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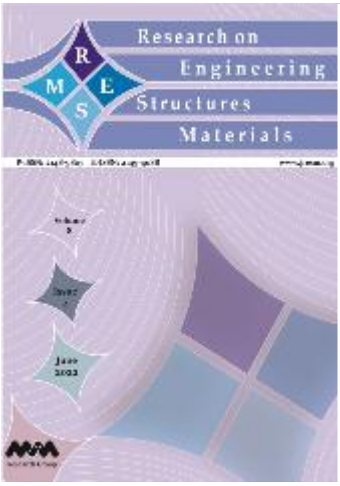

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Online Publication Date: 15 August 2023
URL: http://www.jresm.org/archive/resm2023.819ma0712.html
DOI: http://dx.doi.org/10.17515/resm2023.819ma0712

Journal Abbreviation: *Res. Eng. Struct. Mater.*

To cite this article
Bayapureddy Y, Muniraj K, Gangireddy MM. Characteristic evaluation of concrete containing sugarcane bagasse ash as pozzolanic admixture. *Res. Eng. Struct. Mater.*, 2023; 9(4): 1287-1307.

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Research Article

Characteristic evaluation of concrete containing sugarcane bagasse ash as pozzolanic admixture

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Article Info

Article history:

Received 12 July 2023
Accepted 13 Aug 2023

Keywords:

Sugarcane bagasse ash concrete;
Pozzolanic reactivity;
Microstructure;
Strengths;
Sorptivity;
Acid attack;
Mass loss;
Strength loss

Abstract

This study presents the influence of sugar cane bagasse ash (SCBA) as pozzolanic material on the microstructure, strength and durability properties of concrete. To enhance the pozzolanic properties of raw SCBA, it is incinerated at 6000C for 2 hours in muffle furnace at the rate of 100C/min and ball-milled for 240 minutes to increase its fineness more than cement. SCBA is pre-treated to remove adhered water molecules by heating to 100^{0}C for 24 hours and then it is characterised by SEM/EDS, XRF, FTIR and TGA tests to assess the microstructural properties. In this study cement is replaced by SCBA with 5,10,15,20 and 25% by weight of cement to examine the mechanical and durability properties of concrete. The optimum dosage of SCBA is determined based on various tests conducted on concrete and it is found to be 15%. The tests conducted are compressive strength, split tensile strength, sorptivity, and acid resistance. A maximum strength gain is observed with 15% replacement of cement by SCBA with an increment of 14.8%, 20% and 18.2% for compressive strength at 28, 56 and 90 days, respectively, due to enhanced pozzolanic reactivity and improved microstructure of SCBA concrete and split strength is increased in the range of 16% to 18% over the reference concrete mix. The sorptivity of SCBA concrete is found to reduce by 24.4% compared to reference mix at 15% replacement. The mass loss, strength loss, and dimensional loss are studied on concrete samples based on acid resistance test. The SCBA blended concrete with 15% replacement of cement showed the least acid durability lost factor which is 305.5 with sulphuric acid and 351.72 with hydrochloric acid.

1. Introduction

Agro-based industries generates huge amount of rice husk ash, sugarcane bagasse ash, palm oil fuel ash, wheat straw ash containing inorganic, carbon-rich, fibrous particles causing air, soil and water pollution due to their improper disposal. These ashes have the major composition of carbon and silica oxides which are can be used for enhancing pozzolanic reactivity. Hence, they have wide potential in replacement of cement in concrete composites as mineral admixtures in finely divided form [1-5].

Cement is an important ingredient of concrete which is a widely used material in construction industry. However, concrete has several drawbacks such as low tensile strain, poor microstructure, high permeability and low durability characteristics in aggressive environment. To overcome these drawbacks, supplementary cementitious materials (pozzolans) are widely used in concrete composites. Fly ash, ground granulated blast furnace slag, meta-kaolin, and silica-fume are the commonly used admixtures because of the high silica, alumina and iron oxides content and less loss of ignition. Several studies

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DOI: http://dx.doi.org/10.17515/resm2023.819ma0712

reported that SCBA is highly siliceous and possesses pozzolanic properties as it contains all the elements present in ordinary Portland cement. A comprehensive review on bagasse ash as pozzolanic material is presented by Thomas et al. [6].

The performance of SCBA in pavement concreting, and soil stabilization is examined by Batool et al. [7]. Characterization of laboratory bagasse ash (LBA), filter bagasse ash (FBA), and bottom bagasse ash (BBA) has been performed by Frías et al. [8]. LBA obtained by heating at 400 ^{0}C for 20 minutes and 800 ^{0}C for 60 minutes has shown the highest lime fixation, exhibiting excellent pozzolanic performance compared to BBA and FBA. BBA is observed to be inert because of over-crystallisation and adhered sand particles, represented as quartz in XRD studies.

Arif et al. [9] studied the performance of bagasse ash on cement, mortar, and concrete. The effect excess lime in cement pastes even after the pozzolanic reaction due to the absence of semi-amorphous SCBA and phase transition at high temperature on pozzolanic activity are examined. The pozzolanic activity index higher than 75% due to the filler effect with the replacement levels of 5, 10, and 15% is reported. Arif et al. [10] studied the deterioration in conventional and SCBA concretes with SCBA as a replacement of sand. Mortar cubes are cast and exposed to Na_2SO_4 diluted by 1% in water for 28 and 90 days. It is observed that SCBA is unreactive, and mass loss is less for 10 % and 15% replacements.

Mali and Nanthagopalan [11] observed recalcination of SCBA at 600-700^{0}C as optimum temperature to maintain the inherently amorphous nature to exhibit a good pozzolanic reactivity by confirming with the modified Chapelle test and Frattini test. The effect of calcination temperature and fineness on the pozzolanic performance of bagasse ash is also reported by Bahurudeen et al. [12, 13]. Reduction in fineness and loss of ignition (LOI) is highly recommended to improve the reactivity. ASTM C-618 recommended a maximum LOI of 12 % beyond which the ash cannot be called class F pozzolans [14].

The effect of inclusion of pozzolanic sugarcane bagasse ash on rheology, durability and strength properties with various replacement levels is reported in few studies with significant improvement in these properties. The 10% sugarcane bagasse ash replacement level is observed to be optimum for significant improvement concrete properties [15-19]. Subramaniyan and Sivaraja [20] discussed the performance of SCBA concrete with 0% to 40% replacements of cement on workability, mechanical and durability of SCBA concrete. Durability is assessed using sulphate attack, chloride attack, rapid chloride permeability and sorptivity tests. The strength and durability properties of SCBA concrete are shown to be improved due to pozzolanic reactivity and filler effect of SCBA in concrete mix.

Chindaprasirt et al. [21] assessed the mechanical and durability properties, chloride resistance and microstructure of Portland fly ash cement concrete containing high volume bagasse ash. It is shown that the addition of high-volume SCBA into the concrete mix reduced the water demand and chloride penetration depth due to the reduction of critical pore size resulting from the synergistic effect. Rajasekhar et al. [22] examined the durability characteristics of ultra high strength concrete with treated sugarcane bagasse ash. The ultra high strength gain of 70% with SCBA as admixture attaining 160 MPa at an optimum replacement of 15% is reported along with the resistance to chloride ion penetration and decreased sorptivity.

