysis (EDX) was performed to analyze elemental composition of SCBA. Subsequently, X-ray diffraction (XRD) analysis was performed to elucidate amorphous or crystalline nature of the SCBA. Prior to SEM, EDX, and XRD analysis, the raw SCBA sample was placed in an oven for drying to temperature of 110 °C for 24 h and subsequently sieved through 300 µm sieve (ASTM).

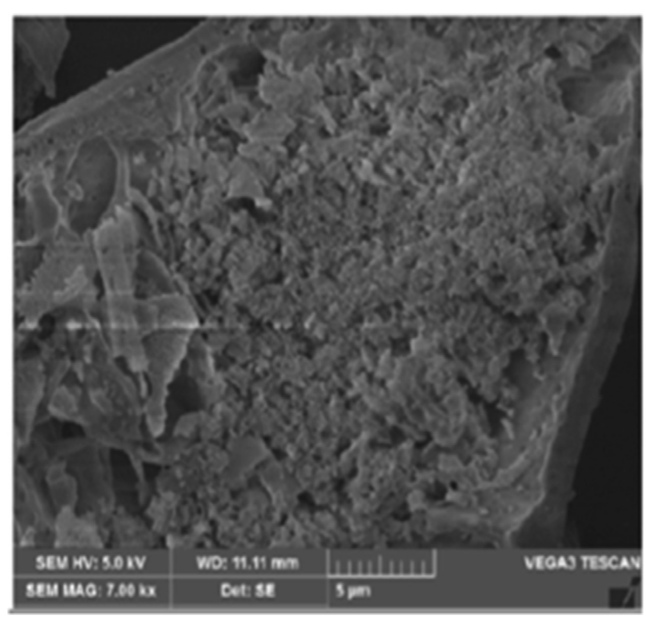

Fig. 1. SEM Image of SCBA at 5 µM magnification.

2.3. SCBA concrete mix proportion

The design mix for M30 grade concrete using water cement (W/C) ratio of 0.45 was prepared according to IS 10262–2009. Subsequently, 15 cm concrete cubes were prepared in triplicates and allowed for curing in potable water. On the other hand, bagasse ash (BA) blended concrete cubes were prepared by substituting cement with 5 % to 30 % SCBA. The fresh properties like slump of the SCBA blended concrete are compared with control mix. The constituents of concrete were mixed as per the procedure given in BS 1881–125 (1986). Table 3 shows concrete mix proportions for all the six SCBA concrete mix (i.e.5 %,10 %,15 %,20 %,25 % and 30 %).

2.4. Test methods

The compressive strength test is performed using 150 mm cubes in compression testing machine as per IS: 516–1959 (reaffirmed 2004). Meanwhile, split tensile strength test was carried out using 100 mm diameter and 200 mm length specimens in accordance with IS: 5816:1999 (reaffirmed 2004) using a compression testing machine. Subsequently, concrete specimens were subjected to compressive strength analysis at 7, 14, 28 and 90 days and split tensile strength at 28 days. Fig. 2(a-b) illustrates the testing of concrete specimens analyzed for compressive and split tensile strength using universal testing machine (UTM).

Table 3
Mix design for SCBA concrete.

Mix	Cement (%)	Bagasse ash (%)
Control mix (OPC)	100	0
BA 5	95	5
BA 10	90	10
BA 15	85	15
BA 20	80	20
BA 25	75	25
BA 30	70	30

3. Results and discussion

3.1. Characterization of SCBA

The Table 2 presents chemical characteristics of BA. It can be observed from the table that SCBA was majorly composed of SiO_2 of ~73 % and ~18.8 % reactive silica. SCBA showed ~15 % loss of ignition. Meanwhile, SCBA is composed of calcium in the form of CaO_2 and alumina in the form of Al_2O_3 that are the main components of a conventional OPC cement. Fig. 1. shows the SEM Image of SCBA at 5 μm magnification. From SEM image it can be observed that the SCBA displayed a granular morphology having tiny surface pores. On the other hand, Fig. 3(a) shows the EDX spectrum of SCBA. EDX analysis indicated that the SCBA was primarily made of oxygen (O) ~51.85 % and silica (Si) ~45.67 %. Furthermore, the XRD spectrum of SCBA is presented in Fig. 3(b). From XRD analysis, it can be elucidated that the presents of sharp peaks at 21°, 27°, 36°, 41° and 45° 2θ angles showed the presence of SiO_2 in SCBA.

