Physicochemical analysis of sugarcane bagasseash (SBA) blended concrete to evaluate the pozzolanic activity of SBA

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Abstract. Sugarcane bagasse ash (SBA) is the residue of burnt sugarcane bagasse used as a fuel in the co-generation units. The enormous quantities of SBA obtained as waste material from the co-generation units can be utilized as a pozzolona. This article presents the investigation on the physical and chemical analysis on concrete made with OPC blended with SBA. Experimental investigation is performed on M30 grade concrete which forms the control mix. SBA blended concrete is obtained by partially replacing the OPC with SBA at different percentages. The workability of the fresh concrete and compressive strength at 7 and 28 days of the control concrete and SBA blended concrete are determined. The particle size distribution, surface area and specific gravity of OPC and SBA were determined using HORIBA zeta analyzer, BET surface area analyzer and Standard Le-chatelier flask respectively. The chemical composition of SBA and OPC was obtained using XRF technique and the mineralogical analysis of SBA was carried out using XRD technique. To evaluate the pozzolanic activity of SBA, the hardened concrete matrix wereanalyzed for their microstructural and chemical composition using SEM and EDS techniques. The compressive strength results indicate that replacement of OPC by SBA upto 20% is beneficial. The SEM images and EDS analysis substantiates the pozzolanicbehavior of SBA at different replacement percentages.

Keywords: Sugarcane bagasse ash (SBA), Pozzolanic activity, Microstructure of concrete, SEM, EDS, XRF, XRD.

1. Introduction
In recent years, research associated with agricultural wastes is intensifying with the aim of evaluating their potential for recycling also because the elimination of the landfills. During this research line, the works are focused mainly on the sugarcane wastes, since sugarcane is widely cultivated across continents for higher profitability as compared to other crops like wheat, paddy and cotton. The term bagasse or migasse refers to the fibrous residue obtained from the milling plant of sugar factories where the sugarcane is crushed to extract the juice[1]. The cogeneration activities in sugar factories have evolved methods of using bagasse more effectively to generate steam and consequently, electric power more efficiently and economically. Bagasse, being a sulphur free fuel (unlike coal, petroleum fuels which contain lot of sulphur) its usage as fuel is an environmental friendly technology. When bagasse is burnt in combustionboiler under controlledconditions, the residue obtained is known as sugarcane bagasse ash (SBA), which has pozzolanic properties.
Enormous quantities of SBA are obtained as waste material from the combustion boilers of cogeneration units in sugar factories. India produces about 67000 tonne of SBA per day, mostly disposed as landfill which leads to environmental problems [2]. The bagasse ash which is characterized by its black color and unburnt matter, when disposed as landfill, will lead to the pollution of water bodies. Also the fine fraction of the SBA causes severe air pollution, affecting the residential areas located in the vicinity of the sugar factories [3]. It's imperative to seek out reuse of bagasse ash rather than disposal.

SBA mainly consists of amorphous silica; hence this byproduct are often used as a supplementary cementitious material in cement-based paste and concrete, thus minimizing the problems related to the disposal of bagasse ash[3]. Utilization of waste byproducts as a blending material in cements to improve the performance of both mortar and concrete will result in reduction of cost. One effective way to reduce the environmental impact is to use mineral admixtures such as SBA, fly ash, rice husk ash as a partial replacement of cement both in concrete and mortar [4]. The utilization of mineral admixtures improves properties of concrete such as compressive strength, split tensile strength, pore sizes and water permeability of the concrete and mortar because porosity decreases with hydration time [5]. From previous research studies it has been reported that the composition of bagasse ash varies from country to country due to variation in soil composition and water quality [6,7]. Also attempts to use SBA as a pozzolana have yielded different results depending on the source and calcinations process, certain studies have indicated that 10% addition of SBA to OPC optimum limit, and the increase in compressive strength may be both due to physical and chemical processes [8]. Studies on cement mortar have suggested that the SBA possess appropriate physico-chemical properties for its use as mineral admixture and its reactivity was mainly hooked in to particle size and fineness [9]. Also studies on processing of SBA have indicated that Raw bagasse ash have lesser value of pozzolanic activity than the minimum requirement within the standards. Sieving the SBA through 300μm sieve and further grinding to cement fineness (300–320 m2/kg) was suggested to get suitable processed bagasse ash with higher pozzolanic activity [10,11]. Ultra finely ground SCBA to a fineness below about 60 μm and Blaine specific surfaces areas above 300 m2/kg have resulted in products which will be classified as pozzolans [12].