Tripathy and Acharya [23], Prabhath et al. [24] presented the reviews on characterization of bagasse ash and its use in concrete as a supplementary binder and reported the studies on rheology, strength and durability of SCBA modified concrete. An optimum replacement of 20% is shown to be effective as a supplementary binder and filler material.

Zareei et al. [25] studied the microstructure, strength, and durability of eco-friendly concretes containing sugarcane bagasse ash. It is concluded that incorporation of SCBA up to 5% improved the performance of concrete in terms of strength, durability and impact resistance.

From previous researches it is observed that optimum replacement dosage of SCBA is varying from 5-20% in production of concrete. The improvement of properties of cement mortar or concrete depend on several factors such as pre-treatment conditions, chemical composition, LOI, and particle size distribution or specific surface area or fineness of SCBA. A detailed investigation is necessary to understand the material properties of SCBA to bring out into the existing usage. Besides, limited studies are observed on acid resistivity of SCBA based concrete.

The present study deals with characterization of locally available SCBA after heating at 600^{0}C for 2 hours followed by ball milling of 240 minutes to enhance the material properties and understanding its morphology by SEM, TG/DTA, and FTIR analysis. The suitability of SCBA is examined for strength and durability studies on standard concrete by replacing cement with SCBA by 5, 10, 15, 20 and 25%. A reference mix of M_{35} grade is used to compare the results of the strength and durability parameters of SCBA concrete. The influence of SCBA is examined on compressive strength, split tensile strength, capillary sorption, and acid resistivity to find the optimum replacement level.

1.1. Research Significance

Cement is the most energy intensive material in concrete production. To minimize the environmental hazards from cement industry, there is a need to use less energy intensive materials. Efforts are being made to find supplementary materials to replace cement. SCBA has such potential. This paper deals with the physiochemical characterization of SCBA and its influence on the properties of concrete and provides information on SCBA modified concrete with respect to strength and durability of standard concrete.

2. Materials and Methods

2.1 Materials

Ordinary Portland Cement (OPC) of compressive strength 53 MPa at 28 days confirming to IS 12269 (2013) [26], granite originated coarse aggregates of 20 mm and 12mm size, and river sand confirmed to IS 383: 2016 [27] are used in the present study for concrete mix design. Results of sieve analysis are presented in Fig. 1.

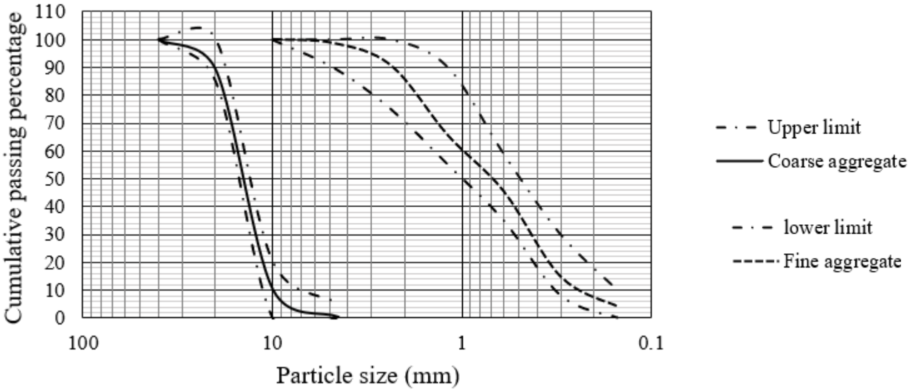


Fig. 1 Sieve analysis of coarse and fine aggregate

SCBA is collected from local sugar mills and pre-treated at 100^{o}C to remove the moisture before mixing with OPC. Further, SCBA is heated at 600^{0}C for 2 hours and pulverized to micro-size (finely divided) by ball milling for 240 minutes to crush the quartz-silica and improve the specific surface area of SCBA particles. Standard sand is used to carry out the strength activity test of SCBA.

2.2 Physical Properties

Specific surface area, soundness, specific gravity of the cement, raw bagasse ash and processed ash are measured confirmed to IS 1727:1967 [28] and loss of ignition (LOI) determined according to IS 4032(1985) [29] by Blaine's air permeability apparatus Soundness test is performed using Le-Chatelier's apparatus to confirm the presence of magnesium in cement pastes which causes volumetric change. Specific gravity is an indirect measure of carbon content. Lower specific gravity leads to low reactivity due to the high porosity, volumetric change and water retention among particles. So, specific gravity is tested to find the influence on the pozzolanic reactivity of concrete.

2.3 Micro-Structural Studies

SCBA is tested in its as-received form and tailored to suit the properties of cement. VEGA 3 SBH (TESCAN Brno SRO) Scanning electron microscope is used to understand the morphology of SCBA and concrete samples. A beam of electrons is allowed to pass through a vacuum medium, only to hit the amorphous sample, which tends to generate secondary electrons, backscattered electrons and x-rays. The images and refracted electrons data from SEM associated with EDS are used to study the bagasse ash's particle size, texture and elemental composition. Mass loss of sugarcane bagasse ash with temperature change is studied by thermos-gravimetric analysis associated with DTG and DTA by Hitachi STA 7200. The energy absorption of the sample is determined to identify the SiO_2 functional group using Fourier transformation infrared spectroscopy (FTIR). XRF study is done to find the complete composition of the sample which is used to characterize the output of experimental result.

2.4 Strength Activity Index (SAI):

SAI is determined by casting 3 cubes of SCBA based motors and 3 cubes of OPC motors of 50 mm size on each side as specified by IS 1727:1967[28]. The compressive strength test of the cubes is evaluated to find the percentage of SAI by the following formula:

Strength Activity Index (SAI) = $\frac{A}{B}x100$

A= Average compressive strength of SCBA motor

B=Average compressive strength of control mix

2.5 Mechanical Properties:

Normal Concrete of M35 grade is prepared according to IS 10262:2019 [30] as a reference mix. The mix proportions of ingredients are shown in Table 1. A poly-carboxylate ether-based superplasticizer is used to attain the desired workability of concrete. Compressive strength and split tensile strength tests are conducted according to IS 516:1959 [31] on standard samples. 90 concrete cubes of 150 mm size for compressive strength and 90 cylinders of 300 x 150 mm for split tensile strength were cast conforming to IS 5816:1999 [32] to understand the behaviour of SCBA concrete in compression and tension. Samples were cured in potable water of pH 7, free from chemicals and particulate solids for 3, 7, 28, 56 and 90 days.

For each variable of compressive strength, mean of 3 samples is taken to present the final test results after finding the difference between the samples is less than 15% of mean compressive strength. The test results of the samples are taken as average of the strength of three specimens after checking the variation which is less than 15% of the average[7].

Table 1. Materials used in the present study (Kg/m^3)

% SCBA replaced	Cement (Kg)	SCBA (Kg)	Aggregates (Kg)	Sand (Kg)	Water (Kg)	Plasticizer (Kg)
0	383.16	0	1287.4	674.37	172.42	3.83
5	364.00	19.16	1287.4	674.37	172.42	3.83
10	344.84	38.32	1287.4	674.37	172.42	3.83
15	325.68	57.48	1287.4	674.37	172.42	3.83
20	306.52	76.63	1287.4	674.37	172.42	3.83
25	287.37	95.80	1287.4	674.37	172.42	3.83

2.6. Durability Properties

Sorptivity is the measure of the surface porosity of concrete. ASTM C 1585:2013 [33] is used to perform this test and study the level of the permeability of the samples on the surface of adsorption. The circumference of the sample is sealed to stop the ingression of molecules from the non-experimental surfaces. The results of sorptivity are evaluated from the formula;

$$I = m_t / ad \tag{1}$$

where I = the absorption in mm, m_t = change in mass of the specimen in gm at time t, a = the exposed area of the specimen, in mm^2, and d = the density of the water in g/mm^3.