3.2. Properties of fresh SCBA concrete

The blended SCBA concrete in its fresh state appears to be homogeneous and consistent. The slump values of SCBA concrete at various fractions of SCBA are presented in Table 4. In the meantime, the slump values obtained depicts nature of workability of blended SCBA concrete for varied % replacement of SCBA with cement. From table, it can be seen that, increase in SCBA % in concrete from 5 to 30 % showed decrease in slump value from 92 mm to 70 mm, respectively. However, the BA 15 showed better slump value (90 mm) than the control OPC mix (85 mm) satisfying the requirement of medium level of workability as per IS 456:2016.

3.3. Compressive strength of SCBA concrete

The compressive strength test was carried out to examine compressive strength of SCBA concrete at 7, 14, 28 and 90 days. Table 5 depicts compressive strength of SCBA concrete from 7 to 90 days. From Table 5 and Fig. 4, it can be observed that compressive strength of both OPC and SCBA concrete increased with increment in time from 7 to 90 days. Meanwhile, increase in SCBA fraction

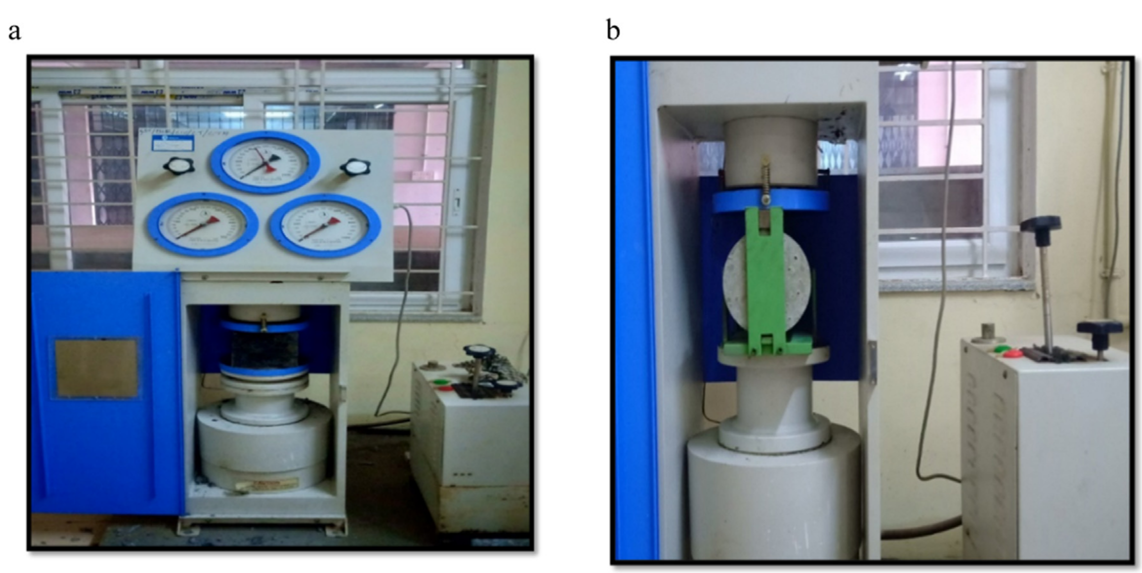

Fig. 2. Testing of concrete cubes: (a) compressive strength test and (b) split tensile strength test.

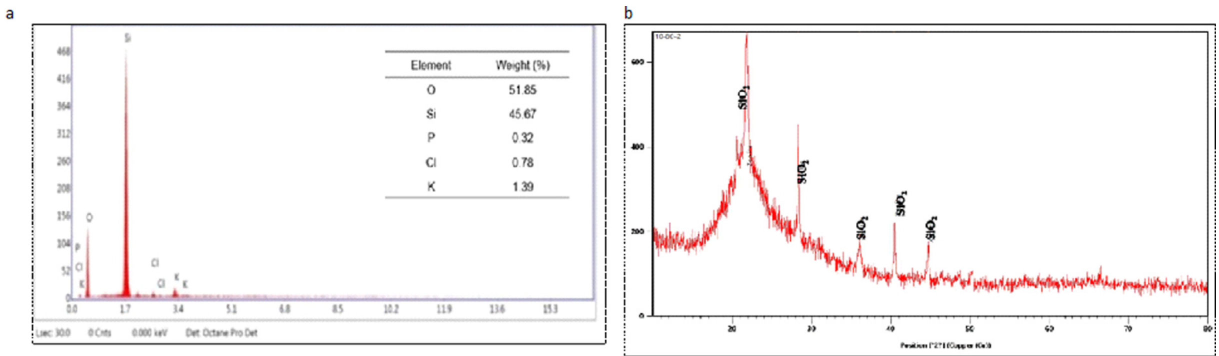

Fig. 3. EDX and XRD spectrum of SCBA: (a) EDX and (b) XRD.