Attempts to use SBA in producing high strength concrete are successful, and therefore the results indicate that the concretes containing up to 30% of SBA exhibit the compressive strength within the range of 65.6–68.6 MPa (at 28 days), which is above that of the control concrete (101–105%) [13]. Investigation on the chemical composition of SBA and their effect on cement mortar have shown that ground bagasse ash with an LOI but 10% provided a superb pozzolanic material and will be wont to partially replace hydraulic cement [14]. From previous studies there is strong evidence that processed SBA exhibits pozzolanic behavior and can be used as a supplementary cementitious material (SCM) in mortar and concrete. The enhancement in the strength properties of concrete is attributed to both physical and chemical processes [8]. As such there is a necessity to conduct a physicochemical analysis of the hardened concrete to understand the pozzolanic behavior of SBA.

The utilization of SBA as a pozzolana in recycled aggregate concrete have shown that replacement of OPC by SBA upto 20% is beneficial [15,16] and it is possible to generate low-cost self compacting concrete with SBA in small percentages [17].

The present study aims at evaluating the pozzolanic activity of SBA used as a supplementary cementitious material for partial replacement of cement. The objective is achieved through strength properties and physicochemical analysis of the hardened concrete. The experimental study is performed on concrete of M30 grade by replacing OPC with 5%, 10%, 15%, 20%, 25% and 30% of SBA by weight. The concrete matrix was analyzed for microstructural and chemical composition using SEM and EDS techniques.

2. Experimental program
2.1. Materials
Ordinary hydraulic cement conforming to 43 grade as per IS: 8112-1995 was used. The fine aggregate used was locally available natural sand conforming to zone-II grading requirements of IS 383-1970 with relative density 2.65 and fineness modulus 2.53, and natural crushed stone of 20mm down size with relative density 2.80 was used as coarse aggregate confirming to IS 383-1970. The sugarcane bagasse ash utilized in the investigation was sourced from a sugar mill located in Ichalkaranji, South Maharashtra region, India. The sugarcane bagasse ash used was collected from cogeneration boilers where sugarcane bagasse is burnt at a temperature of 850°C. The collected ash was processed by sieving through 90 μm and therefore the passing was used during the experimental work. Sieving was done to evacuate the unburnt carbon particles and to expand the area of SBA particles. Sulphonated naphthalene based super-plasticizer was used for correct workability of concrete mix.

The physical and chemical properties of both SBA and OPC have their effect on the strength and durability properties of concrete through filler action and pozzolanic action respectively. Physical characteristics such as particle size distribution, surface area, specific gravity and density were determined. Zeta size of SBA and OPC particles were examined using HORIBA zeta analyzer. The surface area of SBA and OPC were measured using BET surface area analyzer. The specific gravity of SBA and OPC were calculated using the ‘Standard Le Chatelier flask’ according to Indian Standards IS: 1727-2004. Chemical compositions of SBA and OPC in terms of oxides were administered by X-ray fluorescence (XRF) technique. Mineralogical characterization of SBA decided by X-ray diffraction (XRD) technique. Normal consistency and setting time of SBA blended cement paste decided as per IS 4031(part 4)-1995.

2.2 Mix Proportion
The experimental investigation was performed on M30 grade concrete, SBA blended concrete is obtained by partially replacing OPC with SBA at 5, 10, 15, 20, 25 and 30 percent by weight. The mix proportion without SBA (0%) serves as the control mix. The water-binder ratio is maintained at 0.44 for all the mixes. A Sulphonated naphthalene based super-plasticizer with a dosage of 1.7% by weight of binder is used in all the mixes. The mix proportions and mix designation is given in table 1.

