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Reuse of Sugarcane Bagasse Ash (SCBA) for Clay Brick Production

KEYWORDS SCBA, clay brick, X-ray fluorescence, thermal analysis, compressive Strength.

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ABSTRACT *The utilization of industrial waste produced by industrial process has been the focus of waste reduction research for economical, environmental and technical reasons. Sugarcane bagasse ash (SCBA) is a fibrous waste - product of the sugar mill industry. Sugarcane bagasse ash (SCBA) mainly contains silica, ion, calcium and aluminium. In this paper, bagasse ash has been chemically and physically characterized, and partially replaced in the ratio of 0 %, 5 %, 10 %, 15 % and 20 % ash by weight of weight in Clay brick. The samples were fired at temperatures between 800 °C and 1100 °C. X-ray fluorescence, thermal analysis (differential thermal analysis, thermo gravimetric analysis), and test for texture (particle size analysis), compressive strength, porosity, water absorption and shrinkage were carried out to characterize the samples. The results showed that the amount of ash to be incorporated will depend on mainly the composition of clay but also ash, and indicated that the clay used in this work can incorporate up to 15% weight of ash to produce solid bricks. The results also showed an improvement in clay/ash properties at sintering temperature 1000 °C.*

1. Introduction

The fibrous residue of sugarcane after crushing and extraction of its juice, known as "bagasse" is one of the largest agriculture residues in the world (Pandey et al., 2000; Trejo-Hernandez et al., 2007; Mulinari et al., 2009; Hernandez –Salas et al., 2009). Literature illustrates the versatility of sugarcane residue usages; through its conversion inclusive but not limited to paper, feed stock and biofuel (Hernandez-Salas et al., 2009; Pandey et al., 2000; Reddy et al., 1993). An analysis of SCBA indicates that its main constituents are cellulose, hemicelluloses, lignin, ash, and wax (Walford, 2008). This composition of SCBA makes it an ideal ingredient to be applied and utilized as reinforcement fiber in composite materials for the purpose of creating new materials which posses distinct physical and chemical properties.

A comparison of the chemical composition of SCBA reported in the literature (Hernandez Martirena et al., 1998; Caldas et al., 2000; Borlini et al., 2006; Teixeira et al., 2008; Blond et al., 2010; Frias et al., 2011; Ruangtaweep et al., 2011) shows that they are variables due to differences in the soil where the sugarcane was grown. The ashes have a very high silica concentration and contain aluminium, iron, alkalis, and alkaline earth oxides in smaller amounts. In general, the ash produced has a high concentration of quartz and its partly buried or scattered on the ground in the planting area.

The raw material used by the clay brick industry has a heterogeneous nature, in which waste materials of various types and origins are incorporated, maintaining its properties within the limits set by technical standards. The use of industrial wastes has been the focus of many studies, and many of these residues may be included as additives in the clay brick bodies. Some works on the incorporation of SCBA in ceramic bodies (Hernandez Martirena et al., 1998; Caldas et al., 2000; Borlini et al., 2006; Teixeira et al., 2008) have shown a variation in the chemical composition of these ashes, in the crystallinity of silica and in the properties of the sintered ceramic material. The use of SCBA as a stabilizing material in components made from raw earth can be evaluated as an alternative to its use as fertilizer. In addition to being an environmentally safe practice, since the SCBA would be encapsulated in components, it could improve the properties of components made from raw earth. Thus, the SCBA was incorporated to the clay bricks with SCBA addition levels between 0% and 20% aiming at application in non-structural components of masonary. Due to their smaller particle size, the SCBA tends to occupy the voids between the earth and kaolin, permitting increased density and improved mechanical properties of clay bricks.

Therefore, this study was carried out with the aim of investigating the effect of the incorporation of sugarcane bagasse ash in fired clay brick.

2. Materials and methods

Common brick making clay and a dry sugarcane bagasse ash waste in the form of powder were selected as raw materials. The ash waste was collected from a sugarcane plant located in Cuddalore district of Tamilnadu, India. Selected mixtures containing 0, 5, 10, 15 and 20 wt.% waste were prepared and are shown in Table 1.