Table 4
Slump values of OPC concrete and SCBA concrete.

Mix	Slump (mm)
Control mix (OPC)	85
BA 5	92
BA 10	96
BA 15	90
BA 20	86
BA 25	75
BA 30	70

Table 6
Split tensile strength of OPC concrete and SCBA concrete.

Mix	Split tensile strength (MPa)
Control mix (OPC)	2.97
BA 5	3.05
BA 10	3.12
BA 15	3.23
BA 20	3.01
BA 25	2.78
BA 30	2.55

Table 5
Compressive strength of OPC concrete and SCBA concrete.

Mix	Compressive strength (MPa)			
	7 days	14 days	28 days	90 days
Control mix (OPC)	15.21	19.65	31.12	33.26
BA 5	15.96	20.05	31.87	33.57
BA 10	16.87	20.89	32.52	34.15
BA 15	17.25	21.29	33.12	34.67
BA 20	15.95	20.12	30.12	31.25
BA 25	14.37	19.05	28.57	28.96
BA 30	13.65	17.96	27.34	28.12

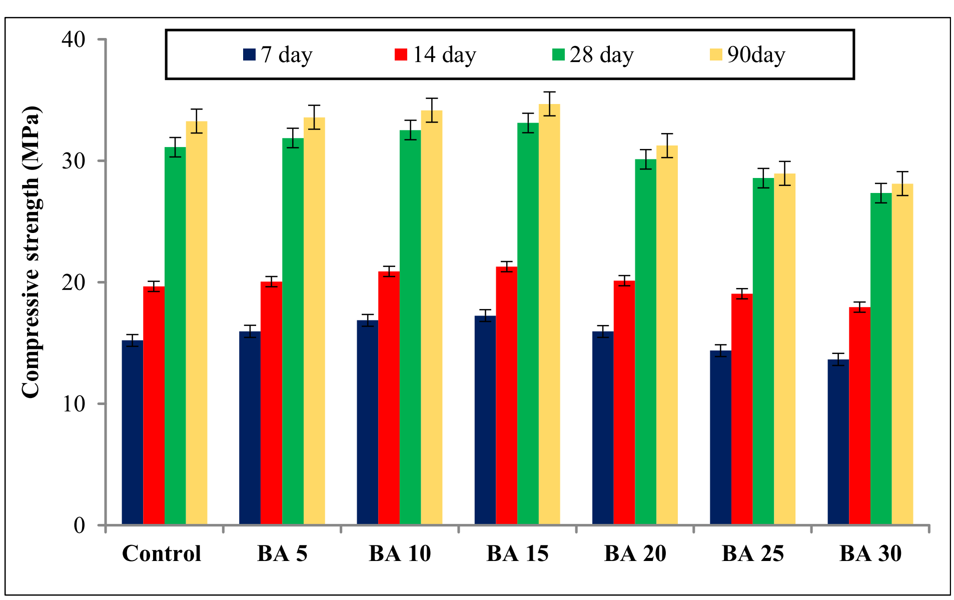

Fig. 4. Compressive strength of OPC concrete and SCBA concrete at 7, 14, 28 and 90 days.

