

# Light Weight Clay Bricks in Combination of Sludge Blended with Agro/Wastes

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**Abstract:** The objective of the study is to produce light weight bricks to use as an isolating layer. So, porous or light weight bricks were prepared from clay, sludge, agro/ashes as Saw dust ash (DSA), sugarcane bagasse ash (SCBA) and corn stalk ash (CSA) fired up to 900°C. Physical and mechanical properties were investigated. The chemical composition of the starting raw materials was carried out by XRF analysis. Results proved that the water absorption (25.51, 25.74 and 25.86%) and apparent porosity (29.31, 29.51 and 29.68%) were slightly lowered up to 6 wt. % of these waste ashes, and then increased with further increase. The bulk density (1.9989, 1.9987 and 1.9985 g/cm<sup>3</sup>) and compressive strength (48.54, 48.45 and 48.26 MPa) improved and enhanced with the replacement up to 6 wt. %, and then diminished. So, the optimum ash content was not more than 6 wt. % because the substitution of more than that had or adverse effect was exhibited. Results also proved that the physical and compressive strength was better in case of SDA > SCBA > CSA. The prepared fired bricks could be successfully used and preferred as isolating bricks against heat.

**Keywords:** Clay, Sludge, Bricks, Water Absorption, Density, Porosity, Strength

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## 1. Introduction

### 1.1. Scope of the Problem

The worldwide use of the natural clay for the brick industry has created a huge lacking of clay. It made the scientists to look for new materials and/or to utilize and exploit the byproducts from different environmental activities [1, 2]. The quality of bricks is significantly influenced with the properties of the used raw materials as well as the used methods and techniques. Ingredients, e.g. SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, CaO and iron oxide, present in clay in various amounts, influencing the properties of bricks [3]. The agro/wastes include rice husk ash (RHA), sugarcane bagasse ash (SCBA), water sludge (WS), high pulverized fly ash (HPFA), saw dust ash (SDA), sun flower ash (SFA), wheat stalk ash (WSA), corn straw ash (CSA), Physalis pith ash (PPA), Coir pith ash (CPA), and many others could be used as pozzolanic materials [4-13]. Many scientific researches in USA, China, Brazil and Egypt have been discussed the utilization of water treatment sludge or alum sludge that contains a high clay percent in many industrials. Some studies could be utilized sludge in the manufacturing of

bricks [14, 15]. Inorganic products of alum sludge are like to those of clay which facilitated the addition of alum sludge to bricks [16]. Unfavorable glass sludge improves and enhances the compressive strength nearly by 20-24%. It can lower the total porosity and even the costs [17]. Few studies [14, 15] could be utilized the alum sludge as a replacement or full substitution for clay in the brick-making industry. In some cases, various ratios of sludge in combination to clay have been studied. Results revealed that the optimum content of sludge to produce bricks from sludge-clay mixes was 50% [15]. It was recommended that more substitutions could be directed towards the incorporation of sludge of water treatment plants with other high-silica-content waste materials, such as rice-husk ash, in brick-making [18, 19]. A huge quantity of dredged sludge could be obtained from the dredging of rivers, seas and reservoirs. The dredged sludge is similar to other sludge from various plants. Many types of wastes can be used in the production of red clay bricks [20-22]. The production of clay bricks incorporating waste by-products certainly diminishes the environmental pollution particularly air pollution that is coming from the disposal of agro/wastes in the open landfills. Also, it often offers the chance to produce a

high quality brick performance. Consequently, the addition of agro/wastes of some plants as sugarcane bagasse and rice husk ashes improves the brick making [23]. The production of rice all over the world is about 800–1000 million ton yearly [24]. In Egypt, it could be produced about 7–9 million tons of rice in 2018 [25]. Moreover, nearly about 3.5 million tons of rice husk and/or stalk are disposed through burning in open fields, causing air pollution, i.e. the disposal of agro/wastes by burning increased the green-house gas in the air [26, 27]. The fibrous residue from sugarcane after the extraction of sugar juice is known as bagasse [27].