| Mix Designation | SBA (%) | Water (Kg/m³) | Cement (Kg/m³) | SBA (Kg/m³) | Cement (Kg/m³) | Sand (Kg/m³) | Aggregate (Kg/m³) |
|-----------------|---------|---------------|----------------|-------------|----------------|--------------|------------------|
| Control, SBA0   | 0       | 170           | 386.36         | 0           | 386.36         | 686          | 1245             |
| SBA5            | 5       | 170           | 367.05         | 19.31       | 367.05         | 686          | 1245             |
| SBA10           | 10      | 170           | 347.73         | 38.63       | 347.73         | 686          | 1245             |
| SBA15           | 15      | 170           | 328.41         | 57.95       | 328.41         | 686          | 1245             |
| SBA20           | 20      | 170           | 309.09         | 77.27       | 309.09         | 686          | 1245             |
| SBA25           | 25      | 170           | 289.77         | 96.59       | 289.77         | 686          | 1245             |
| SBA30           | 30      | 170           | 270.46         | 115.90      | 270.46         | 686          | 1245             |

2.3. Preparation of specimens
The binder component consisting of cement and SBA were weighed according to their mix proportion and were dry mixed on non-absorbent, platform. The fine and coarse aggregates were maintained in saturated surface dry (SSD) state. All the dry ingredients were placed into a pan mixer and to this mix required quantity of water and superplasticizer were added and mixed thoroughly.

The fresh concrete was used to cast cube specimens of size 150 x 150 x 150 mm for compressive strength test. Six cube specimens were cast for each mix proportion, three each for 7 day and 28 day compressive strength test. The specimen were placed in water tanks for curing under controlled environment.

2.4. Testing of concrete

To measure the workability, slump test and compaction factor tests as per IS 1199-1959 were administered on the fresh concrete for every of the combination proportion. Concrete cubes of size 150x150x150 mm were tested for compressive strength as per IS: 516-1959. For every proportion three specimen were tested at 7 day and 28 day respectively. Microstructural and elemental composition of sugarcane bagasse ash blended concrete were investigated on the fractured surface of concrete specimen after 28-day curing using Scanning microscope (SEM) images including microanalysis by Energy dispersive spectroscopy (EDS).

3. Results and discussion

3.1. Physical properties of SBA and OPC

The particle size distributions of SBA and OPC determined using HORIBA zeta analyzer are represented in figure 1(a) and 1(b) respectively. The ashes exhibits similar particle size distributions with mean grain size as 1.3 nm. The mean particle size of OPC was found to be 1191.4 nm. The mean particle size of SBA is far lesser than that of OPC. This fact was further confirmed by the precise area of SBA and OPC which were found to be 7.832 m²/gm and 0.752 m²/gm respectively. The area of SBA is almost about ten times above OPC thanks to the presence of sunshine weight fine particles. As a matter of fact, each particle will participate in hydration reactions supported the particle size and area. The specific gravity of SBA and OPC are 2.1 and 3.15 whereas densities are 410 Kg/m³ and 1025 Kg/m³ respectively due to which SBA particles are Very light in weight as compared to OPC. This is often mainly thanks to the burning of bagasse fibres at higher temperature of about 850°C. Table 2 presents the physical properties of SBA and OPC.
Figure 1(a): Particle size distribution of SBA

![Particle size distribution of SBA](image)

Figure 1(b): Particle size distribution of OPC

Table 2: Physical properties of SBA and OPC

| Physical property        | SBA  | OPC   |
|-------------------------|------|-------|
| Mean grain size (nm)    | 1.3  | 1191.4|
| Surface area (m²/gm)    | 7.832| 0.752 |
| Specific gravity        | 2.1  | 3.15  |
| Density (kg/m³)         | 410  | 1025  |

3.2 Chemical characterization

3.2.1 XRF analysis of OPC and SBA

XRF (X-ray fluorescence) analysis was carried out to study the oxide composition of OPC and SBA. Table 3 presents oxide composition of OPC and SBA. Loss on ignition (LOI) of OPC and SBA was also determined using XRF analysis. The requirements of ASTM C618, which covers the specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete is presented in the table. The results show that the oxide composition and LOI of OPC are within the limits as specified in IS: 8112-2013.