2.7. Acid Resistivity

An acid tolerance test is conducted on 100 mm cube samples which are cured in water for 28 days with 3% HCl and H_2SO_4 as per ASTM C666 [34] and tested according to ASTM C267-01 [35]. The effect of acid reaction on cement compounds is studied by exposing the samples to acid media in the laboratory with respect to stability of dimensions, mass loss and strength loss of concrete and assessed the effects with following procedures.

- The change in diagonal dimensions is evaluated before and after immersing the samples in an acid bath, and an acid attack is noted from the formula
  Acid attack factor = $(\Delta A/A) * 100$,
  ΔA = Change in dimensions with respect to immersion for 28 days,
  A = Original dimensions before immersion.
- Mass loss is the effect of acid on turning the calcium hydroxide into a white precipitate, which affects the bonding properties of concrete.
  Mass loss factor (%) = $(\Delta M/M) * 100$,
  ΔM = Change in mass with respect to immersion for 28 days,
  M = Mass of OPC/SCBA concrete before acid attack.
- The mechanical properties of acid-immersed samples are evaluated to find the resistance to chemical attack and the integrity of the concrete. The strength of samples is taken at the age of 28 days curing, and it is calculated as
  Strength loss factor (%) = $(\Delta C/C) * 100$
  ΔC = Compressive strength changed due to acid attack,
  C = Compressive strength of reference samples (0% SCBA) at 28 days.

The durability loss due to several factors are studied from the following formula.

Acid durability loss factor (ADLF) = (Mass loss) * (Strength loss) * (Dimension loss)

3. Results and Discussion

3.1. Physical Properties

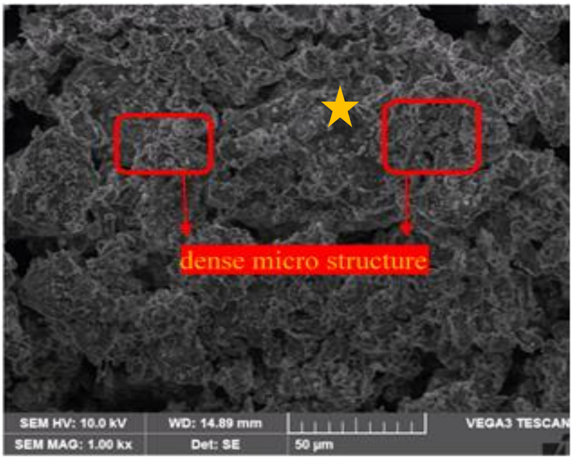
Results in Table 2 shows the soundness of SCBA is observed to be within the limits of 10mm. Due to pre-treatment, there appeared to be mass loss and particle morphology in SCBA. Presence of high carbon, organic substances lead to high LOI. Reduction in LOI and specific gravity resulted from testing the sample at 1000^{0}C heated for 30 minutes is observed in the present study. Studies reported a low binding property and poor pozzolanic reactivity due to high LOI [14, 19]. High LOI leads to less reactivity as reported by earlier studies. Increased specific surface area in SCBA from 132 m^2/Kg to 441 m^2/Kg is resulted from grinding the particles.

Table 2. Physical properties of SCBA and OPC

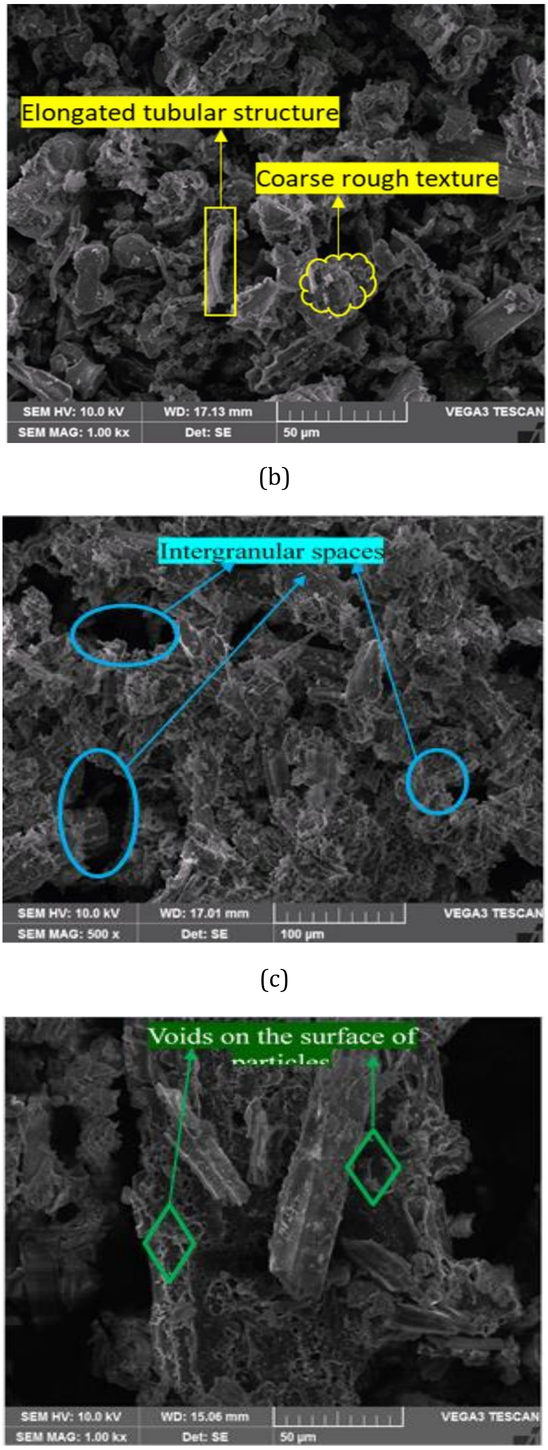
Property	Raw SCBA	Processed SCBA	OPC
Specific surface area (m^2/Kg)	132	441	300
Specific gravity	1.8	2.00	3.15
Soundness (mm)	2.1	1.79	1.80
LOI (%)	22.5	4.20	3.00

3.2. Micro-Structural Properties

SEM micrographs of OPC and SCBA show a variation in particle size, texture, and package density. Fig 2(a) represents a thick and densely packed molecular structure of OPC. In SCBA samples, SEM micrographs shown in Fig. 2(b) depicts tubular, flaky, cylindrical, coarse, and rough textured structure. Rough texture replicates the original particle texture of SCBA whose particle size was above 150 microns. Researches noted that the rough texture led to water retention and reduced flowability of SCBA while mixing with concrete ingredients [11]. Fig. 2(c) shows higher spaces between the particles which reduced density of SCBA and resulted in low specific gravity. Fig. 2(d) shows voids on the surface of SCBA particles resulted from partial or improper combustion.



