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; Mulinarí 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 possess 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 15% weight of ash to produce solid bricks. The results also showed an improvement in clay/ash properties at sintering temperature 1000 °C.

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 (Rajamannar 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 silt, consequently, a low plasticity.

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 SiO₂ 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 Al₂O₃. The low percentage of SiO₂ and high percentage of Al₂O₃ 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.

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 (SiO₂), Microcline (KAlSi₃O₈), Calcite (CaCO₃), and Kaolinite (Al₂Si₂O₅(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 (Al₂O₃), and moderate level of calcium oxide (CaO), potassium oxide (K₂O), magnesium oxide (MgO) and iron oxide (Fe₂O₃). Thus result is consistent with the X-ray diffraction pattern Fig 1.
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 (S4) unfired, and sintered at different temperatures (800 –1100 °C).

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 phyllosilicates and free chains of [AlO4]5-. Metakaolinite 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 montmorillonite 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 (Schwertmann and taylor 1989).

At 1100 °C, mullite, Quartz and cristoballite were identified in S4 samples with SCBA. At 1000 °C, in the S4 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.
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 S1, 100 % brick
making clay piece) were considered as references pieces.
As may be observed, all clay brick pieces exhibited low fir-
ing shrinkage, varying within a range from 2.14 to 2.85 %
(Fig 5), considered to be within the safety limits for indus-
trial production of clay bricks.

3.6 Compressive strength

The mechanical strength of clay brick pieces was deter-
mined 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 addi-
tion 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.
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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REFERENCE

Blond JSL, Horwell CJ, Williamsd BJ, Oppenheimer C (2010) Generation of crystalline silica from sugarcane burning. J. Environ. Monit 12: 1459-1470. | Borlini MC, Mendonca JLLC, Conte RA, Pinatti DG, Viera CMF, Monteiro SN (2006) Effect of particle size of an ash from sugarcane bagasse in the properties of red ceramic. Mater. Sci. Forum 530-531: 538-543. | Caldas A, Neta AAM, John VM, Sobrinho CWA (2000) Technologies alternatives Para Habitação: O Uso de Cinzas Residuais Para Producao de Novos materiais e Componentes Constructivos. In: II Congresso internacional de Tecnologia e Gesteo da Qualidade na Construcuo Civil. Recife-PE, Brazil. http://antorionmelo.pcc.usp.br/Publicacoes.htm. | Dond M (2003) Technological characterization of clay material: experimental methods and data interpretation. Int. Ceram. J 55-59. | Frias M, Villar E, Savastano H (2011) Brazilian sugarcane bagasse ashes from the cogenesis industry as active pozzolans for cement manufacture. Cem. Conc. Comp. 33: 490-496. | Hernandez Martiela JF, Middenborg B, Gehrke M, Budelmann H (1998) Use of wastes of the sugar industry as Pozzolana in lime-Pozzolana binders: study of the reaction. Cement concrete Res. 20: 1525-1536. | Hernandez-Salas JM, Villa-Ramirez MS, Velaz-Rendido NJS, Rivera-Hernandez KN, Gonzalez-Cesar RA, Pascencena-Espinosa MA, et al. (2009) Comparative hydrolysis and fermentation of sugarcane and agave bagasse. Bioresources Technology 100: 1238-45. | Kute A (1986) Methods of Soil Analysis: Physical and Mineralogical Methods Part 1, Second ed. Soil Science Society of American Book Series, Madison, Wisconsin, USA. n. 9 (Part I) Agronomy Series. | Malini DR, Voorwald HJC, Cicof MOH, Silva MLCPO, Cruz TGD, Saron C (2009) Sugarcane bagasse cellulose/ HDPE composites obtained by extrusion. Composites Science and Technology 69: 214-9. | Osawa CC, Beltran CA (2005) Mullite formation from mixtures of alumina and silica sols: mechanism and pH effect. J. Braz. Chem. Soc 16: 251-258. | Pandey A, Soccol CR, Nigam P, Soccol VT (2000) Biotechnological potential of agro-industrial residues. I. Sugarcane bagasse. Bioresources technology 74: 69-80. | Rajamannan B, Ramesh M, Viruthagiri P, Ponnaras K (2011) Mechanical properties of ceramic whiteware samples with different amounts of quartz addition. Elixir Chem phys 33: 2219-2222. | Reddy MR, Chandrasekharraiah M, Goudaiah T, Reddy GV (1993) Effect of physical processing on the nutritive value of sugarcane bagasse in goats and sheep. Small ruminant Research 10: 25-31. | Ruangtaewee Y, Kawkhao J, Kedkaew C, Limwuttan P (2011) Investigation of biomass fly ash in Thailand for recycling to glass production. Proc. Eng 8: 58-61. | Schwertmann U, Taylor RM (1989) Iron oxides. In: Dixon JB, Weed SB. (Eds.), Mineral in soil Environments, 1. Soil Science Society of America Book Series Madison, Wisconsin, USA. | Segadelas AM, Carvalho MA, Ferreira HC (2003) Using phase diagrams to deal with moisture expansion. Ceram. Int 29: 947-954. | Teixeira SR, Souza AE, Santos QTA, Pena AVF (2008) Sugarcane bagasse ash as a potential quartz replacement in red ceramic. J. Am. Ceram. Soc 91: 1883-1887. | Trejo-Hernandez MR, Ortiz A, Okoh AI, Morales D, Quinton R (2007) Biodegradation of heavy crude oil Maya using spent compost and sugar cane bagasse wastes. Chemosphere 68:848-55. | Walford Sn. (2008) Sugarcane bagasse: how easy is it to measure its constituents? Proceedings of the South African Sugar Technologists Association 81: 266-73.