Table 1 The proportions of the mixtures for the formulation (Wt %).

Formulation	Clay	Sugarcane bagasse ash
BMC0 W	100	0
BMC5 W	95	5
BMC10 W	90	10
BMC15 W	85	15
BMC20 W	80	20

The selected raw materials were classified into the three major sieve groups (Textural analysis) using the sieve and pipette method (Klute, 1986). Table 2 shows the concentration of each fraction (Sand, Silt and Clay) of the brick making Clay and SCBA; the material had a high concentration of sand and silt, consequently, a very low plasticity.

The chemical composition of the SCBA and brick making clay were determined by X-ray fluorescence (XRF, model PW 1400 Philips) (Table 3). The ash and brick making clay crystalline phases were identified by X-ray diffraction (XRD, model SEIFERT JSO-DE BYE FLEX-2002). A thermo gravimetric system and a thermo differential analysis (TG/DTA-NETZSCH-STA 449 F3 JUPITER) were used to characterize both materials with the heating rate of 20°C/min in nitrogen atmosphere.

The rectangular specimens were prepared on a laboratory scale by uniaxial pressing at 10 Mpa, and dried at 110 °C for 24 h. The green pieces formed were fired at various temperatures in the range 800-1100 °C (1 hr soaking time). The firing step was carried out in an electrical kiln. Heating and cooling rates have been controlled.

The following technological properties of the clay bricks have been determined in accordance with standard procedures: linear shrinkage, firing shrinkage, water absorption, porosity and compressive strength. Linear shrinkage values upon drying and sintering were evaluated from the variation of the length of the rectangular specimens (Rajamannan et al., 2011). Water absorption values were determined from weight differences between the as-sintered and water saturated pieces (24 hrs). The same procedure was repeated to determine porosity, the specimens immersed in boiling water (for 6 h). The mechanical strength of the sintered pieces was determined in terms of compressive strength. (Six pieces of each sample were determined for four different temperatures (800, 900, 1000 and 1100 °C)). All the values presented are the averages for six specimens for each sample.

3. Results and Discussion

3.1 Particle Size analysis

The clay brick raw material was classified into three major size groups (textural analysis) using the sieve and pipette method (Klute, 1986). Table 2 shows the concentration of each fraction (Clay, silt and sand) of the brick making clay and SCBA samples; these materials have a high concentration of sand and, consequently, a low plasticity.

Table 2 Particle size distribution of BMC and SCBA

Classification	Group	Concentration (%)	
		BMC	SCBA
< 2µm	clay	14.79	10.45
2 µm-20 µm	slit	25.19	30.225
> 20 µm	Sand	60.02	59.325

The addition of non-plastic materials (sand) is not a sufficient condition for obtaining good-quality products. Other factors, such as combinations of moisture content, firing temperature, particle size distribution and compaction pressure, influence the characteristics of the products in the complete process, from conformation of the peaces until the final sintering.

3.2 Elemental analysis

The chemical analysis of brick making clay and SCBA is shown in Table 3. As shown in table sugarcane bagasse ash contained SiO_2 as the major compound with lower concentrations of aluminium and iron oxides. It also had a low concentrations of fluxing agents but higher than those found in the brick making clay material. The obtained results are identical with the results reported by Teixeira et al., 2008. The brick making clay material showed a typical composition of clay minerals of the Kaolinite group, with low percentage of fluxes and high content of Al_2O_3 [The low percentage of SiO_2 and high percentage of Al_2O_3 confirmed the higher percentage of clay minerals as determined by textural analysis]. Besides the major components (Si and Al) common in clay minerals, it was seen that the concentration of iron and titanium oxides was greater among the minor elements. Iron oxides enhance the action of alkalis flux, causing melting to start at lower temperatures with more abundant liquid phases. Titanium acts as an intermediary vitreous oxide and may contribute to form or modify the network of glassy materials. Thus, titanium is a nucleating agent that can influence the crystallization of new phases.