### 1.2. Objectives of the Study

An environment-friendly method is needed to simplify the disposal of the CO<sub>2</sub> emissions from burning saw dust (SD), sugarcane bagasse (SCB) and corn stalk (CS) wastes which are available in Egypt [27–29]. In the present study, SD, SCB, and CS are burnt in a suitable muffle furnace at 700°C for 2 hours soaking time to create what is known as ash [1]. The present article studied the properties of 50% clay and 50% sludge waste brick mixture as a control mixture. The sludge portion was substituted by 5, 10, 15 and 20 wt. % of saw dust ash (SDA), sugarcane bagasse ash (SCBA) and corn straw ash (CSA) in clay bricks. The physical properties of the prepared brick batches in terms of bulk density, apparent

porosity and water absorption as well as the mechanical properties in terms of compressive and flexural strengths of the fired clay bricks are investigated.

## 2. Experimental

### 2.1. Raw Materials

The clay (CL), sludge (SG), saw dust (SD), sugarcane bagasse (SCB), and corn stalk (CS) were brought from local plants in Assuit, Egypt. The SD, SCB, and CS were first subjected to firing up to 800°C to convert them to ashes. The chemical oxide compositions, the particle size distribution and the physical properties of these raw materials are shown in Tables 1–3, respectively. The clay sample was composed of five major crystalline phases as kaolinite (Al<sub>2</sub>O<sub>3</sub>·2SiO<sub>2</sub>·2H<sub>2</sub>O), montmorillonite (Al<sub>2</sub>H<sub>2</sub>O<sub>12</sub>Si<sub>4</sub>), illite (K<sub>0.65</sub>Al<sub>2</sub>(OH)<sub>2</sub>), Quartz (SiO<sub>2</sub>) and calcite (Ca CO<sub>3</sub>), while the sludge sample was composed of only four phases as montmorillonite (Al<sub>2</sub>H<sub>2</sub>O<sub>12</sub>Si<sub>4</sub>), quartz (SiO<sub>2</sub>), calcite (Ca CO<sub>3</sub>) and albite (Na Al Si<sub>3</sub> O<sub>8</sub>) [30]. The SDA and CSA samples were composed of only three phases as Quartz (SiO<sub>2</sub>), halite (NaCl) and sylvite (K Cl), while SCBA sample of four phases as Quartz (SiO<sub>2</sub>), albite (Na Al Si<sub>3</sub> O<sub>8</sub>), sylvite (K Cl) and halite (NaCl) were identified.

Table 1. Chemical analysis of the raw materials, wt. %

Materials Oxides	Clay	Sludge	SDA	SCBA	CSA
SiO <sub>2</sub>	51.47	64.48	65.17	70.83	66.47
Al <sub>2</sub> O <sub>3</sub>	28.78	16.50	4.35	9.21	8.29
Fe <sub>2</sub> O <sub>3</sub>	3.99	3.43	2.36	1.95	3.13
CaO	0.61	2.81	10.06	8.16	3.13
MgO	1.38	3.15	4.41	1.32	5.46
MnO	0.04	0.05	2.19	-----	4.16
Na <sub>2</sub> O	1.15	2.04	0.08	0.12	2.52
K <sub>2</sub> O	1.19	0.69	0.12	1.65	2.06
SO <sub>3</sub>	--	0.49	0.30	1.47	0.51
TiO <sub>2</sub>	1.14	0.82	-----	-----	-----
P <sub>2</sub> O <sub>5</sub>	0.53	0.38	0.46	-----	-----
Cl <sup>-</sup>	--	0.29	-----	-----	-----
LOI	9.72	4.85	0.84	6.91	1.02
Total	100	100	100	100	100

Table 2. Particle size distribution of the starting raw materials, wt. %.