(a)

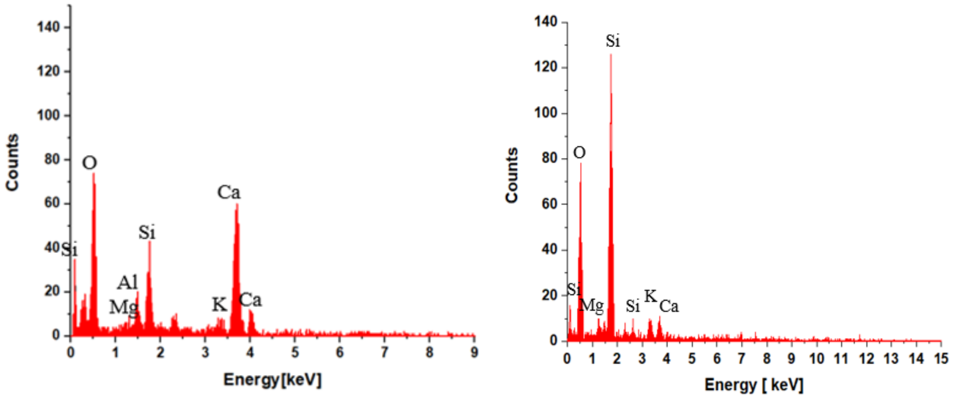


(b)

(c)

(d)

Fig. 2 SEM images of OPC and SCBA



(a) (b)

Fig. 3 EDS of OPC and SCBA

Elemental composition of OPC and SCBA, associated with SEM from Fig. 3 indicates that silica oxide dominates other elemental oxides in SCBA, and Ca dominates in OPC. The results of EDS are presented in Table 3. The total oxide composition of silica, alumina and iron are found to be 79.45% which satisfies the minimum criteria of class N pozzolan [36]. Fig.4 shows FTIR spectra with a huge peak with a wavenumber of 1048 due to stretching of SiO_2 ions after absorbing the energy. Mali and Nanthagopalan [11] observed broad peak at 1104 cm^{-1} which is recognized as vibration of Si-O bond.

Table 3. Mineral composition of OPC and SCBA

Mineral Oxides	Raw SCBA	Processed SCBA	OPC
SiO_2	43.10	68.38	19.82
CaO	3.45	5.26	63.2
Al_2O_3	4.42	5.25	4.08
Fe_2O_3	6.45	5.82	3.28
MgO	2.13	2.65	4.32
Na_2O	1.23	0.06	0.05
K_2O	2.55	2.62	0.78

Thermo-gravimetric analysis (TGA) studies are conducted to find the amount of organic and inorganic composition in material. Results are shown in Fig. 5. The volatile, thermal sensitive and non-metallic oxides are expected to exhibit their behaviour when exposed to gradual heating. From previous thermo-gravimetric analysis on mass loss of rice husk ash particles, there appeared 3 major peaks. In 1% of total weight reduction, 5.87% of weight loss is due to elimination of water molecules, 48.05% due to active pyrolysis and 20.14% due to passive pyrolysis [37]. In present study, SCBA shows a weight loss from 100 to 95.8% with a major weight loss in 2 peaks. Out of total mass loss of 4.2%, a loss of 48% occurred between 85 to 100 ^{0}C and 28.25% between 200 to 300 ^{0}C due to removal of water molecules and CO_2, caused by heating after which temperature gets flattered. DTA graph (Fig. 4) shows an exothermic hump from 100^{0}C to 400^{0}C and a gradual decrease from 400^{0}C onwards showing a release of thermal energy caused by decomposition. The results agree with LOI and TGA studies.

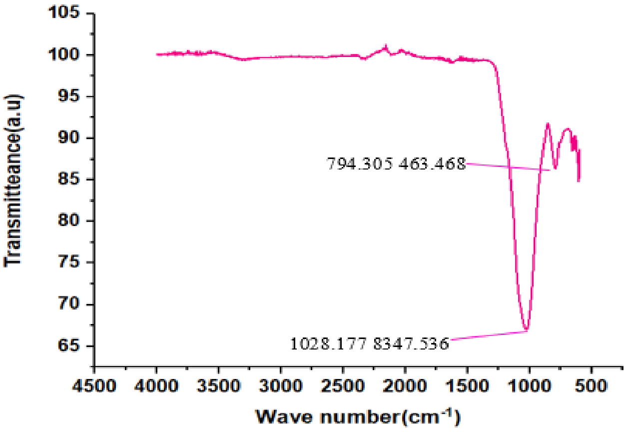
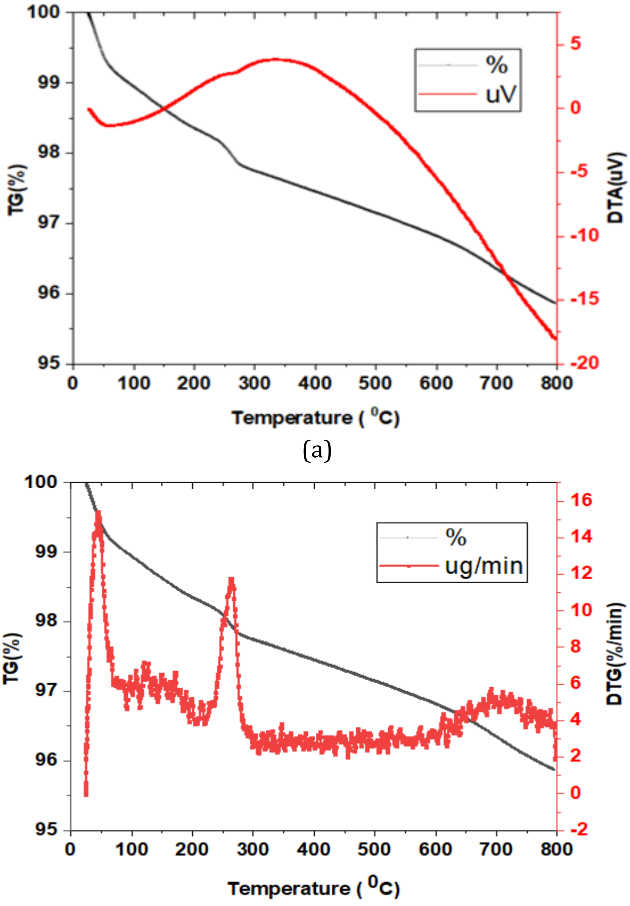


Fig. 4 FTIR of SCBA



(a)

(b)

Fig. 5 TGA of SCBA

The pozzolanic reactivity of SCBA is observed by strength activity index at 28 days. Results show an activity index of 82.98% for SCBA motors showing a reactivity of SCBA particles with OPC.

3.3. Mechanical Properties of Concrete

3.3.1. Compressive Strength

Conventional concrete and SCBA modified concrete are cured for 3, 7, 28, 56 and 90 days to study the effect of curing on the compressive strength of SCBA concrete. The results are shown in table 4. Fig. 6 depicts the results of compressive strength. Increase in strength is observed in all ages and replacement levels of SCBA and increased with the age of curing. SCBA samples exhibit strength gain from day 3 onwards, continued till 7 days. At 28 days, highest strength gain is observed in 15% replaced SCBA concrete. Ganesan et al. [38] observed similar results; an optimum replacement of 10% among 5,10,15,20,25 and 30% replacements of SCBA in concrete samples mix designed for a characteristic compression strength of 25 MPa, crediting the enhanced particle morphology of SCBA resulted from pre-heating at 650^{0}C. Till 20% replacement, the strength attained is similar to conventional concrete. Andrade et al. [39] found an increase of 3.72%, 22.56% and 20% for 5, 10 and 15% replacements due to physical effect, dense packing and pozzolanic reaction. Several researchers reported the strength gain with an optimum replacement of 5 to 15% with an increase in properties of concrete [13]. The results vary by different pre-treatment conditions, chemical composition, and material properties of SCBA.