Table 3: Oxide composition of OPC and SBA

| Oxide composition (%) | OPC   | SBA   | Requirement of ASTM C618 |
|-----------------------|-------|-------|--------------------------|
| SiO₂                  | 23.22 | 79.82 | ----                     |
| TiO₂                  | 0.30  | 0.25  | ----                     |
| Al₂O₃                 | 5.89  | 1.88  | ----                     |
|       |       |       |       |
|-------|-------|-------|-------|
| MnO   | 0.00  | 0.04  | ----  |
| Fe₂O₃ | 2.06  | 1.09  | ----  |
| CaO   | 62.34 | 2.04  | ----  |
| MgO   | 0.95  | 1.98  | ----  |
| Na₂O  | 0.19  | 0.19  | ----  |
| K₂O   | 0.34  | 3.82  | ----  |
| SO₃   | --    | --    | <4    |
| P₂O₅  | 0.41  | 1.36  | ----  |
| LOI   | 3.41  | 7.09  | <10   |
| SiO₂ + Al₂O₃ + Fe₂O₃ | ---- | 82.79 | >70 |

The XRF analysis of SBA particles shows SiO₂ (about 79.82%) as major oxide, the rationale being plants consume orthosilicic acid from groundwater [18], which is later polymerized as silica within the plant cells. The residue after combustion presents a chemical composition dominated by silica [19]. Thanks to controlled burning of sugarcane bagasse particles within the cogeneration boiler, reactive amorphous silica is obtained and exists as main component within the residual ashes [7]. The qualitative analysis indicates that SBA has 3 times higher silica content than OPC. The XRF analysis of SBA shows that the sum of (SiO₂+Al₂O₃+Fe₂O₃) is above the minimum requirement stated for sophistication N pozzolan (>70%) consistent with ASTM C618. Moreover the share of sulphur trioxide (SO₃) and LOI of SBA are well below the utmost requirement of 4% and 10% respectively as specified by an equivalent standard.

3.2.2 XRD analysis of SBA
Mineralogical characterization of SBA was determined by X-ray diffraction (XRD) technique. The results of the XRD mineralogical analysis of SBA is shown in figure 2. The XRD spectra of SBA particles indicates the presence of quartz, cristobalite, iron oxide, dolomite and alumina. The mineralogical analysis is typical of SBA from the Indian sub-continent, showing calcareous and cristobalite next to the quartz as main components [20]. The presence of cristobalite in SBA may be due to the burning of bagasse particles at higher temperature (> 800°C) in cogeneration boiler. These findings are in agreement with the results obtained by XRF analysis as presented in previous sections.
3.3 Water consistency, initial and final setting time
Table 4 presents the water required for the normal consistency and the initial and final setting times of the SBA blended paste.

The water required for the normal consistency of the SBA blended paste increases with the percentage replacement of OPC by SBA. Also it is observed that increasing the SBA level in blended cement considerably increases the initial and final setting times. However, all the results are within the acceptable limits specified by IS 8112-1995.

Table 4: Normal consistency, initial and final setting time of SBA blended paste

| Mix    | Normal consistency (%) | Initial setting time (min) | Final setting time (min) |
|--------|------------------------|---------------------------|--------------------------|
| SBA-0  | 28                     | 64                        | 189                      |
| SBA-5  | 29.5                   | 71                        | 210                      |
| SBA-10 | 30.5                   | 83                        | 234                      |
| SBA-15 | 32                     | 110                       | 270                      |
| SBA-20 | 33                     | 140                       | 305                      |
| SBA-25 | 34.5                   | 168                       | 348                      |
| SBA-30 | 36                     | 182                       | 385                      |

3.4 Workability of concrete
The workability of control and SBA blended concrete measured in terms of slump and compaction factor are presented in Table 5. From both the slump and compaction factor test results, it is clearly noticed that the flowability of SBA blended concrete decreases as cement replacement level increases as compared to control mix. This may be due to the higher surface area and presence of nano particles of SBA that demands
more water for proper workability of fresh concrete mixtures. Similar observation was observed in the compaction factor test results as shown in Table 5. Compaction factor test results shows that as cement replacement level increases the compaction factor values decreases.