Particle size, %	Starting raw materials				
	Clay	Sludge	SDA	SCBA	CSA
>63	1.39	0.12	0.09	0.09	0.15
63–16	1.72	0.18	0.19	0.18	0.28
16–8	2.91	0.81	0.08	0.21	0.16
8–2	9.11	10.48	4.59	1.16	6.38
<2	84.87	88.41	96.15	98.36	93.03
Total	100	100	100	100	100

Table 3. Physical properties of the starting raw materials.

Property Materials	Specific gravity	Color
Clay	2.71	Grayish
Sludge	2.36	Grayish
SDA	2.07	Dark gray
SCBA	1.96	Dark gray
CSA	1.98	Dark gray

## 2.2. Preparation of Brick Specimens

The constitution of the various prepared clay brick batches is shown in Table 2. One mixture was composed of 50 wt. % clay and 50 wt. % sludge which was considered as a blank to which all results were compared. Then, there are three groups; each group was containing only one type of the available agro/ashes namely, SDA, SCBA and CSA as clearly shown in Table 2. Each group was containing four brick batches as 0, 3, 6, 9, 12 and 15 wt. % [30]. The clay content was kept constant by the ratio 50 wt. %, while all other ingredients were variable. The addition of the agro/ashes was at the expense of the sludge. Thereafter, the mixing process was first carried out manually and then mechanically by a suitable mixer using 5 balls to ensure the complete homogeneity of all brick batches. The brick batches were let to dry in the open air for three days, and then in a suitable dryer at 105°C for another three days to illuminate the free and evaporable water [31]. Then, the drayed clay and sludge were crushed, ground and quartered to have a representative sample which was fine ground to pass a 200 mesh sieve using a suitable agate mortar.

Table 4. Batch ratios of the prepared bricks, wt. %.

Materials Gp. mixes	Clay	Sludge	SDA	SCBA	CSA
Blank	50	50	----	----	----
	50	47	3	----	----
	50	44	6	----	----
	50	41	9	----	----
I	50	38	12	----	----
	50	35	15	----	----
	50	47	----	3	----
	50	44	----	6	----
II	50	41	----	9	----
	50	38	----	12	----
	50	35	----	15	----
	50	47	----	----	3
III	50	44	----	----	6
	50	41	----	----	9
	50	38	----	----	12
	50	35	----	----	15

The water was then added to the prepared powder brick batches inside a suitable blender and stirred well. Thereafter, the pastes of the brick composites were inserted into 2.5 x 2.5 x 2.5cm<sup>3</sup> stainless steel lab. cube moulds for physical properties [30, 32], or inserted into a cylindrical samples of 3 cm height and 1 cm diameter for compressive strength [33, 34]. The green bricks were then air dried in sunlight for another 4 days to avoid cracks during firing [33-36]. Thereafter, the dried bricks were inserted into the furnace up to 600°C for 30 minutes, and up to 800°C for another 30 minutes and finally up to 900°C for 2 hours soaking time. After complete the firing process, the furnace was let to gradually cool to the room temperature. The produced fired bricks were then subjected to determine the physical properties [35, 37] in terms of water absorption (WA), bulk density (BD) and apparent porosity (AP)

using the following equations:

$$WA, \% = W1/(W-W2) \times 100 \quad (1)$$

$$BD, g/cm^3 = W3/(W1-W2) \quad (2)$$

$$AP, \% = (W1-W3)/(W1-W2) \times 100 \quad (3)$$

Where, W1: Saturated weight in air, W2: Suspended weight in water, W3: Dried weight. The crushing or compressive strength of the fired cube samples [33, 38] could be measured by the following relation:

$$CS = (D)/(L) \times (w) = kg/cm^2 / 10.2 MPa \quad (4)$$

Where, CS is the crushing or compressive strength kg/cm<sup>2</sup>, D is the load kg, L and W are the length and width of the samples, respectively.