Table 4 Compressive strength of SCBA concrete

% of SCBA	3 days	7 days	28 days	56 days	90 days
OPC	2.125	30.25	44.12	46.12	47.11
5% SCBA	2.250	31.13	46.45	47.15	47.58
10% SCBA	2.300	32.64	48.32	50.00	50.53
15% SCBA	2.502	34.10	50.50	55.21	55.67
20% SCBA	2.125	31.00	44.10	46.20	47.26
25% SCBA	2.100	30.25	43.08	45.23	47.00

Bahurudeen et al. [40], Jagadeesh [41] observed strength gain in concrete and mortars at an optimum replacement of 25% at the 28 days curing due to pozzolanic reactivity resulted from enhanced material properties of SCBA. In the present study, there appeared an increment in strength due to the pozzolanic effect resulting from the pre-treatment of SCBA. After an optimum replacement of 15%, there appeared a reduction in strength compared to SCBA but an increase in strength (20% replaced SCBA concrete) compared to conventional concrete due to the filler effect (which gave the strength results similar to conventional concrete) and a reduction in strength at 25% due to dilution effect resulted from the exhaustion of free lime and inert SCBA particles. Among all the specimens, maximum strength gains of 55.65, 55.52 and 50.50 MPa are observed at 90, 56, and 28 days of curing, respectively, with 15% SCBA samples. The highest strength at 90 days is due to extended hydration period. A reduction in strength at 25% replacement of SCBA is observed because of the inertness of SCBA. The high volume of bagasse ash has reduced the proportion of cement, reducing the compressive strength of concrete. SCBA can be used as a filler material at a replacement of 20% as the strength of SCBA concrete is similar to OPC. SCBA can be used to replace cement by 5,10 and 15% in concrete due to its high silica content and attaining higher strength than conventional concrete due to reaction with free lime, forming additional C-S-H bonds as a result of pozzolanic reactivity [42].

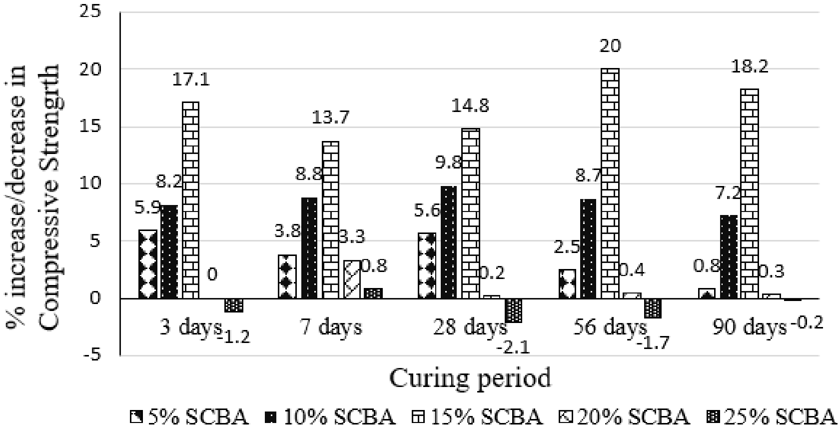
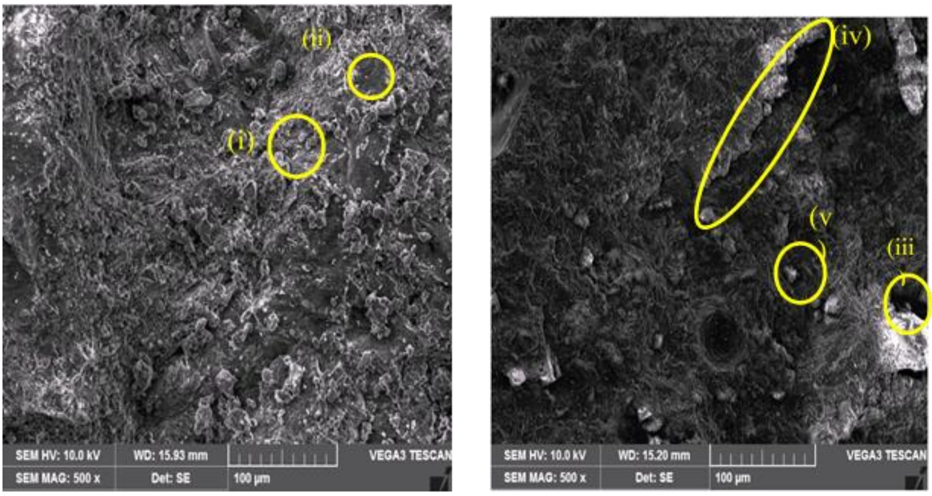


Fig. 6 Results of compressive strength of SCBA concrete

The powdered sample is collected from the core of the concrete cube, after conducting compressive strength test. The micro-structure evaluation is carried out by conducting SEM/EDS tests on the powdered samples.



(a) (b)

Fig. 7 (a) SEM images of hydrated SCBA concrete at 28 days of curing (b) SEM images of hydrated conventional concrete at 28 days of curing.

Fig. 7 shows SEM analysis of hydrated SCBA and conventional concretes. Visual inspection of micrographs in Figs. 7(a) and 7(b) revealed that SCBA has formed a dense micro-structure with the reaction products varying with the availability of water molecules and calcium silica oxides. Fig. 7(a) shows the formation of hardened concrete. (i) a non-porous hardened compound (ii) thick dense, fibrous formation is identified as C-S-H gel from EDS (Fig. 8) studies and comparative study with previous literature. SEM images in Fig. 7(b) show a complex structure of conventional concrete with (iii) micropores of higher radius,

(iv) appearance of fissure due to a weak bonding between few compounds at 28 days and
(v) unreacted particles in the composition of OPC samples.

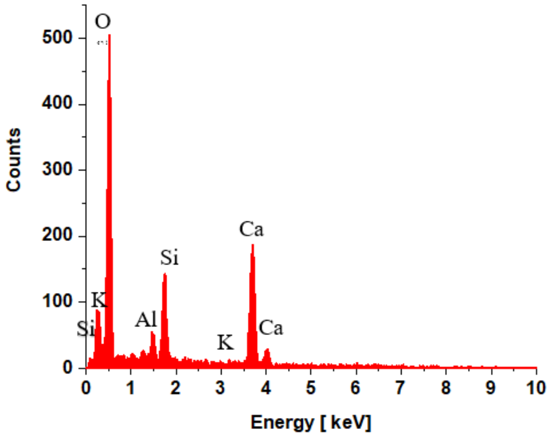


Fig. 8 EDS at (v) showing presence of Calcium-Silica as major composition along with Aluminium and Potassium oxides

3.3.2. Split Tensile Strength

The numerical results of tensile strength of conventional and SCBA concretes are presented in Table 5 and Fig. 9. For structural applications, tensile strength is important to know the resistance of concrete under tensile and flexural stresses. This strength increased continuously with increase in SCBA up to 15% and then showed the decreasing trend. The highest split tensile is observed in 15% replaced SCBA samples at all ages of curing compared to the reference concrete. The highest tensile strength 5.6 MPa in 56 days and 5.7 MPa in 90 days cured samples is observed with 15% SCBA. The increase in this strength is attributed to the additional C-S-H bonds formed by pozzolanic reactivity and the enhanced hydration. The reactive silica of SCBA has bonded with Ca $(OH)_2$ and water, which has led to the additional formation of C-S-H gel, increasing the strength and stiffness of concrete.