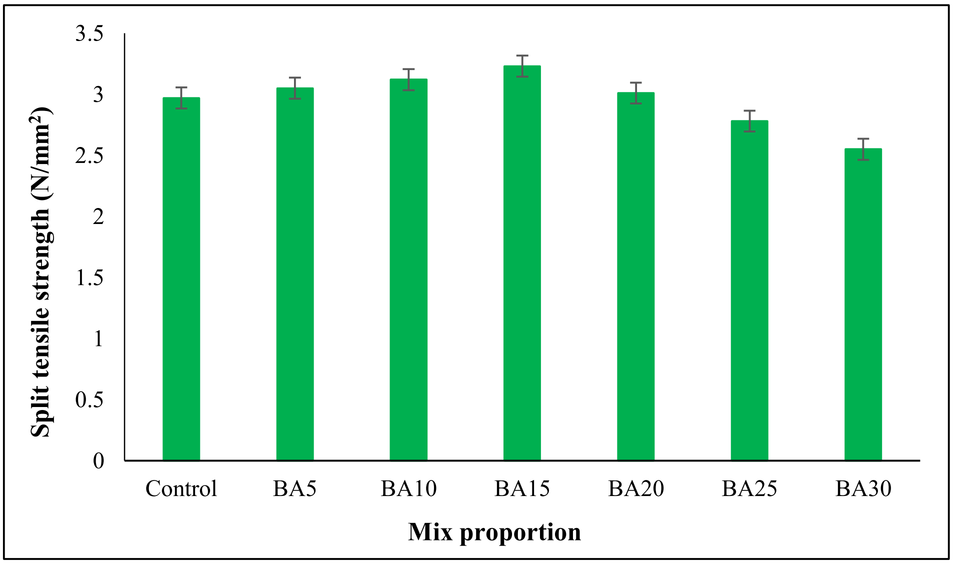

Fig. 5. Split tensile strength of OPC concrete and SCBA concrete at 28 days.

from 5 % to 15 % showed increase in the compressive strength at 7, 14, 28 and 90 days. This might be attributed to the fact that increment in SCBA fraction from 5 % to 15 % increased the reactive silica content, and in turn compressive strength increased. On the other hand, further increase in SCBA fraction from 15 % to 30 % showed reduction in compressive strength of the SCBA concrete at 7, 14, 28 and 90 days. This might be attributed to the fact that increment in SCBA fraction from 15 % to 30 %, decreased the lime content (CaO) present in the OPC cement added to the SCBA concrete mix. Furthermore, the BA15 mix was found to be the optimum mix with high compressive strength of 33.12 MPa at 28 days. Moreover, compressive strength attained at 28 days by the BA15 mix was better in comparison with control mix i. e. OPC concrete (31.12 MPa) [18,19].

3.4. Split tensile strength of bagasse ash concrete

The tensile strength of SCBA concrete at 28th day is depicted in Table 6. From table, it can be observed that increase in SCBA fraction from 5 % to 15 % showed improvement in tensile strength at 28th day. Further increase in SCBA fraction from 15 % to 30 % showed reduction in tensile strength of SCBA concrete. Furthermore, BA15 mix was found to be the optimum mix with high tensile strength of 3.23 MPa at 28 days. Moreover, the compressive strength attained at 28 days by BA15 mix was better compared to OPC concrete control mix (2.97 MPa). In general, tensile strength of BA concrete gradually increased up to 15 % SCBA replacement with cement. However, there is a decline in strength beyond 15 % replacement of SCBA with cement. The variation in split tensile strength of OPC concrete and SCBA concrete at 28 days is shown in Table 6 and Fig. 5. The tensile strength test was conducted to examine split tensile strength of SCBA concrete at 28th day.

4. Conclusion

In this research, partial replacement of blended SCBA with OPC cement to achieve compressive strength 30 MPa. Characterization of SCBA showed that SCBA majorly composed of SiO_2 of ~73 % and ~18.8 % reactive silica. The addition of 15 % SCBA improved workability of fresh concrete as per IS-456 recommendations. The BA10 mix having 10 % replacement of SCBA with cement showed highest slump value compared to OPC concrete and all other SCBA mix. Meanwhile, increase in SCBA fraction from 5 % to 15 % showed enhancement in compressive and tensile strengths for different time periods of curing. On the other hand, further increase in SCBA fraction from 15 % to 30 % showed decrement in tensile and compressive strength of SCBA concrete. The BA15 mix was found to be optimum mix with high compressive strength of 33.12 MPa at 28 days in comparison with OPC control mix (31.12 MPa). In conclusion, the synthesized SCBA concrete (M30 Grade) with BA15 mix can be recommended for concrete applications like reinforced cement concrete slabs, beams, footings, columns and other structural elements.

Ethics approval

Not applicable.

Consent to participate

Not applicable.

Consent for publication

Not applicable.

Funding

This research did not receive any specific grant from any funding agencies.