Table 5: Workability test results

| Mix  | Workability through Slump (mm) | Compaction factor |
|------|-------------------------------|-------------------|
| SBA-0 | 74                            | 0.93              |
| SBA-5 | 70                            | 0.90              |
| SBA-10| 67                            | 0.89              |
| SBA-15| 61                            | 0.87              |
| SBA-20| 58                            | 0.85              |
| SBA-25| 55                            | 0.82              |
| SBA-30| 51                            | 0.80              |

3.5 Compressive Strength Test Results

The 7-day and 28-day average compressive strength of bagasse ash-blended concrete specimens is presented in Table 6. Table also gives the share variation of compressive strength with reference to the control mix. The results show that as compared to the control mix (0% SBA), the compressive strength increases with increase replacement of OPC by SBA up to 20%, the increase in compressive strength for 20% replacement is about 5.36% at 7-days and 1.96 at 28 days. The utmost compressive strength is attained for 15% replacement of OPC by SBA, whereas at 25 and 30% of SBA, the compressive strength decreases to below that of control mix (SBA0). The variation of compressive strength is represented in figure 3.

Table 6: Average 7-day and 28-day Compressive strength test results

| Mix  | Average 7-day Compressive strength (MPa) | Percentage variation of 7-day compressive strength with respect to control mix | Average 28-day Compressive strength (MPa) | Percentage variation of 28-day compressive strength with respect to control mix |
|------|------------------------------------------|--------------------------------------------------------------------------------|------------------------------------------|--------------------------------------------------------------------------------|
| SBA 0| 24.61                                    | - -                                                                            | 37.96                                    | - -                                                                            |
| SBA 5| 26.38                                    | 7.19                                                                           | 39.37                                    | 3.71                                                                           |
| SBA 10| 26.92                                    | 9.39                                                                           | 41.33                                    | 8.88                                                                           |
| SBA 15| 28.75                                    | 16.82                                                                          | 42.73                                    | 12.57                                                                          |
| SBA 20| 25.93                                    | 5.36                                                                           | 38.70                                    | 1.95                                                                           |
| SBA 25| 21.89                                    | -11.05                                                                         | 33.90                                    | -10.7                                                                          |
| SBA 30| 18.87                                    | -23.32                                                                         | 29.18                                    | -23.13                                                                         |
Figure 3: Variation of average compressive strength of SBA blended concrete

The reason for strength development of bagasse ash blended concrete and the increase in compressive strength of SBA blended concrete up to 20% replacement may be attributed to better physical properties of SBA like higher specific surface area, fineness, amorphous phase and pozzolanic action between calcium hydroxide and reactive silica in SBA. The higher percentage of SiO₂ in the ash is the principal reason for the increase in the strength. Calcium-Silicate-Hydrate (C-S-H) from the pozzolanic reaction between SBA and Portlandite [Ca(OH)₂] fills the voids of concrete and thereby improves the compressive strength, in addition, the products could reduce the pore diameter in the concrete matrix, resulting in a denser blended concrete. The better bond between aggregates and cement paste can contribute to increased strength. The use of higher percentage of SBA (>20%) to replace OPC resulted in low cement content in concrete leading to low compressive strength which may be due to lower quantity of Ca(OH)₂ available during the hydration reaction of concrete. Thus, the quantity of Ca(OH)₂ was not enough for the pozzolanic reaction resulting in much lower compressive strength of blended concrete with 25 and 30% of SBA. Therefore, 20% of bagasse ash in blended concrete seems to be the optimal limit, this is in conformity with previous studies [5,12].

3.6. Microstructure and Elemental Composition

The structure of the cementitious matrix was examined by scanning electron microscopy (SEM) to determine the morphological structure of the concrete matrix sample. SEM image representing the morphology of the control concrete obtained on the fractured surface of cube specimen tested under compression after 28-day curing is shown in figure 4.

Similarly, the SEM image representing the morphology of the SBA blended concrete, obtained on the fractured surface of cube specimen tested under compression after 28-day curing is shown in figure 5. Energy dispersive X-ray (EDS) analysis was also used along with SEM to obtain the elemental composition of the matrix. The area of the SEM image on which EDS is carried out is marked by a rectangle. The elemental composition of the control concrete and SBA blended concrete is reported in Table 7.

Table 7: Elemental composition of SBA blended concrete mix in % by weight
3.6.1. **Microstructure of control concrete (SBA0)**

The SEM images (Figure 4) show that the bulk of the particles are irregularly shaped and are porous in nature. SEM image shows whiter particles present within the cementious matrix. This fact is confirmed by the presence of whiter particles within the concrete matrix, which indicates the presence of Portlandite (Ca(OH)2). The EDS analysis indicates that the main elements are calcium, silica and oxygen having mass of 36.69, 14.76 and 38.44%, respectively, and other elements in trace quantities as presented in table 7.

