Characterization of Sugar Cane Bagasse Ash: A Comparison to Densified Silica Fume and Fly Ash

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ABSTRACT In this study the Sugar cane bagasse ash (SCBA) was characterized for chemical composition, morphological and mineralogical properties. From XRF analysis it was found that the SCBA has SiO₂, Al₂O₃, Fe₂O₃ and CaO content of 67.25%, 6.37%, 4.21% and 13% respectively and it has a very low LOI value of 0.34% and can be classified as Class F ASTM pozzolan according to ASTM C 618-2009. SCBA can be used as a pozzolanic material after grinding to less than 45 Micron. Based on the properties obtained from the characterization in this study it can be concluded that, utilization of SCBA in concrete will positively affect hardened concrete properties due to pozzolanic reaction, cementing properties and filling effect of SCBA. Moreover it will minimize the negative impacts associated with SCBA disposal.

Keywords: Densified silica fume, fly ash, pozzolan, sugar cane bagasse ash.

1. INTRODUCTION

Sugarcane is one of the leading industries in the world due to the high demand of sugar. It depends mainly on the sugarcane which is a tall grass with big stems and is widely grown in tropical countries [1], [2]. About 1683 metric ton of sugarcane was produced worldwide in year 2009–2010 which amounts to 22.4% by weight of the total world agricultural production [1].

There are various by products accompanying the sugar industry such as leaves and ends, cane washing water, bagasse, filter tart and yeast. Washing water can be reused in the biogas production and in fertilized irrigation. Bagasse is used as fuel to produce energy in the form of steam and electricity, paper pulp, cellulose, and wood veneer. Filter tart which result from stock clearing process in the sugar industry is used as a fertilizer, and the yeast which obtained after stock fermentation is also used as fertilizer [3].

A. Bagasse

Bagasse as shown in Figure 1 is the waste left after extraction of juice in the sugar industry. Previously it was burnt as a means of solid waste disposal but with increasing cost of natural gas, electricity, fuel oil and due to its calorific properties of bagasse, it has been used as a fuel for boilers in the sugar and alcohol factories. The gross calorific value of bagasse is 19250 kJ/kg at zero moisture and 9950 kJ/kg at 48% moisture [1].

B. Bagasse cogeneration

Bagasse cogeneration was pioneered by Mauritius and Hawaii in 1926–1927, and by that time 10% of Hawaii’s and 26% of Mauritius’ electricity generation was from the sugar factories. Figure 2 illustrates bagasse cogeneration process. There are many benefits from bagasse
cogeneration as listed below [4]:

1- Increasing the viability of sugar mills: Appropriate remuneration of electricity from bagasse cogeneration would increase the added value to the alcohol and sugar sectors.

2- Less cost of fuel paid in local currency and commercial use of by-product: the capital costs of bagasse cogeneration plant are the lowest among all renewable forms of power generation.

3- High fuel efficiency and reduction in the cost of transmission and distribution line.

4- Social benefits represented in employment of local population, and widespread availability of electricity especially for rural areas where the sugar factories are usually located.

5- Environmental benefits associated with low emission of CO$_2$, SO$_2$, and NO$_x$ compared to coal and other fossil fuels: Bagasse cogeneration is being further encouraged through projects qualifying for the Kyoto Protocol’s Clean Development Mechanism (CDM).

![Fig. 2. Bagasse cogeneration process [4].](image)

**C. Problem Statement**

There is a continuous increase in sugarcane production worldwide. Approximately 1500 million tons of sugarcane are annually produced all over the world which leave about 40-45% bagasse after juice extraction giving an average annual production of about 600 million tons of bagasse as a waste material.

Sugarcane bagasse ash (SCBA) is an agro-industrial by-product and there are many environmental problems associated with its disposal for instance: landfill volumes, underground water pollution, global warming and methane emission which cause degradation of the ozone layer. Although the SCBA is a pozzolanic material but still it is disposed to the landfills every day.

Utilization of such by product as CRM in concrete production will be beneficial from environmental perspective as it will reduce the cement production and the CO2 emission associated with its industry, and it will reduce the negative impacts associated with its disposal.

Sudan or Republic of Sudan as officially known is a North-African country in the Middle East bordered by Egypt to the north, South Sudan to the south, Eritrea and Ethiopia to the east and Chad to the west. Sudan was selected as a case study for this doctoral research because of the following reasons:

1- The sugarcane plantation covers one fifth of the arable land in Sudan and the sugar industry is well established.

2- There are six sugar factories which are working efficiently with a total production capacity of about 1,200,000 tons of sugar per year which is expected to increase to according to the government plan.

3- According to World Alliance for Decentralized Energy (WADE) report 2004: Sudan has the highest potential among the African countries of producing electricity from bagasse and over 40% of its electricity can be produced from bagasse cogeneration due to long crushing seasons of sugarcane (8-9 months), which will produce high amount of ash after burning.