## 3. Results and Discussion

### 3.1. Physical Properties

#### 3.1.1. Water Absorption

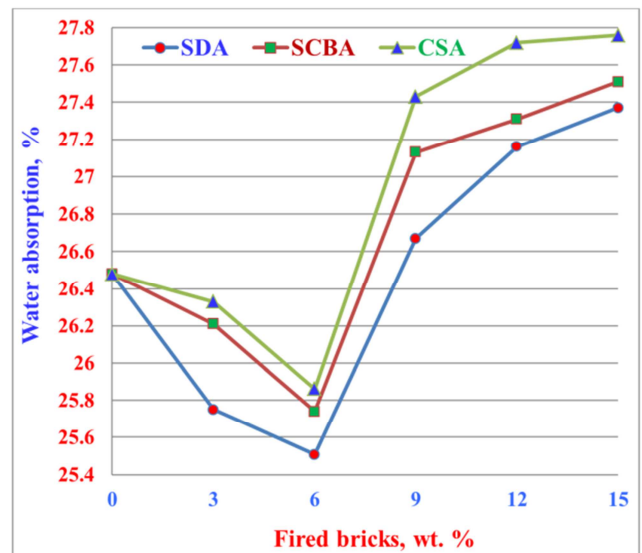


Figure 1. Water absorption of the various fired bricks containing different ratios of agro/ashes.

The water absorption of the prepared fired brick samples containing SDA, SCBA and CSA by 0, 3, 6, 9, 12 and 15 wt. % at the expense of sludge (SD) are graphically plotted in Figure 1, respectively. The values of water absorption of brick samples containing SDA or SCBA or CSA were slightly higher than that of the blank only up to 6 wt. %, i.e. a positive response was existed. The decrease of water absorption is mainly contributed to the thermal reactions that happened among the particles of the clay and/or sludge with the active nano-silica of the agro/ashes [33, 34]. With any further increase of these waste ashes, the water absorption started to increase. This may be due to the spongy nature of SDA, SCBA and CSA which made the

bricks to absorb more water due to the open pore structure [39, 40]. In addition, the large content of nano-silica enhances the total porosity. As a result, the pore structure of the fired samples could be increased.

### 3.1.2. Bulk Density

The bulk density of the prepared fired brick samples incorporating SDA, SCBA and CSA by 0, 3, 6, 9, 12 and 15 wt. % at the expense of sludge (SD) are graphically represented in Figure 2, respectively. The bulk density of the brick samples of the blank slightly improved and enhanced with the increase of these waste ashes only up to 6 wt. %, but decreased with any further increase of its contents. This is mainly attributed to that the used ashes are too light to decrease the bulk density compared with of sludge [40, 41]. Moreover, the increment in the total porosity due to the fact that the addition of these ashes played an important role to decrease the weight of the brick specimens on account of the lower specific gravity of SDA, SCBA and CSA compared with that of clay and/or sludge. Therefore, the higher quantities of SDA, SCBA, and CSA in the bricks, the weight of the brick will be lighter. As the contents of SDA, SCBA, and CSA increased in the bricks, the bricks became much lighter. Accordingly, the higher amounts of the agro/ashes must be avoided. However, the lighter clay bricks would be required in building construction due to its beneficial reduction in the weight of building [42].

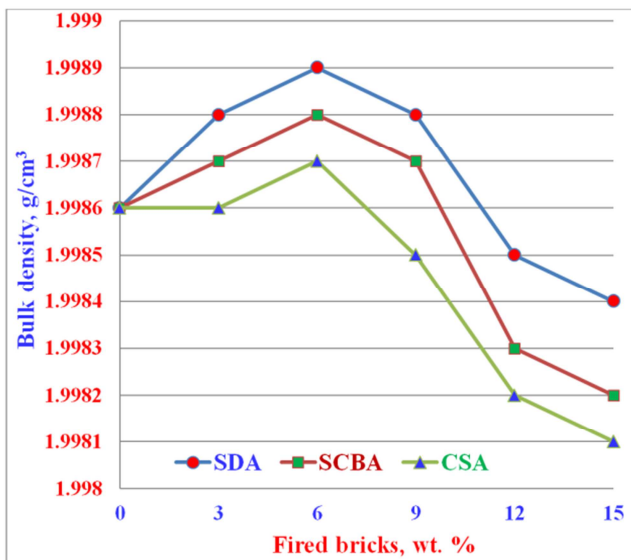


Figure 2. Bulk density of the various fired bricks containing different ratios of agro/ashes.