![Figure 4: SEM micrograph of control concrete matrix (SBA0).](image)

| Element | SBA0  | SBA5  | SBA10 | SBA15 | SBA20 | SBA25 | SBA30 |
|---------|-------|-------|-------|-------|-------|-------|-------|
| O       | 38.44 | 38.51 | 39.44 | 40.24 | 41.35 | 42.88 | 43.40 |
| Na      | 0.63  | 0.35  | 2.64  | 0.37  | 0.32  | 1.22  | 3.69  |
| Al      | 4.2   | 3.5   | 5.63  | 5.26  | 4.69  | 5.49  | 6.33  |
| Si      | 14.76 | 15.33 | 16.13 | 16.88 | 19.11 | 25.41 | 28.86 |
| Ca      | 36.69 | 36.02 | 33.25 | 29.28 | 26.88 | 20.93 | 13.58 |
| Fe      | 2.42  | 3.06  | 1.79  | 3.95  | 1.88  | 1.85  | 1.34  |
| S       | 1.0   | 1.0   | 0.74  | 1.30  | 1.02  | 0.91  | 0.65  |
| Mg      | 0.75  | 0.82  | 0.39  | 0.70  | 2.41  | 0.62  | 1.67  |
| K       | 0.76  | 0.87  | --    | 0.86  | 1.27  | 0.69  | 1.18  |
| Cl      | 0.2   | 0.28  | --    | 0.20  | 0.45  | --    | 0.29  |
| P       | 0.14  | 0.26  | --    | 0.26  | 0.38  | --    | --    |
| Ti      | --    | --    | --    | 0.70  | 0.25  | --    | --    |
Figure 5: SEM micrograph of SBA blended concrete matrix
3.6.2. Microstructure of SBA 5

The SEM image of SBA5 (Figure5(a)) represents dense microstructure as compared to regulate units. The EDS analysis indicates that the main elements are calcium, silica and oxygen having mass of 36.02, 15.33 and 38.51%, respectively, the opposite elements in trace quantities as presented in Table 7. The calcium concentration of SBA5 is marginally lesser than that in SBA0 mix. On the opposite hand, silica concentration is more in SBA5 than that within the control units (SBA0) because of the SBA content within the SBA5 mix. The 28-day compressive strength of SBA5 is about 3.71 to a higher than that of the control concrete. The aforementioned changes in chemical composition (higher silica concentration) cause an improvement in compressive strength in SBA5 after 28 days aged.

3.6.3. Microstructure of SBA 10

The microstructure of SBA10 was very different from that of control mix SBA0, SEM image (Figure 5(b)) clearly indicates the dense microstructure compared to SBA5 and SBA0 mix. EDS analysis shows that the matrix of reaction products is composed of calcium (Ca), silica (Si) and oxygen as major elements as shown in table 7. The other elements in trace quantities are aluminum, sodium, sulphur, magnesium, and iron. The calcium concentration of SBA10 is lesser than that in SBA0 and SBA5 due to the reduction in the cement content, while the silica concentration in SBA10 is higher than that in SBA5 and control mix. The increase in Si content can be attributed to the fact that SBA has higher silica concentration (as seen in table 3). The 28-day compressive strength of SBA10 is 41.33, which is more than that of SBA0 and SBA5 mix, and is 8.88 % higher than that of the control concrete. This is due to the increase in silica concentration, which supplements the formation of calcium silicate hydrate (C-S-H) gel in SBA10 mix.

3.6.4. Microstructure of SBA 15

After 28 days, the microstructure of SBA15 was very different from that of control mix, SBA5 and SBA10. The SEM image (Figure5(c)) clearly shows the dense microstructure and the presence of trace amounts of white particles in blended cement matrix and indicates the hydrated cement grains. The EDS analysis shows that the matrix of reaction products is composed of calcium, silica and oxygen as major elements of masses 29.28, 16.88 and 40.24%, respectively. The calcium concentration of SBA15 is lesser than that in the previous mixes due to reduction in the cement content, while the silica concentration in SBA15 is higher than that in SBA5, SBA10 and control mix. The reason being, SBA has higher silica concentration (as seen in table 3). The 28-day compressive strength of SBA15 was 42.73 MPa which is more than those of SBA0, SBA5 and SBA10 mixes, and is 12.6 % higher than that of the control concrete. These values for SBA15 are the highest compared to other mixes. The reason for the gain in strength is due to the pozzolanic reaction taking place between nanosilica particles and Portlandite (Ca(OH)2) supplementing the formation of the C-S-H gel in SBA15 mix.