Table 5 Split tensile strength of SCBA concrete (MPa)

% of SCBA	3 days	7 days	28 days	56 days	90 days
OPC only	0.225	3.10	4.50	4.80	4.92
5% SCBA	0.270	3.25	4.80	4.90	5.10
10% SCBA	0.225	3.30	5.13	5.35	5.36
15% SCBA	0.270	3.50	5.30	5.60	5.77
20% SCBA	0.241	3.36	4.75	5.03	4.75
25% SCBA	0.224	3.20	4.44	4.50	4.72

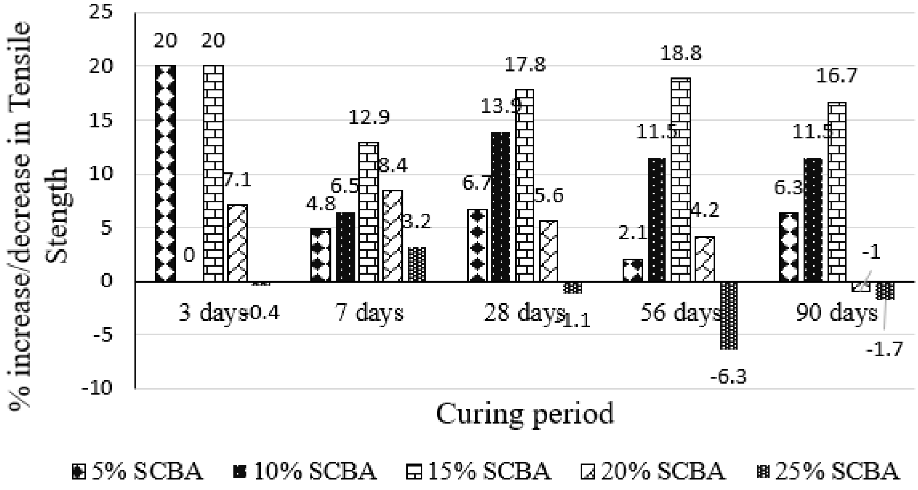


Fig. 9 Results of split tensile strength of concrete

3.3.3. Sorptivity

The change in weight of concrete discs (samples) is noted with reference to time in intervals of 1, 5, 10, 20, 30 and 60 minutes till 9 days according to ASTM C-1585 and represented in Fig. 10. The saturation level is shown with no gain in weight of the sample and steady absorption rate.

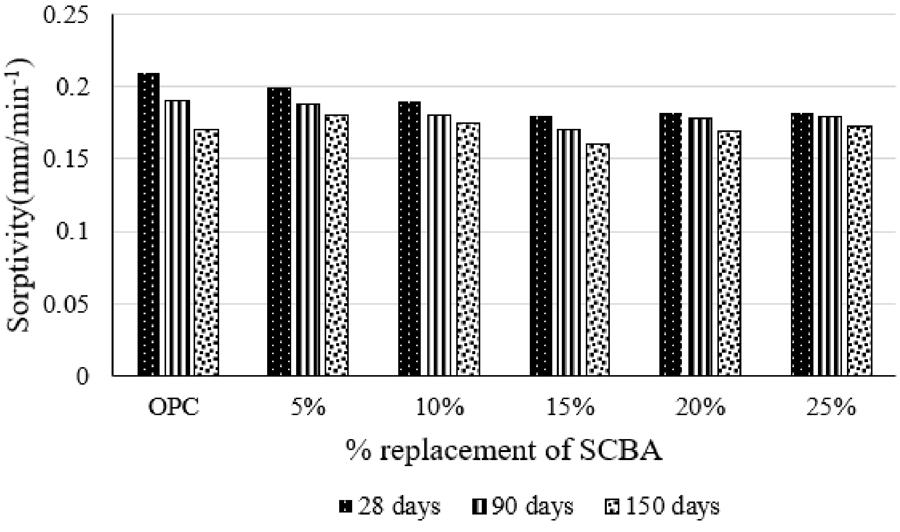


Fig. 10 Sorptivity of SCBA concrete

The sorptivity values of the concrete specimen with OPC retain high moisture content due to high porosity, observed at the end of the saturation period of 28, 90 and 150 days, with values of 0.21, 0.19, 0.17 mm/min$^{1/2}$ as shown in Fig. 10. Bahurudeen and Santhanam [36] found a deviation of the Sorptivity index results from other permeability tests at 56 days showing a least absorption rate at 5% replacement of SCBA. In the present study, the sorptivity experiment for 28, 56 and 90 days of curing are conducted to assess a comparative performance. Sealing of the surface of the specimen on circumference allows permeability uni-directionally which is equally exposed to cement matrix and coarse aggregate. The present study allows high saturation conditions by extended curing of 56 and 90 days. Results in Fig. 11 show that the moisture content is found to be minimum in samples of 15% replacement which is 88.1, 81 and 76.2 for 28, 90, and 150 days, respectively. The reduction in moisture content is attributed to filler effect and the fragmentation of pores due to the pozzolanic reactivity of SCBA, which has reduced the porosity and capillarity of water molecules. Similar results were observed in sorptivity tests carried out by Muthadhi and Kothandaram [43] in rice-husk ash which kept reducing with an increment in the replacement level of rice husk ash in 5,10, 15, 20 % with an optimum replacement level of 20%.

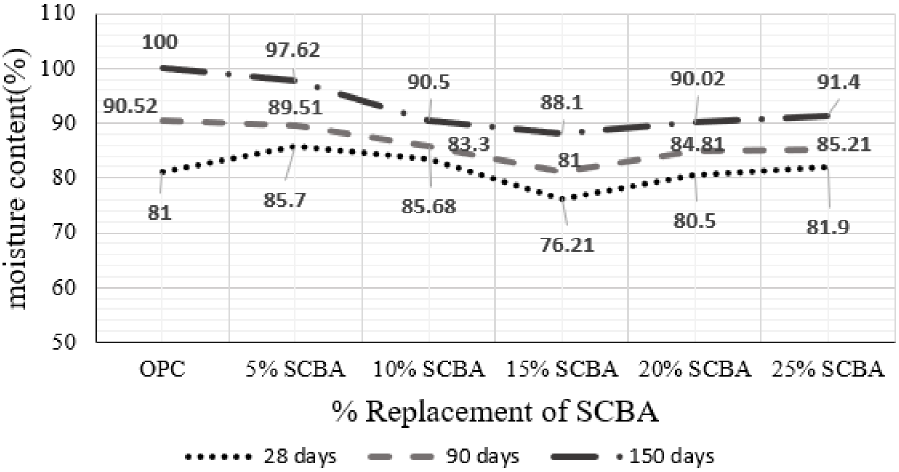


Fig. 11 Change in moisture content with change in replacement level of SCBA

3.3.4. Acid Resistivity

Samples cured for 28 days are collected, surface rubbed with soft cloth are weighed and dimensions are measured. The mass loss, strength loss and dimension loss are calculated and results are tabulated below (Table 6 and Table 7). Cement-based materials deteriorate in acidic atmospheres due to the high alkaline nature of OPC. Calcium silicates, on hydration, is expected to form C-S-H and free lime; forms an insoluble organic compound calcium sulphate ($CaSO_4.2.H_20$) in the presence of sulphuric acid. Instead of hardening, weak bonds develop between the molecules leading to reduction in strength [44]. Joshaghani and Moeini [45] observed an increase in the mass of OPC and SCBA samples due to the formation of ettringite and gypsum when the samples were cured in Na_2SO_4 at 28 days and a decrease in mass at 360 days. In present study, it is observed that the dimension, strength and mass losses are reduced in SCBA samples with replacement levels of 5,10,15,20 and 25%.

