Overview on properties of sugarcane bagasse ash (SCBA) as Pozzolan

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This review paper will explore the detailed information on the Sugar Cane Bagasse Ash (SCBA) historical experimental studies, morphological aspects, chemical and physical properties of SCBA along with some fresh and hardened SCBA blended concrete properties. Importance of this overview is to understand the variation of SCBA properties with respect to geological variation, sugarcane cultivation methods and production of ashes methods. Based on the SCBA test properties, the characterization of SCBA at different parts of the world are reviewed and recommendations are suggested that it can be used as pozzolan suitable for marine environment construction.

[Keywords: Sugar Cane Bagasse Ash, concrete properties, fresh and hardened properties, marine environments]

Introduction

Ordinary Portland Cement (OPC) is recognized as the major construction material throughout the world. After the extraction of all economical sugar from sugarcane, about 40-45% fibrous residue was obtained, which is reused in the same industry as fuel in boilers for heat generation leaving behind 8 -10 % ash as waste, known as SCBA. The largest producer of sugarcane is Brazil and India is the second largest. The non-availability of land for public use is because of dumping of SCBA. Each ton of the cement produces approximately one ton of Carbon dioxide (CO2) and the cement industry is responsible for about 5% of global anthropogenic CO2 emission. Green House Gas emissions can be substantially reduced if 20% to 30% of bagasse ash is replaced in concrete industry. Presently on the inclusion of any Supplementary Cementitious Material (SCM) as a component replacement in the concrete mainly concerns over the durability property of the concrete. There is also strong relation exists between microstructural properties of elements and durability properties of concrete. The durability tests have to be validated along with the mechanical property tests for the inclusion of the waste SCBA in the concrete. The concrete structure service life is limited by chloride induced reinforcement corrosion. Chlorides originates from marine environment penetrate the cover and causes corrosion when they exceed critical level. In concrete, the chloride ions are found as calcium chloro aluminate hydrates such as Friedel’s or Kuzel’s salt, they can be absorbed into Calcium Silicate Hydrate (CSH). In addition to chlorides, sea water contains magnesium, sulfate and carbonate ions which are potentially harmful for concrete. These additional ions influence the chloride to access by affecting chloride binding capacity or affecting porosity of concrete cover or causing concrete to deteriorate.

Basic properties of SCBA and SCBA blended concrete properties helps the construction industry for the identification of innovative technologies using available materials that promote efficiency and effectiveness more economically by recycling and reusing of SCBA, and also by reducing the transportation charges.

Pozzolan

When pozzolanic materials are added to cement, the silicon dioxide (SiO2) present in these materials reacts with free lime released during the hydration of cement and forms additional CSH as new hydration products, which improve the mechanical properties of concrete formulation. The capability of pozzolanic materials of enhancing the strength of concrete is more closely associated with physical than chemical effects. It is reported that, cement blended with pozzolan would produce 65 to 95 % strength of OPC concrete in 28 days and at later ages their strength
normally improves because pozzolan like fly ash react more slowly than cement due to different composition and at one year about the same strength is obtained. SCBA cements have a history starting from the 1990’s, and Table 1 summarizes a historical background about important events in the development of SCBA blended concrete and also it presents the details of investigations carried out on SCBA in different countries.

**Morphological Aspects**

*Scanning Electron Microscope*

SEM imaging facilities identification of cementitious minerals in SCBA with greater contrast and greater spatial resolution and provides ancillary capability for element analysis and investigating the structure of minerals.

Some typical morphological studies in SCBA are shown in Figure 1. Figure 1a shows a heterogeneous mixture of cristobalite particles with porous and smooth surface, typical for organic and inorganic materials\(^\text{15}\).

Origin of SCBA which contains only fibers, even after combustion could yield particles of similar morphology of fibers observed in Figure 1b & 1c. The carbonaceous particles are seen in Figure 1d, prismatic silica particles in Figure 1e and air bubbles retain as shown in Figure 1f, indicating that ashes are

<table>
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<th>Year</th>
<th>Country</th>
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Fig. 1 (a) — Smooth surface in SCBA

Fig. 1 (b) — Fibres in SCBA

Fig. 1 (c) — Fibrous particles (layers like structure) in SCBA

Fig. 1 (d) — Carbonaceous particles in SCBA

Fig. 1 (e) — Prismatic particles in SCBA

Fig. 1 (f) — Air Bubbles in SCBA Surface

Fig. 1 (g) — Porous Structure in SCBA

Fig. 1 (h) — Irregular shapes of SCBA

Fig. 1 — Typical SEM Images (Contd.)
Irregular shaped particles are observed in Figure 1h, suggesting that the combustion temperature reached in the burning process did not produce the melting of inorganic matter. This shows factor that the SCBA still need some high burning temperature to remove air bubbles and inorganic minerals.