Table 3 Chemical composition of the raw materials [Sugarcane bagasse ash, brick making clay].

Element composition	SCBA Concentration (%)	Brick making Clay (BMC) Concentration (%)
SiO_2	69.640	61.840
Al_2O_3	1.940	18.220
CaO	6.264	4.674
Fe_2O_3	2.052	6.890
K_2O	8.715	2.573
MgO	3.285	1.91.
MnO	0.080	0.109
Na_2O	0.909	2.150
TiO_2	0.146	1.090
SO_3	2.550	0.053

In general, the K_2O content in clay is higher than the content of Na_2O, since micaceous minerals are more resistant to weathering. During sintering, K_2O and Na_2O give rise to liquids making crystallization difficult, and they tend to remain in the sintered body in a glassy phase. These ions (Na^+, K^+ and Ca^{2+}, among others) are called modifiers, because they enter the interstices of the glass lattice, weakening the chemical bonds and causing a decrease in the melting temperature, facilitating the formation of glass (Segadães et al., 2003). MgO may indicate traces of smectite and micaceous clay minerals. CaO and MgO act as network modifiers and tend to lower the refractoriness of clays. They generally come from calcite, dolomite and gypsum, and are rarely found in clays of the refractory type.

3.3 XRD analysis

The X-ray diffraction pattern of sugarcane bagasse ash is shown in Fig 1. The following crystalline phases were found: Quartz (SiO_2), Microcline ($KAlSi_3O_8$), Calcite ($CaCO_3$), and Kaolinite ($Al_2Si_2O_5(OH)_4$) with predominance of quartz. The SCBA sample's chemical compositions are provided by Table 3. According to said data, the ash waste sample contains a large amount of silica (69.64%) and to a lesser extent alumina (Al_2O_3), and moderate level of calcium oxide (CaO), potassium oxide (K_2O), magnesium oxide (MgO) and iron oxide (Fe_2O_3). Thus result is consistent with the X-ray diffraction pattern Fig 1.

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As shown in Fig 2, the brick making clay added with different wt% of SCBA without heat treatment has kaolinite as the major phase, whose diffraction peaks disappear in samples fired at 800 °C. Fig.3 shows a sequence of diffraction patterns of the brick making clay added with 15% ash ((S_4) unfired), and sintered at different temperatures (800 –1100 °C).

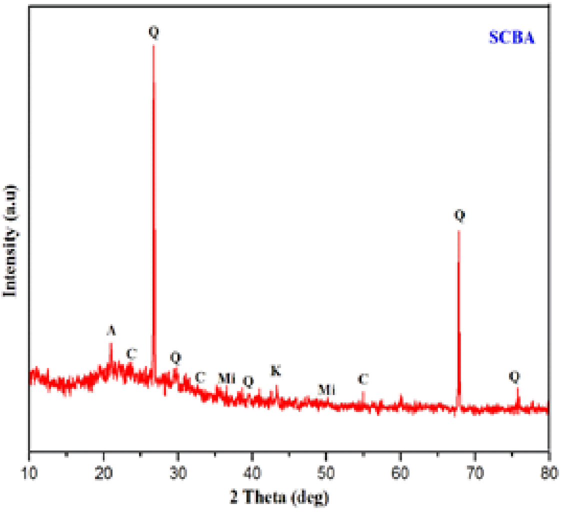

Fig. 1 XRD spectrum of SCBA sample

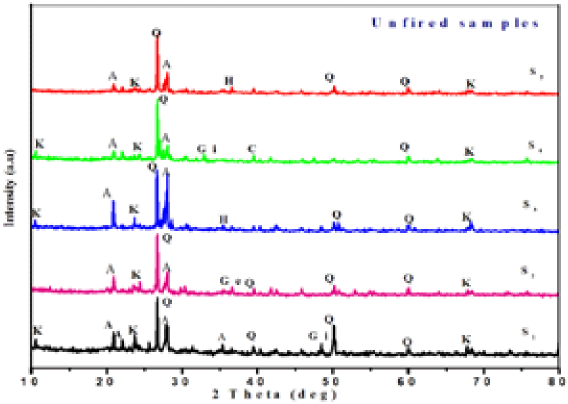

Fig. 2 X- ray diffraction patterns of the brick making clay with ash incorporated (wt. %) samples: (S_1) 0%, (S_2) 5%, (S_3) 10%, (S_4) 15% and (S_5) 20%.