Degrading the outer layer by precipitating portlandite increases the intensity of acidic corrosion into inner layers either by pores or through the transportation of ions. Gutberlet et al. [46] studied the effect of degradation by HCl and observed a mass loss due to the dissolution of portlandite from de-calcification of C-A-S-H in hydrated samples cured for 90 days. HCl tends to form a layered structure due to the formation of Friedel's salt and ettringite in the presence of magnesium. Silica gel and silica polymorphs agglomerated at the transition zone initiate the layering, which has high intensity of chlorine attack on concrete. From the durability loss index results from present study, it is understood that the concrete produced with OPC and SCBA showed less reactivity in H_2SO_4 atmosphere compared to that in HCl. It is observed that the loss in durability caused by mass loss, which showed a co-relation coefficient value 0.987 and 0.989 for curing conditions in H_2SO_4 and HCl. Figure 12 shows the formation of white precipitate around cementitious compounds in acid-cured samples. Improper hydration, dissolution of calcium ions, and deterioration of internal structure has led to mass reduction of concrete.

Table 6 Effect of HCl on SCBA concrete at the age of 28 days curing

% of SCBA	Mass loss factor (%)	Dimension loss factor (%)	Strength loss factor (%)	Durability loss factor (%)
OPC	3.28	2.520	70.25	580.65
SCBA 5%	3.15	2.458	68.74	532.23
SCBA 10%	2.54	2.357	68.10	407.70
SCBA 15%	2.20	2.358	67.80	351.72
SCBA 20%	2.80	2.490	68.00	474.10
SCBA 25%	2.81	2.474	68.67	477.39

Table 7 Effect of H_2SO_4 on SCBA concrete cured for 28 days

% of SCBA	Mass loss factor (%)	Dimension loss factor (%)	Strength loss factor (%)	Durability loss factor (%)
OPC	3.20	2.50	68.50	548.00
SCBA 5%	3.12	2.45	67.20	510.38
SCBA 10%	2.50	2.35	66.32	389.63
SCBA 15%	2.03	2.34	65.00	305.50
SCBA 20%	2.75	2.40	65.53	432.50
SCBA 25%	2.71	2.47	65.62	437.62