On other hand to improve pozzolanic reactivity and also to reduce size below 5μm, mechanical grinding techniques are adopted. Figure 1i to 1n show that the morphology of the SCBA with different grinding time. The grinding process did not change significantly the particle shape after 120 min. Apart from this, some points observed are

- SCBA can be made as regular shape pozzolan
- SCBA particles has rough surface
- Initial grinding up-to two hours helpful for improving the microstructure of SCBA as pozzolan
- Increase the grinding time will increase the specific surface area of SCBA

Fig. 1 — Typical SEM Images
X-Ray Diffraction Spectroscopy

X-ray beam interacts with planes of atoms of SCBA, part of the beam is transmitted, part is absorbed by the sample, part is refracted and scattered, and part is diffracted at well-defined angles. Every crystalline phase has its own diffraction angle. Figure 2a, describes that the presence of an amorphous silica structure with small quantities of crystal phases such as quartz and cristobalite are present in SCBA. Figure 2b represents the predominance of silica as cristobalite and quartz.

This high content of quartz is ultimately due to sand adhered to the sugarcane and that is harvested along with it. Figure 2c shows that the initially ash contains cristobalite as main crystalline cubic compound, followed by tridymite. Traces of potassium magnesium silicate were also detected. The patterns presented in Figure 2d indicates the variation of crystallinity of silica, is dependent on temperature of burning of dry bagasse and when temperature increased beyond 800°C, some sharp and intense peak starts to shows up on the top of amorphous background as detected.

This formation of cristobalite is due to recrystallization process taking place in SCBA at high temperature from crystalline silica to amorphous form. Most of researchers found that the phase variation is between 15 to 35° (2θ), which shows that the presence of minerals in amorphous manner in which some specific observations include:

- The material essentially consists of an amorphous silica
- Other minerals also found are phosphate, un-burn carbon, magnesium and oxides
- Variation of crystallinity as function of temperature and grinding time is observed
- The burning of SCBA above 600°C will increase the specific surface area
- SCBA burned above 900°C, SCBA is converted into crystalline form which is difficult to react

![Fig. 2(a) — Cristobalites and amorphous structures at angles between 18 to 60 (2θ) of SCBA](image1)

![Fig. 2(b) — Cristobalites and amorphous structures at angles between 20 to 56 (2θ)](image2)

![Fig. 2(c) — Cristobalites and amorphous structures at angles between 21 to 46 (2θ)](image3)

![Fig. 2(d) — Cristobalite and amorphous structures as function of temperature and at angels between 20 to 30 (2θ)](image4)

![Fig. 2 — XRD Images of SCBA](image5)
The volatile compounds are removed when it is burned once again and micro structure properties are improved within certain degree of burning.

**Particle Size Distribution of SCBA**

Now-a-days only the researchers are focus on particle size distribution of SCM’s like SCBA, because it will be directly related to physical and chemical properties of pozzolan. The SCBA particles that are dumped in an open area shows larger diameter size compared to lime and OPC as shown in Figure 3a. So, raw SCBA has a large particle size and a high porosity, so it needs more water content in the concrete mixture and thus results in a lower compressive strength of concrete. It is found that the particle size of SCBA is 4.6 times greater than that of the OPC particle size. The original SCBA can be reduced to 56.5% smaller by grinding, which is less than OPC particle size and the fraction of particles retained on a 45-µm sieve was 2.8% as shown in Figure 3b.

It is also observed that the particle size of SCBA is decreasing with the burning temperature as shown in Figure 3c, on other study it is observed that particle size depends on the grinding time of SCBA as shown in Figure 3d. The results also indicate that after 60 minutes of grinding there is no significant reduction in the particle size since the vibratory mill was not efficient enough to ground the residual ash to size smaller than 0.3µm. This happens because sub-micron particles are naturally more resistant and tend to deform plastically instead of breaking in smaller sizes. The other observations made are:

- The temperature at which SCBA burnt is responsible for particle size of SCBA
- SCBA particles can be available at any required particle size based on grinding time
- SCBA specific surface is increased rapidly with respect to grinding then burning of SCBA.