### 3.1.3. Apparent Porosity

The apparent porosity of the prepared fired brick samples incorporating SDA, SCBA and CSA by 0, 3, 6, 9, 12 and 15 wt. % at the expense of sludge (SD) are graphically represented in Figure 3, respectively. The apparent porosity of the brick of the blank batch decreased slightly with the replacement of SDA, SCBA and CSA at the expense of sludge (SD). This could be attributed to the thermal reaction among the constituents of the agro/ashes with those of the

clay and/or sludge. With any further increase of these agro/ashes, the apparent porosity increased too. This could be led to produce porous bricks. The obtained data are similar to some of previous studies [29, 43, 44]. Porous bricks are generally preferred owing to its insulating properties, and it could be used to resist the high heat of the atmosphere [45].

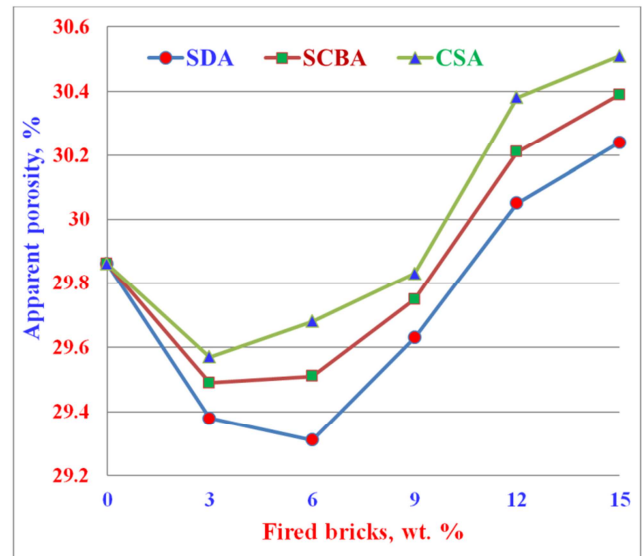


Figure 3. Apparent porosity of the various fired bricks containing different ratios of agro/ashes.

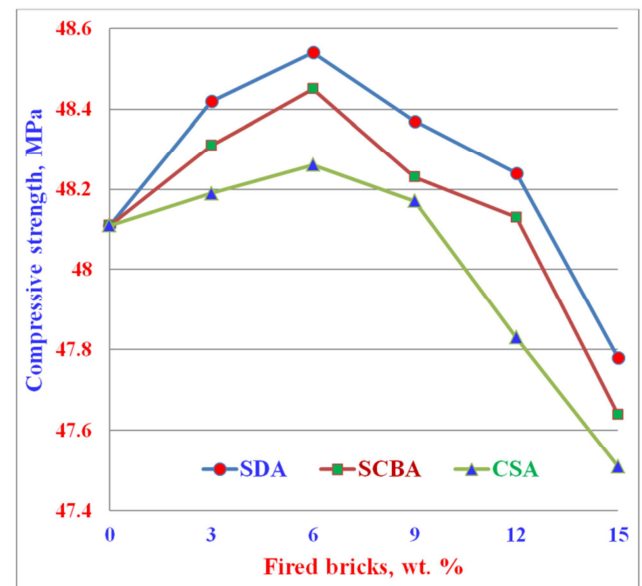


Figure 4. Compressive strength of the various fired bricks containing different ratios of agro/ashes.