The main objective of this study was to comprehensively investigate the morphological, mineralogical and chemical properties of SCBA to characterize against the established cement replacement materials namely densified silica fume and fly ash and to determine the possibility of using SCBA as Cement replacement in concrete.
D. Pozzolanic materials

A pozzolan is a siliceous or siliceous and aluminous material that possesses little or no cementing properties, but in a finely divided form and in the presence of moisture will chemically react with the calcium hydroxide released during the hydration of Portland cement to form compounds possessing cementitious properties [5]. The fundamental requirements and classifications for coal fly ash and raw or calcined natural pozzolans are clearly stated by ASTM C 618, the sum of the silicon dioxide (SiO$_2$), aluminum oxide (Al$_2$O$_3$) and iron oxide (Fe$_2$O$_3$) should be 70% at minimum, and the other chemical requirements are presented in Table 1.

<table>
<thead>
<tr>
<th>Class</th>
<th>N</th>
<th>F</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon dioxide (SiO$_2$) plus aluminum oxide (Al$_2$O$_3$) plus iron oxide (Fe$_2$O$_3$), min, %</td>
<td>70.0</td>
<td>70.0</td>
<td>50.0</td>
</tr>
<tr>
<td>Sulfur trioxide (SO$_3$), max, %</td>
<td>4.0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Moisture content, max, %</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Loss on ignition, max, %</td>
<td>10.0</td>
<td>6.0</td>
<td>6.0</td>
</tr>
</tbody>
</table>

2. MATERIALS AND METHODS

A. Materials

Three materials were used in this study namely sugar cane bagasse ash (SCBA) Densified silica fume (DSF) and fly ash (FA).

Raw sugarcane bagasse ash was obtained from the boilers of Guneid Sugar factory, located in Gezira state, Sudan, during the boiler cleaning operation, where it is used as boiler fuel; therefore it was further ground by Los Angeles abrasion machine for two hours to reduce the particle size to less than 45 micron. The particles passed 45μm-sieve (about 80%) were utilized in characterization and the particles coarser than 45μm were rejected.

The established materials used in this research such as densified silica fume fly ash were obtained in the finished state (no further preparation was needed).

The SF used in this investigation was obtained from Elkem materials in dry densified form with Grade 920 conforming to the mandatory requirements of ASTM C1240 [7]. The silica fume is densified to avoid the difficulties of shipping of submicron-sized particles (dust).

The fly ash used in this study was obtained from Manjung Power Station at Lumut, Perak, Malaysia, that was classified as low lime fly ash or ASTM Class F fly ash.

After bringing all materials into the final form, their morphology, mineralogy and chemical composition was determined using the relevant techniques. Figure 3 shows the SCBA, DSF and FA used in this study.

B. Characterization of materials

The pozzolanic materials were characterized by using different methods and techniques. For instance the chemical oxides of the pozzolans can was determined by X-ray fluorescence (XRF) and the morphology of the particle’s surface of the pozzolan was be investigated with the aid of field emission scanning electron microscope (FESEM).

X-ray diffraction powder (XRD) technique was used to determine the mineralogical characteristics of the pozzolan by providing some indication of the abundance of the amorphous silica and it also shows the peaks of the crystalline compounds present in the pozzolan. If the pozzolan is fully crystalline, then it would be less reactive as the crystallinity will reduce the specific surface area available for the reaction thus reduce the reactivity of the pozzolan.

3. RESULTS AND DISCUSSION

A. Chemical composition

Table 2 presents the oxides content obtained by XRF analysis of the SCBA, DSF and FA. The major oxide observed in SCBA is silica (SiO$_2$), which is about 67.25%, the summation of SiO$_2$+ Al$_2$O$_3$+ Fe$_2$O$_3$ is 77.83%, the calcium oxide, CaO is 13.05%, which indicate that SCBA possesses cementing properties. SO$_3$ is 0.11% and LOI is 0.34%. Hence this ash is classified as class F pozzolan according to ASTM C 618 2009 [6].
DSF has SiO$_2$ content of 91.7%, the summation of SiO$_2$+ Al$_2$O$_3$+ Fe$_2$O$_3$ is 93.63%, the calcium oxide, CaO is 1.68%, SO$_3$ is 0.87% and LOI is 2.3%.

The major oxide observed in fly ash is silica (SiO$_2$), which is about 56.39%, the total summation of SiO$_2$+ Al$_2$O$_3$+ Fe$_2$O$_3$ is 89.03%, the calcium oxide, CaO is 5.47%, SO$_3$ is 0.55% and LOI is 0.22%. This ash is classified as class F fly ash according to ASTM C 618: 2009 [20]. The very small value of LOI can be considered as one of the reasons behind the enhancement of fly ash to the concrete workability beside its spherical-shaped particles.