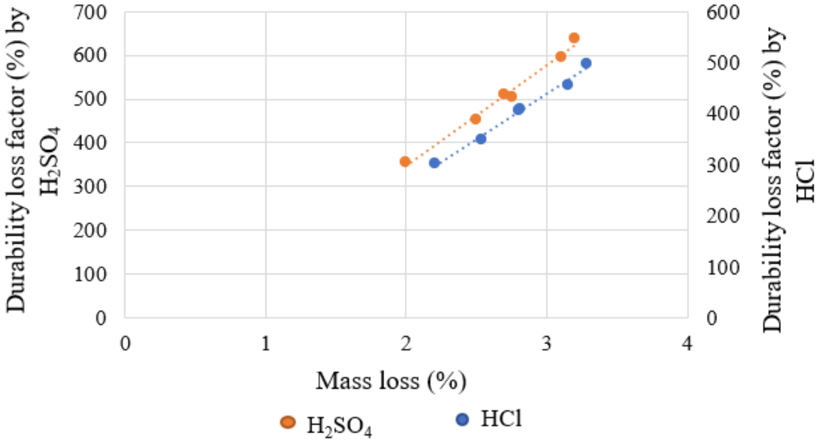


Fig. 12 Co-relation between mass loss and durability of concrete

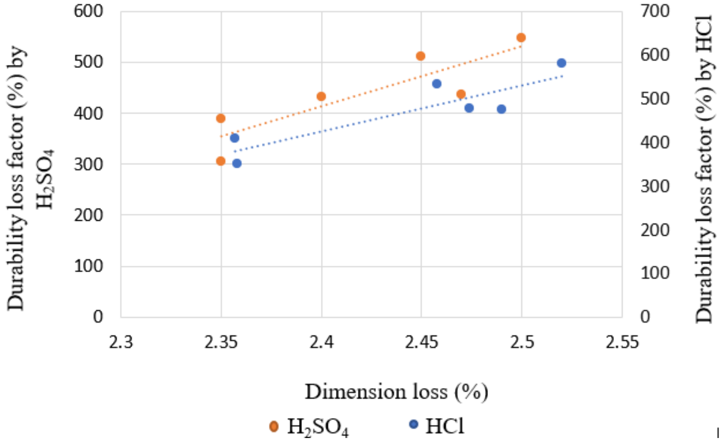


Fig. 13 Co-relation between dimension change and durability of concrete

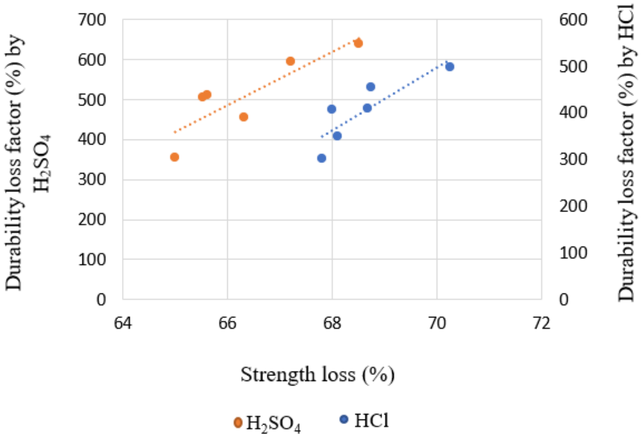


Fig. 14 Co-relation between strength loss and durability of concrete

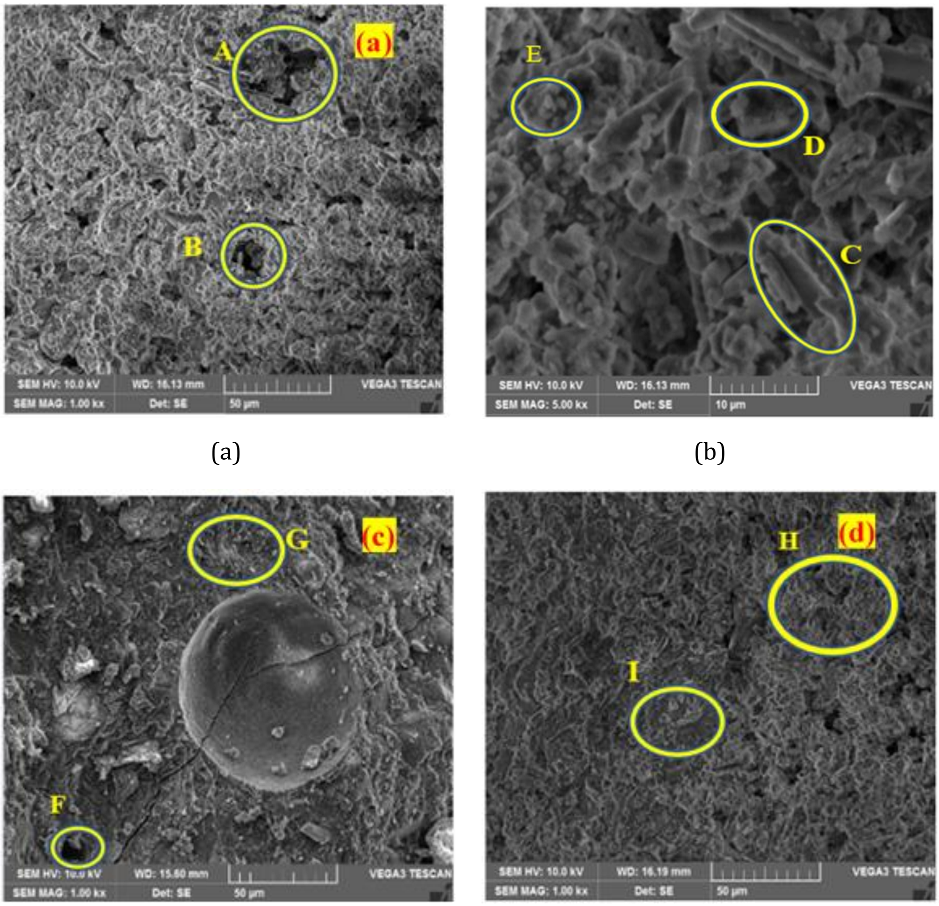
Table 8 Correlation between the durability properties of concrete cured in acid solution

Acid environment	Factor affected	Regression Equation	R^2
H_2SO_4 acid	Mass loss	y = 197.58x - 97.847	0.9870
	Strength loss	y = 57.709x - 3392.4	0.7483
	Dimension loss	y = 1186.2x - 2433.3	0.7552
HCl acid	Mass loss	y = 207.74x - 110.36	0.9890
	Strength loss	y = 78.854x - 4938.2	0.7297
	Dimension loss	y = 1056.1x - 2109.2	0.7841

There is a reduction in strength, dimension change and mass loss due to HCl and H_2SO_4 in all the samples. Table 6 and 7 show that the highest loss is caused in conventional concrete due to the excess calcium levels present in OPC, which precipitates in presence of HCl and H_2SO_4.While silica being a semi metallic compound, doesn't precipitate and react as aggressive as OPC. It is difficult to evaluate the durability quotient when several parameters judge deterioration. Co-relation between the individual factors is plotted and represented in figure 12, 13 and 14 where the influence of both the acids on the three properties of concrete is observed. The linear regression graphs shown in Table 8 indicated that mass loss of acid cured samples had highest correlation of 0.97 and 0.98 with maximum durability loss of concrete.

3.3.5. SEM Analysis of Acid Cured Concrete

There appears to be a white precipitate around hydrated samples resulting from dissolution. The following conclusions are drawn from the micro-structural analysis of SCBA concrete exposed to H_2SO_4.



(a) (b)

(c) (d)

Fig. 15 SEM images of SCBA concrete at 28 days

- *A* - Hydration of concrete with high porosity,
- *B* - Presence of voids and white precipitate around hydrated samples,
- *C* - Unreacted SCBA particle,
- *D* - Higher magnification of C-S-H, white precipitate around the hydrates,
- *E* - White precipitate found all over the matrix,
- *F* - Unreacted portion with low density of cement matrix,

- *G* - Hydrated portion.
- *H,I*- C-S-H in acidic medium

Microscopic images of hardened concrete cured in acid solution is shown in Figure 15.Fig. 15(a) shows the complete hydrated concrete in the presence of dilute sulphuric acid. Despite the presence of acid, there appeared a hydration. However, week bonding between the cementitious particles is represented as white precipitate in Fig. 15 (b). Fig. 15 (c) depicts a porous concrete matrix in H and completely hardened matrix in I where G also shows similar texture which is formed due to C-S-H. Micro voids and cracks are appeared in Fig. 15(d). The elemental composition shows the presence of sulphur along with Ca, Al and silica oxides as observed in EDS studies shown in Figure 16.

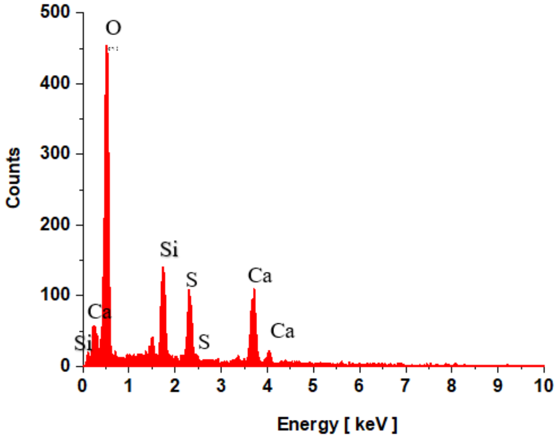


Fig. 16 EDS for SCBA concrete cured in H_2SO_4

4. Conclusions

An in-depth investigation on the material properties of SCBA and its performance in SCBA-modified concrete is assessed from mechanical, durability and micro-structural tests. The following conclusions are drawn from the results and discussion:

- Silica dioxide is found as major composition of SCBA from EDS and FTIR test results; which is an important elemental oxide for pozzolanic reaction. TGA studies show a mass loss around 100 and 250^0C conforming the presence of moisture entrapped between the particles along with CO_2. SEM images show a non-spherical, elongated particle shape and rough-granular texture and is highly porous topography of SCBA. Studies on physical properties show that pre-treatment has increased the fineness, and reduced the carbon content and LOI, enhancing the material properties of SCBA. Strength Activity Index test confirms the pozzolanic reactivity of treated sugarcane bagasse ash.
- The highest compressive strength as 55.65 MPa at the age of 90 days curing and highest split tensile strength as 5.35 MPa at 56 and 90 days of curing are found in 15% replaced SCBA concrete due to pozzolanic reactivity of SCBA with cement. At 20% and 25% replacements, the compressive strength gain has started reducing, however, SCBA concrete attained the mean target strength of 43.25 MPa as per design specifications.

- The water sorptivity of SCBA samples is found to be reduced in all the samples containing SCBA. Least moisture content of 88.1%,81% and 76.21% is found in 28,90 and 150 days of curing in 15% SCBA concrete. The discretization of pores resulting from pozzolanic reactivity has enhanced the micro-structure of SCBA concrete. Further, SCBA particles acted as fillers in capillary pores, obstructing water molecules' ingression into the concrete. A reduction in resistivity of water molecules in 20% and 25% is observed because of reduced C-S-H matrix.
- OPC and 5% SCBA samples exposed to HCl suffered maximum durability loss with Acid Durability Loss Factor (ADLF) of 580.65% and 532.23%. Unlike other durability test results, SCBA concrete has shown high resistance to acid attack with 10%, 15%, 20%, 25% replacement levels due to the inert reaction of silica to HCl and H_2SO_4.
- The conclusions suggest that SCBA can be used as mineral admixture after selective pre-treatment at an optimum replacement of 15% to enhance the strength, durability, and acid resistivity of concrete.

Acknowledgement

The authors are thankful to the Vignan's Foundation for Science, Technology, and Research (Deemed to be University) for infrastructure, lab facilities, and constant support for this research work.

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