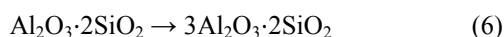
### 3.2. Compressive Strength

The compressive strength of the prepared fired brick samples containing SDA, SCBA and CSA by 0, 3, 6, 9, 12 and 15 wt. %, respectively, at the expense of sludge (SD) are graphically plotted in Figure 4. The compressive strength of the fired blank bricks increased with the incorporation of SDA, SCBA and CSA only up to 6 wt. %, and then decreased. The brick batch containing SDA achieved the

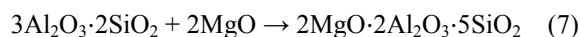
highest values of compressive strength at all contents up to 15 wt. %, while that containing CSA exhibited the lowest, noticing that the same trend was displayed by all brick batches. The increase of compressive strength is mainly due to the thermal reactions that happened between the ingredients of the clay and the active nano-silica of the agro/ashes [33, 34]. The decrease of the compressive strength is essentially attributed to the fact that the larger amounts of these ashes decreased the bulk density of the bricks, which in turn reflected negatively on the mechanical properties in general [30, 34]. Moreover, the resulting volatile gases during firing, and the higher contents of silica could be led to the increase of the porosity. So, the larger quantity of silica is unwelcome in brick-making [30, 44, 45]. Therefore, the production of porous or light weight bricks could be successfully achieved by using  $SDA > SBA > CSA$ .

## 4. General Discussion

To throw light on the behavior of samples during firing, the firing cycle for the green samples started with the evaporation of any moisture content left in the samples after drying and also any hygroscopic moisture that picked up from the atmosphere were also driven off at 300°C. At the temperature range 500–600°C, the kaolinite ( $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$ ) was converted to metakaolin ( $Al_2O_3 \cdot 2SiO_2$ ) as shown in Eq. 5. At 800°C, the organic matter existed in the raw materials were burned off. At 980°C, the formed metakaolin was converted to mullite phase ( $3Al_2O_3 \cdot 2SiO_2$ ) as shown in Eq. 6.



In presence of mullite, the thermal reactions could be enhanced and some calcium-rich phases were formed [24, 35, 46]. The thermal reactions increased in presence of  $CaO$ ,  $SiO_2$ ,  $Al_2O_3$  and alkali oxides ( $Na_2O$  and  $K_2O$ ) that were available in the agro/ashes. Mullite could be reacted with the available  $CaO$  and  $MgO$  to form cordierite ( $2MgO \cdot 2Al_2O_3 \cdot 5SiO_2$ ) as shown in Eq. 7.



The formation of these new phases could be combined to those already existing in the fired samples, is an advantage for sintering of the clay composite since this could be reflected positively on the mechanical strength. Moreover, the collapse or the partial decomposition of other crystalline phases, would favor the abundant viscous flow phase formation, which fill the pore volume, involving a decrease in the apparent porosity and water absorption [46–48]. So, the bulk density and compressive strength were improved. The excess of the agro/waste ashes increased the silica content in the brick body, which in turn reflected negatively on both physical and mechanical properties of the fired bricks. Therefore, the large replacement of the agro/ashes is undesirable [4, 5, 7, 10, 49].

## 5. Conclusions

This paper presents an approach for the safely disposal of agro/wastes, and its recycling in the brick-making. Clay bricks containing agro/wastes like saw dust ash (SDA), sugarcane bagasse ash (SCBA) and corn straw ash (CSA) could be used as a combustible replacement in the clay-making bricks. The SDA, SCBA and CSA have high nano-silica content which could be incorporated with clay and sludge in clay-brick making. Apparent porosity and water absorption decreased with the replacement of SDA, SCBA and CSA only up to 6 wt. %, and then re-increased with further addition. The bulk density and compressive strength improved and enhanced with the increase of agro/wastes content but only up to 6 wt. %, and then decreased, the same trend was displayed by all brick samples. Accordingly, the best ratio of replacement of waste materials to get the best performance of the bricks is 6 wt. % of the SDA, SCBA and CSA. This could be created a sustainable source of new and alternative raw materials in the brick-making. The recycling of agro/wastes as SDA, SCBA, and CSA in clay-making bricks showed positive responses in terms of environmental protection, waste management, alternative raw materials and moreover, the raw material saving.

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## Declaration of Competing Interest

The authors declare that they have no competing interests.

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