3.6.5. Microstructure of SBA 20

The SEM image of SBA20 indicate less dense cementitious matrix as compared to the previous mixes. The EDS analysis indicate the presence of silica, calcium and oxygen as major elements which are derived from sugarcane bagasse ash and cement. Compared to the previous mixes, the EDS analysis reveals reduction in calcium concentration content which is due to reduction in the cement in SBA20 mix. On the other hand, there's significant increase in silica concentration thanks to increase in SBA particles within the SBA20 mix. Other elements, like aluminum, magnesium, iron, sodium, sulphur, potassium and titanium (Table 7), were also observed in trace quantities. The 28-day compressive strength of SBA20 was 38.70MPa. The compressive strength of SBA20 was over that of SBA0 but that of SBA15 mix. The aforementioned changes in chemical composition cause a decrease within the compressive strength in SBA20 after 28 days aged.

3.6.6. Microstructure of SBA 25
The SEM image of SBA25 indicates less dense cementitious matrix as compared to the previous mixes. The EDS analysis indicate the presence of silica (Si), calcium (Ca) and oxygen as major elements having 25.41, 20.93 and 42.88% mass respectively, which are derived from sugarcane bagasse ash and cement. Compared to the previous mixes, the EDS analysis reveals reduction in calcium concentration which is due to reduction in the cement content. Secondly, the increase in silica content is significant which can be attributed to increase in SBA particles. Other elements such as aluminum, magnesium, iron, sodium, sulphur and potassium were observed in trace quantities (Table 7). The 28-day compressive strength of SBA25 was 33 MPa. The compressive strength observed in SBA25 was lesser than those in the previous mixes. The rationale for this might be the sudden decrease within the calcium concentration because of which it had been unable to supply the specified C-S-H gel within the mix.

3.6.7. Microstructure of SBA 30

The SEM image (Figure5(f)) of the microstructure of SBA30 was very different from that of the previous mixes. Consistent with the EDS analysis, the matrix of reaction products is especially composed of silica (28.86%) and is observed that the calcium concentration (13.58%) considerably decreases compared to previous mixes. The strength characteristics observed in SBA30 are lesser than those within the previous mixes thanks to significant decrease in the calcium concentration which results in insufficient formation of C-S-H gel within the SBA30 mix.

4. Conclusions

Based on the results obtained in the present study, the following conclusions are made. SBA is finer than OPC and has a larger surface area to react during hydration process. Chemically, SBA is mainly composed of the oxides of silica, alumina and iron. The XRF analysis reveals that, the sum of (SiO2 + Al2O3 + Fe2O3) is 82.79% and LOI is about 7% by mass. These findings satisfy the requirements of ASTM C618 standards for class N pozzolan. The mineralogical analysis shows that, SBA is formed by quartz as the main crystalline compound with other minerals present in trace amounts. Due to its fineness, the presence of SBA in blended cements leads to an increase in water uptake, resulting in reduced workability. On the basis of microscopic study using SEM and EDS analysis the pozzolanic activity of SBA can be mainly attributed to two factors; higher percentage of silica and low concentration of calcium. For smaller percentage replacement of OPC by SBA (5, 10 and 15%) the Calcium-Silicate-Hydrate (C-S-H) from the pozzolanic reaction between SBA and Portlandite [Ca(OH)2] fills the voids of concrete and thereby improves the compressive strength. Further as the percentage of replacement increases beyond 15% (i.e for 20, 25 and 30%), there is a significant reduction in the calcium concentration which leads to insufficient formation of C-S-H gel resulting in strength reduction. Based on the compressive strength test results, 15% replacement of OPC by SBA yields the maximum strength and considered as optimum replacement percentage. However, the compressive strength of SBA blended concrete is higher than the control mix for replacement of OPC by SBA up to 20%.

The current study clearly shows that adding SBA has great advantages. This may open the door for using a byproduct of sugar cane production, which otherwise would end up in landfills causing severe pollution to the environment.

5. References

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