CRediT authorship contribution statement

G.D. Kumara: Conceptualization, Methodology, Data curation, Formal analysis, Supervision, Writing – review & editing. **P.V. Sivapullaiah:** Conceptualization, Methodology, Data curation, Formal analysis, Investigation, Writing – original draft. **A. Sreenivasa Murthy:** Writing – review & editing.

Data availability

Data will be made available on request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

None.

References

[1] C. Gunasekara, D.W. Law, S. Setunge, J.G. Sanjayan, Zeta potential, Gel formation and compressive strength of low calcium fly ash geopolymers, Constr. Builder. 95 (2015) 592–595.
[2] India Brand Equity Foundation web Page Annual report 2021.
[3] S.V. Manjunath, R.S. Baghel, M. Kumar, Performance evaluation of cement–carbon composite for adsorptive removal of acidic and basic dyes from single and multi-component systems, Environ. Technol. Innovat. 16 (2019) 100478.
[4] World Cement Association Web page.
[5] S. Deepika, G. Anand, A. Bahurudden, M. Santhanam, Construction products with sugarcane bagasse ash as binder, J. Mater. Civ. Eng. 29 (2017).
[6] N. Chusilp, C. Jaturapitakkul, K. Kiattikomol, Effects of LOI of ground bagasse ash on the compressive strength and sulfate resistance of mortars, Constr. Build. Mater. 23 (2009) 3523–3531.
[7] Na Yang, Rui Wang, Sustainable technologies for the reclamation of greenhouse gas CO_2, J. Clean. Produc. 103 (2015) 784–792.
[8] Caroline Brogan, Best Ways to cut Carbon Emissions from the Cement Industry Explored, Imperial College London, 2021.
[9] M.L. Marceau, J. Gajda, M.G. VanGeem, Use of Fly Ash in Concrete: Normal and High-Volume Ranges, Portland Cement Association, Skok, 2002, 2604, pp. 2604.
[10] P. Saranya, P. Nagarajan, A.P. Shashikala, Eco-friendly GGBS Concrete: A State-of-The-Art Review, IOP Confe. Series: Mater. Sci. Eng. 330 (012057) (2018), https://doi.org/10.1088/1757-899X/330/1/012057.
[11] Indian Sugar Mills Association (ISMA), Statistics data of Sugarcane Production (2016-17), New Delhi, India, 2017.
[12] A. Bahurudden, M. Santhanam, Characterisation of Sugarcane bagasse ash as supplementary cementitious material in concrete, in: Proceedings of UKIERI Concrete Congress Innovations in Concrete Construction, India, 2013, pp. 181–185.
[13] V.S. Batra, S. Urbanite, G. Svensson, Characterisation of carbon in unburned bagasse fly ash, Fuel 87 (2008) 2972–2976.
[14] S.V. Manjunath, Mathava Kumar, Removal and recovery of nutrients using low-cost adsorbents from singlecomponent and multicomponent adsorption systems, Sustainable Resour. Manage.: Technol. Recovery Reuse Energy Waste Materials (2021) 397–435.
[15] K. Ganeshan, K. Rajgopal, K. Thangavel, Evaluation of Bagasse ash as supplementary cementitious material, Cem. Concr. Compos. 29 (35) (2007) 515–524.
[16] M.S. Priyanka, O.S. Nayanathara, S.V. Manjunath, S. Abhinaya, E.V. Aswathy, V. K. George, Competitive adsorption analysis of antibiotics removal from multi-component systems using chemically activated spent tea waste: effect of operational parameters, kinetics, and equilibrium study, Environ. Sci. Pollut. Res. 22323 (2022).
[17] G.C. Cordeiro, R.D. Toledo Filho, E. De Filho, M.R. Fairbairn, Use of ultra-fine sugar cane bagasse ash as mineral admixture for concrete, ACI Mater. J. 105 (2008) 487–493.
[18] A. Sreenivasa Muthy, M.B. Patil, N. Maya, Comparative study on geo-polymer concrete using naturalsand & M-sand, Mater. Today Proc. (2022) 2214-7853, https://doi.org/10.1016/j.matpr.2022.01.013.
[19] A. SreenivasaMuthy, M.B. Patil, M. Naik, Mechanical properties of low concentration alkaline activated crimped steelfiber reinforced geopolymer concrete, J. Struct. Eng. 49 (2) (2022) 93–105.