**Chemical Properties of SCBA**

It is not clear if the advantageous use of SCBA is due to physical or chemical effects. This difficulty is partially due to the fact that both effects are coupled to influence the results from most commonly used

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Fig. 3 (a) — Two gradations in SCBA

Fig. 3 (b) — Gradation of different types of SCBA

Fig. 3 (c) — Gradation of different burning temperature of SCBA

Fig. 3 (d) — Gradation of different timing grinded SCBA

Fig. 3 — Particle size distribution of SCBA
evaluation methods. For instance, if the particle size distribution of the SCBA is refined it can increase the packing density of the mixture as well as the chemical reactivity of the ash due to the increase in the specific surface area\textsuperscript{29}. Table 2 shows the chemical compositions of SCBA ashes observed by most of researchers.

The main oxide present in SCBA is silica (SiO$_2$) with 70% of total mass that react with free lime from cement hydration and made a CSH compound which directly contributes to the mechanical properties of concrete. But only un-crystal silica oxide i.e., amorphous silica has a reactive property. From Table 2, it can be notified that the sum of the proportions of SiO$_2$, Aluminum oxide (Al$_2$O$_3$) and Fe$_2$O$_3$ is well below 70, and sum of proportions of Sodium Hydroxide (Na$_2$O) is less than 1.5%, and sulphur tri oxide (SO$_3$) is below 2 and LOI is less than 4%. Based on the review, SCBA can be classified as Class N type pozzolan\textsuperscript{30} & \textsuperscript{31}. LOI value is high means the suitable engineering properties of material is not yet reached, it still needed more temperature to form required shape and size of material\textsuperscript{32}, the selection of LOI could have a direct influence on the performance of the blended cement matrices and the values of LOI decrease with increasing the burning temperatures\textsuperscript{33} & \textsuperscript{21}. Apart from that, the following observations can be made.

- SCBA as N pozzolan
- Less MgO, means less expansion of blended cements

### Physical Properties of SCBA

The chemical properties are related to the hydration of cement compound, Ca(OH)$_2$, CSH compound and formation of other compounds. However, the physical properties are clearly associated with the particle packing density; voids in the mixtures and the fineness of particle are associated with specific surface area which will increase the reactivity spot of particle. Mechanical properties of blended concrete associated with the physical properties of the SCBA, so it is necessary to investigated in this review will include the specific surface area, particle size of ashes, ashes retained on sieve number 325 as particle size 45µm, density and specific gravity as shown in Tables 3. As per requirement, the particle retained on sieve number 325 must be maximum\textsuperscript{35} but from Table 4, it can be noted that, the size of particle can be vary based on the requirement.

From Table 4, it can be observed that the particle size of SCBA is large 107.8µm but it can be reduced below the particle size of OPC, which will increase the specific surface area, which will make SCBA to react easily. The micro and macro courses present in the concrete were completely filled; voids in hydrate cement pastes are reduced by finer particles, thus making them almost impermeable even at earlier age.

### Table 2 — Chemical Composition of SCBA

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<th>SiO$_2$ (A)</th>
<th>Al$_2$O$_3$ (B)</th>
<th>Fe$_2$O$_3$ (C)</th>
<th>CaO</th>
<th>MgO</th>
<th>K$_2$O</th>
<th>Na$_2$O</th>
<th>SO$_3$</th>
<th>LOI</th>
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Abbreviation: SiO$_2$ – Silicon di oxide, Al$_2$O$_3$ – Aluminium di oxide, Fe$_2$O$_3$ – Ferrous oxide, CaO – Calcium Oxide, K$_2$O – Potassium oxide, Na$_2$O – Sodium oxide, SO$_3$ – Sulphate tri oxide and LOI – Loss on Ignition.

### Table 3 — Physical properties of SCBA

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<th>Median particle size</th>
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<th>Specific Gravity</th>
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<td>107.8</td>
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<td>2.35</td>
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When particle size is reduced means, the chemical reactive surface area will increase, which makes them to increase the packing density of concrete by filling the pores. Apart from that, the following observations can be made.