The loss of hydroxyls that connect the silicon tetrahedra to the aluminium octahedra, transforms kaolinite into meta kaolinite. This destroys the characteristic laminar structure of the phylosilicates and free chains of $[AlO_4]^{5-}$. Metakaolin can exist as a metaphase with total structural disorder, or one partially ordered, that is, with some hydroxyls that remain until just before the first exothermic reaction. Below 500 °C, some mineral hydroxides such as gibbsite and goethite, which are common in this type of material, lose their hydroxyls. Up to approximately 900 °C, the OH^- groups of illite and montroillonite are gradually removed, causing these phases to disappear in the XRD patterns. Above 900 °C, the crystallization process of new phases (mullite and cristobalite) begins, characterized by their diffraction peaks and with consequent reduction in the intensities of the XRD peaks of quartz. According to osawa and Bettran 2005, the doublet of peaks around 26° (2θ) indicates the formation of orthohombic mullite. In this temperature range (> 900 °C), XRD peaks corresponding to hematite are also identified, which may have been formed from hydroxides such as goethite, and from iron released during the break down of the structures of some clay minerals, such as illite, which has isomorphous substitution of Al for Fe in the octahedral layer (Schwectmann and taylor 1989).

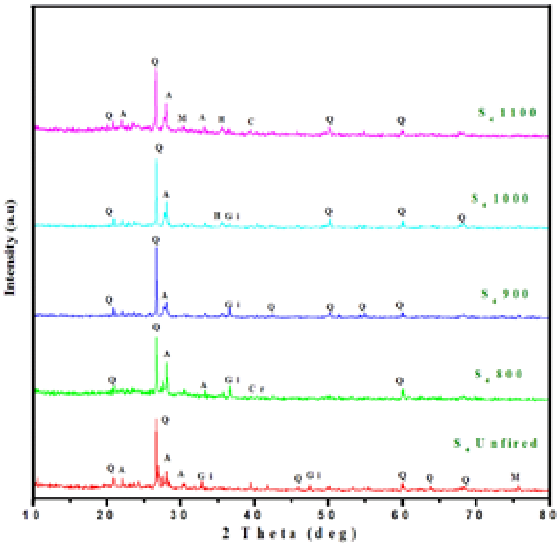

Fig. 3 X-ray diffraction patterns of brick making clay added 15% ash

At 1100 °C, mullite, Quartz and cristoballite were identified in S_4 samples with SCBA. At 1000 °C, in the S_4 sample of brick making clay material and 15 % SCBA ash, there is a shift in peak position and a substantial increase in the intensities of the quartz peaks (Fig 3). Although quartz is one of the purest minerals known, the reactions occurring in this complex and multiphase material could from metastable phase with elemental contaminants in quartz, such as aluminium or iron.

3.4 Thermal analysis

Thermo gravimetric and differential thermal analysis (TG and DTA) for the SCBA are shown in Fig 4. In the temperature range of 50 °C – 100 °C, there is a small loss of mass corresponding to the elimination of free water between the particles. When this water is removed, the particles draw closer (due to capillary forces), causing a contraction of the raw material. This retraction is proportional to the amount of free water that is removed and consequently to the amount of clay minerals (plasticity) in the samples. Another significant weight loss occurs between 200 and 350 °C (321 °C) and is associated with: the combustion of organic matter, water loss from iron (goethite) and aluminium (gibbsite) hydroxides and loss of water coordinated with cations in 2:1 clay minerals. Around 600 °C, there is the largest mass loss due to dissociation of water (structural water) or the hydroxyl component of the clay mineral kaolinite group. Generally the SCBA, DTA thermal patterns (Fig. 4) show two low-intensity ranges (probably some aluminium silicate from the kaolin minerals family) and the characteristic peak of α ⬄ β quartz transformation, confirming the predominance of this crystalline silicate in SCBA.