<table>
<thead>
<tr>
<th>Oxide</th>
<th>SCBA</th>
<th>Weight (%)</th>
<th>DSF</th>
<th>FA</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO$_2$</td>
<td>67.25</td>
<td>91.7</td>
<td>56.39</td>
<td></td>
</tr>
<tr>
<td>CaO</td>
<td>13.05</td>
<td>1.68</td>
<td>5.47</td>
<td></td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>6.37</td>
<td>1.00</td>
<td>23.57</td>
<td></td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
<td>4.21</td>
<td>0.93</td>
<td>9.07</td>
<td></td>
</tr>
<tr>
<td>K$_2$O</td>
<td>3.34</td>
<td>1.02</td>
<td>1.98</td>
<td></td>
</tr>
<tr>
<td>MgO</td>
<td>2.61</td>
<td>1.80</td>
<td>0.98</td>
<td></td>
</tr>
<tr>
<td>Na$_2$O</td>
<td>1.38</td>
<td>0.12</td>
<td>1.91</td>
<td></td>
</tr>
<tr>
<td>P$_2$O$_5$</td>
<td>0.59</td>
<td>0.13</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>TiO$_2$</td>
<td>0.58</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>MnO</td>
<td>0.27</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>SO$_3$</td>
<td>0.11</td>
<td>0.87</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td>LOI</td>
<td>0.34</td>
<td>2.3</td>
<td>0.22</td>
<td></td>
</tr>
</tbody>
</table>

B. Morphological Properties

The morphologies of the SCBA particles are shown in the Figure 4. It can be seen that the SCBA at 10KX and 5KX magnifications have agglomerated particles with an irregular shape. According to Tanaka 1998 [8], amorphous is the word to express such a state ‘chaos just start to settle’. It is derived from the Greek language from a word with a meaning of without definite shape. From this definition it can be said that the amorphous material should not have a definite shape and one cannot yet recognize any entity nor describe its form [8].

The majority of the SCBA particles have a particle size in the range of 29.55 – 31.53 μm whereas there are very few (approximately less than 5%) coarse particles have a size of 204–245 μm. Some of the SCBA parties are of rounded edges and some are of angular edges.

The morphologies of DSF particles are shown in FESEM images in Figure 5. At 10KX and 5KX the particles are agglomerated and have a hexagonal shape as shown by the white arrows in Figure 4.5 and the surface of the particle is very rough, some particles are semispherical while other particles have either rectangular or irregular in shape, a porous texture was detected at 5KX, the regular hexagonal shape is an indication of the presence of some crystalline phase in the DSF. The DSF particles have a semi spherical shape and they are bubble-like shaped particles, the particle size of the majority of DSF is in the range of 81.41 – 200 μm.

The morphologies of fly ash particles from FESEM images. At 10KX and 5KX the spherical shape of fly ash is very evident and the surface of the particles is smooth, more than 95% having a particle size of 20 micrometer and the rest have a particle size of 47-51 μm. The fineness and the spherical shape of the particles are expected to improve the workability due to ball bearing effect, fly ash particles create lubricating action and produce concrete with high plasticity, similar observations were also reported in the available research by Neville, 1995 [9], Brooks et al., 2000 [10] and Atış, 2005 [11]. Mechanical properties can also be improved due to reduction in water content.

C. Mineralogical Properties

The X-Ray diffraction was used to identify the crystalline and amorphous phases of the
materials. XRD patterns can show whether the material is in crystalline, partially crystalline or in an amorphous state. The gradual dense scatter of XRD graph is an indication of the amorphous state of a material. Meanwhile the intensity is the degree or level of crystallinity of the material.

Figure 7 shows The XRD pattern of the SCBA, there are two sharp peaks at \(2\theta = 21^\circ\) and \(27^\circ\), with very low intensities of about 18 and 25 respectively. From the dense scatter along the XRD graph it can be said that the SCBA is amorphous with traces of quartz (Q) and illite (I) as the peaks do not have a high intensity. The presence of partially crystalline phase in SCBA sample may be due to high burning temperature in the boilers.

From the XRD pattern in Figure 8, it can be observed that the DSF is highly amorphous silicon oxide, however, at \(2\theta = 26^\circ\) there is a dull peak of silicon oxide of about 9.9 intensity suggesting the presence of some minor crystalline compounds such as quartz and illite in the DSF.

Figure 9 shows the XRD pattern of fly ash. Fly ash XRD pattern is more or less similar to that of the DSF, at \(2\theta = 27^\circ\) there is a gentle peak of illite with an intensity of about 9.4 while more than 90% is in an amorphous state.

4. CONCLUSION

In this research, sugarcane bagasse ash (SCBA) was characterized in comparison to densified silica fume (DSF) and fly ash (FA). From the characterization of three materials the following conclusions can be drawn:

1- SCBA has \(\text{SiO}_2\), \(\text{Al}_2\text{O}_3\), \(\text{Fe}_2\text{O}_3\) and \(\text{CaO}\) content of about 67.25%, 6.37%, 4.21% and 13% respectively and it has a very low LOI value of 0.34% can be classified as Class F ASTM pozzolan. Inclusion of SCBA as a cement replacement material in concrete is expected to improve the mechanical performance as well as durability of concrete due to pozzolanic reaction and the cementing properties attributed to the presence of CaO.

2- LOI content for SCBA, DSF and FA was found to be 0.34%, 2.3% and 0.22% respectively.

3- SCBA is expected to reduce the workability of concrete similar to DSF due to the fluffy and angular/irregular shape of its particles while fly ash particles will increase the workability due to their spherical shape.

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REFERENCES


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