- SCBA particles can be reduced to below OPC
- SCBA can be used as filler material
- Specific gravity of SCBA value increases with decrease in SCBA particle sizes in most of cases
- The density of SCBA decreases with decrease in particle size of SCBA
- Surface area of SCBA increase with decrease in particle size of SCBA

**Fresh Properties of SCBA Blended Concrete**

On Table 4, observed that the increase in percentage of SCBA will decrease the slump level for SCBA blended concrete. When SCBA proportion was increased means, the blended concrete needed more admixtures i.e., more superplasticizer for the workability. It is also observed that for lower w/c ratio, an amount of admixtures needed is more when compared to that of the higher w/c ratio. And also, for increasing the slump level of conventional or control concrete, certain percentage of SCBA replacement with cement should improves the slump level. This behavior clearly shows that the SCBA can be used as modifying SCM in terms workability and flowability. These admixtures also enhance the properties of mortar or concrete. In some cases, a boost in early strength becomes apparent, while in others, an increase in late strength. Some other observations are

- Admixture quantity increase with increase in percentage of SCBA replacement
- Increase in admixture quantity will decrease the water cement ratio
- Increase in admixture with increase in SCBA replacement percentage will decrease slump level

**Strength Properties of SCBA Blended Concrete**

**Cylinder Split Tensile Strength**

The split tensile strength values of SCBA blended concretes after 28 days of curing are shown in Figure 4. It can be clearly seen that split tensile strength will increases from 5% to 20% of SCBA. Majority of other researchers found that there is rapid decreasing of split tensile strength for SCBA blended concrete. Other observations observed from Figure 4 are

- 5% SCBA replacement shows higher split tensile strength in most of cases
- 15% SCBA replacement shows high strength than control concrete in few case

**Cube Compressive Strength**

Cube Compressive strength is the critical parameter drives the design process and can influence the cost of a structure, as well as a project. For compressive strength at 7 days, the increase in percentage of strength is observed up-to 20% SCBA blended concrete.
concrete and after that it starts decreasing, this because at initial stage there is more amount of Ca(OH)\textsubscript{2} is available for reaction with SiO\textsubscript{2}, which influence the formation of CSH. Figure 5, the 30% of SCBA replacement shows cube compressive strength nearer to the control concrete. But from Figure 6, it is observed that the compressive strength for 10% to 20% of SCBA blended concrete is increased this is because due to proper portion of SiO\textsubscript{2} from SCBA and Ca(OH)\textsubscript{2} the by-product of hydration reaction between lime (CaO) and water to become CSH compound from the pozzolanic reaction. And after that it is decreased due to either unavailability or low reactivity of SiO\textsubscript{2} with remaining amount of Ca(OH)\textsubscript{2} obtained in hydration reaction process. From both Figure 5 and Figure 6, it is observed that the 30% of SCBA replacement shows higher compressive strength then control concrete.

**Durability Properties of SCBA Blended Concrete**

If SCM’s are used, reactive silica present in these materials react with Ca(OH)\textsubscript{2} and produce additional CSH gel which has improved pore structure, pore connectivity and interfacial transition zone of concrete improving durability properties\textsuperscript{20}. Hence, it is necessary to understand the effect of durability studies on SCBA blended concrete are need to be discussed for marine environmental conditions.

**Sulfate based durability**

If CaO and Al\textsubscript{2}O\textsubscript{3} contents in SCBA is increased, it combines to form Tri Calcium Silicate (C\textsubscript{3}A) that is vulnerable to sulfate attacks\textsuperscript{31}. If the content of Fe\textsubscript{2}O\textsubscript{3} is high and Al\textsubscript{2}O\textsubscript{3} is low, then the resistance to sulfate attacks is increased also on low LOI increases the sulfate resistance \textsuperscript{36, 37, 38 & 39}. In most of case form Table.2, the Al\textsubscript{2}O\textsubscript{3} is more, the formation of C\textsubscript{3}A is more frequent but it can be controllable by decreasing LOI value.