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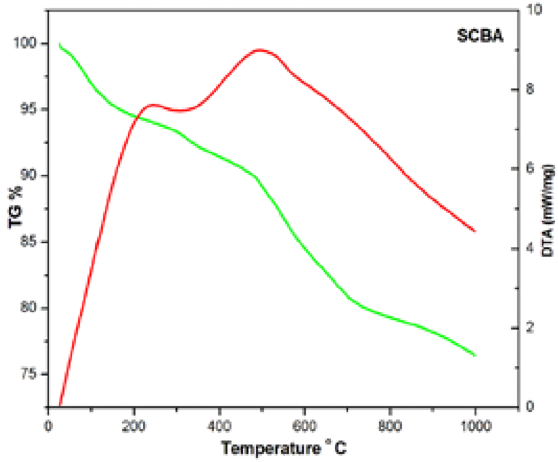

Fig. 4 TG/DTA curve for SCBA sample

3.5 Mechanical properties

The quality of clay brick pieces obtained with up to 15 wt.% sugarcane bagasse ash waste after firing at 1000 °C was determined on the basis of their technological properties (linear shrinkage, firing shrinkage, water absorption, porosity and compressive strength). The pieces with 0 wt.% sugarcane bagasse ash waste (sample S_1, 100 % brick making clay piece) were considered as references pieces. As may be observed, all clay brick pieces exhibited low firing shrinkage, varying within a range from 2.14 to 2.85 % (Fig 5), considered to be within the safety limits for industrial production of clay bricks.

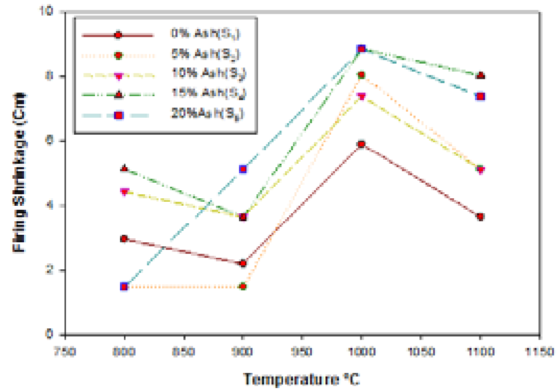

Fig 5. Firing shrinkage (FS) as a function of temperature for the samples (S_1 to S_5)

In this case, the sintering was dominated by particle-to-particle contact, especially of metakaolinite platelets (Milheiro et al., 2005). The linear shrinkage was found to decrease, as the waste content increased up to 15 wt.%. This effect is related to the waste sample composition, rich in crystalline silica, which is a non-plastic component and, as such, behaves as a filler material and decreases the plasticity of the clay/ash waste mixes.

3.6 Compressive strength

The mechanical strength of clay brick pieces was determined in terms of compressive strength (Fig 6). It can be seen that the compressive strength decreased, as waste was added >15 wt.%. Such a behavior is mainly related to the following factors: (i) decomposition of organic matter from the waste sample, thus generating porese in the fired structure; and (ii) presence of high content of crystalline silica particles in the waste sample, that tends to induce flaws in the fired body. The above data suggest that addition of very high amounts of sugarcane bagasse ash waste (above 15 wt.%) into brick making clay should be avoided, because it impairs the mechanical strength of the pieces.