**Chloride based durability**

The total charge (coulombs) passing through bagasse ash-blended concrete specimens decreases with the increase in bagasse ash content up to 25%. At 30%, there is an increase in total charge passing through specimen; however, the value is less than that of control for 28 and 90 days cured specimens\textsuperscript{40 & 41}. Replacement of OPC with SCBA remarkably enhanced resistance of concrete also considerable reduction in electrical conductance was observed\textsuperscript{42} as depicted in Figure 7. The resistance to chloride attacks increases with increase in replacement ratio of SCBA for SCBA blended concrete mixes can be attributed to a combination of many factors, the primary factors are:

(a) The conductivity pore solution (CaOH) is reduced by using it in pozzolanic reaction with silica from SCM’s (b) From the result of pozzolanic reaction, there is an improvement in pore structure by lowering of pore connectivity, increases the density of SCBA blended concrete\textsuperscript{43} and (c) pore refinement of SCBA blended concrete.

**Electrical conductivity-based durability**

There is inverse relationship exists between electrical surface resistivity and ion penetrability\textsuperscript{44}. Higher surface resistivity was observed for all concrete specimens at 56 days, but the enhancement in resistivity was significantly greater for the 15% and 25% SCBA replaced concretes\textsuperscript{43}. This is clearly an evidence for enhancement in the pore structure, reduction in the permeability of cover concrete as well as that of lowering the risk of corrosion.
Conclusions

A comprehensive review of literature on SCBA properties as pozzolan has been carried out. SEM results shows that SCBA are porous in nature and having irregular shape typical for morphology of fibres. SCBA also retains air bubbles, indicates that they are in molten state, which suggesting that combustion temperature reached in burning process did not produce the melting of volatile matter. So, that spherical shaped particle can be obtained either at high combustion temperature or higher grinding time. Quantitative confirmation of SEM is done by using XRD in order to identify the crystalline phases of SCBA. Most of researchers found that the phase relation of Bragg’s angle is 15° to 35° (2θ) is observed. The vitreous phase indicates that SCBA are in amorphous state and small quantities of quartz, unburn carbon and iron oxides are identified with predominance of silica as cristobalite form. To confirm the results from SEM, the presence of cristobalite indicates that 800°C temperature is required for conversion of silica to reactive silica form. The reactivity nature of SCBA is determined by using particle size distribution curve which shows that the mean particle size is helpful for increasing the packing density of concrete. SCBA is classified as N type pozzolan31 based on chemical properties only. Having large amount of silica, SCBA exhibits excellent pozzolanic property. From physical properties it is noted that the size of SCBA are actually obtained from dump yard has approximately 2 to 4 times particle size of OPC but it can be reduced by various techniques. The density of SCBA is decreases with decreasing particle size of it, so that it can be used as filler material.

In reality, incorporation of SCBA both in cement and concrete contributes to perform dual roles: fulfills the demand of cement in concrete industry and improves the mechanical properties of concrete. From properties of SCBA, it can be used as SCM. SCMs replace cement, the strength is reduced at first, but as time proceeds, this gap is gradually eliminated and the strength becomes higher than that of the control concrete. Fresh concrete properties are also confirming SCBA increase the workability of blended concrete. Based on the past research results, it is concluded that the strength development of concrete containing a particular level of SCBA replacement is the same or higher as compared to OPC concrete at later age. Most of researchers found out that the optimum level of cement replacement is between 10% - 20% of SCBA by various techniques. As whole, SCBA can be used as pozzolan in concrete based on its hardened and durability properties.

References


31 ASTM C 618, Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete (2005).


43 Bahurudeen A., Manu Santhanam, Performance evaluation of sugarcane bagasse ash blended cement for durable concrete, 4th international conference on the durability of structures, 24th to 26th July, 2014, Purdue University, USA

44 Rupnow TD, Icenogle PJ. Evaluation of surface resistivity measurements as an alternative to the rapid chloride measurements as an alternative to the rapid chloride permeability test for quality assurance and acceptance. Report No. FHWA/LA.11/479; 2011.

50 Moises Frias., Ernesto Villar. & Holmer Savastano., Brazilian sugar cane bagasse ashes from the cogeneration industry as active pozzolans for cement manufacture, *Cement & Concrete Composites*, 3: (2011), 490-496.
61 Suaiam, G. & Makul, N., Use of increasing amounts of bagasse ash waste to produce self-compacting concrete by adding limestone powder waste, *Journal of Cleaner Production*, (2013a), 1-12.