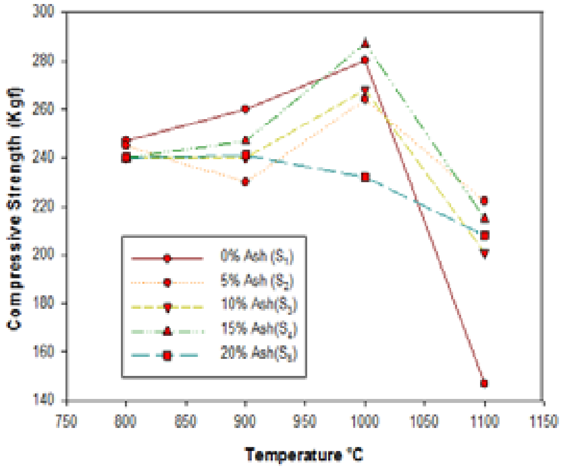

Fig. 6 Compressive strength (CS) as a function of temperature for the samples (S_1 to S_5)

3.7 Water absorption

Fig 7. Show the water absorption values for the clay brick pieces. It was observed that water absorption (9.99–28.27 %) tends to increase with an addition of waste. This result is in accordance with the porosity values (Fig .8). On the other hand, the sugarcane bagasse ash waste bearing clay bricks presented acceptable values of water absorption for clay brick industrial production (Dondi, 2003), regardless of the added waste amount.

The firing color is another important parameter to qualify clay bricks. In this study, all clay brick pieces fired at 1000 °C presented a red color, regardless of the waste amount that had been added to them. In addition, no clay brick piece has indicated the presence of surface stains and black core defects that might be due to the addition of sugarcane bagasse ash waste.

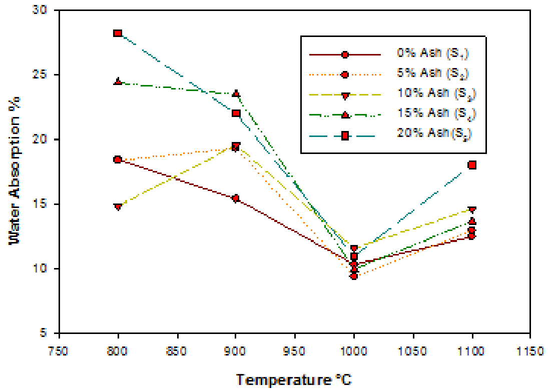

Fig 7. Water Absorption (WA) as a function of temperature for the samples (S_1 to S_5)

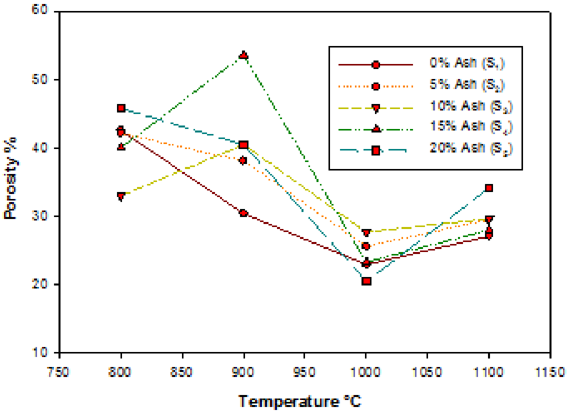

Fig 8. Porosity (P) as a function of temperature for the samples (S_1 to S_5)

4. Conclusions

Although the incorporation of ash inhibits the formation of mullite during sintering of the clay material, SCBA behaves like non- plastic material and decreases the linear shrinkage of clay bricks during drying and firing. The sugarcane bagasse ash waste used in this study is a low-cost material, rich in crystalline silica (SiO_2), which behaves as a filler material, and reduces the clayey formulations plasticity.

The temperature of 1000 °C is a target for changes in the sintering process. Below this temperature, the properties of the clay bricks are little affected by the different concentrations of ash. For temperatures above 1000 °C, the additive (ash) participates in the liquid phase and the formation of new phases (mullite and cristobalite). The results show that for temperatures up to 1000 °C, 15 wt.% ash can be incorporated in brick making clay used to produce bricks. Therefore, the ash (SCBA) may be used as an additive to produce clay bricks that meet the Indian standards. Hence, this process can lower the volume of solid residues disposed on the environment and to increase the lifetime of the reserves of raw materials.

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