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Use of Agricultural Waste in the Preparation of Insulating Fireclay Bricks

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Abstract

Sugarcane bagasse and wheat straw are among the agricultural wastes that are abundantly available in Egypt. The present investigation researches the potential of incorporating these two wastes into the production of insulating fired clay brick. It focuses on the feasibility of using them in fired clay brick mixtures with a percentage replacement up to 5% by weight. Physical, mechanical and thermal properties of the bricksfired at 1250ºC for 2 hours were tested according to standard procedures. The results indicated that adding up to 5% of wastes with 0.5% polystyrene beads (by weight) to standard mixture of bricks reduced the density and improved the brick thermal insulating properties. Even though incorporating the wastes has resulted into a decrease in the mechanical properties, the bricks still comply by the minimum standard for compressive strength. In conclusion, the incorporation of these two wastesat 5% level with 0.5% polystyrene into fired clay bricksproducedinsulating fire bricks with acceptable properties while providing at the same time an alternative way of disposing the sugarcane bagasse and wheat straw waste.

Keywords: sugarcane bagasse, wheat straw, polystyrene, fired clay brick, physical and mechanical properties

INTRODUCTION

Sugar is one of the main substrates of human diet. The five top sugar producing countries in the world are India, Brazil, Thailand, Australia and China. Their production accounts for 40% of the total global sugar production out of the 115 countries producing sugar in the world, Out of these countries, 67 produce sugar from sugarcane, 39 from sugar beet and 9 countries from both cane and beet. Thus, 70% of the sugar is produced from sugarcane and 30% from sugar beet and cassava [1].Sugarcane is considered to act as a solar cell, converting solar energy to chemical energy. In 2009-10, it was estimated that 1683 million tons of sugarcane was planted worldwide, amounting approximately to 22.4% of the total world agricultural production [1].

Sugar industry in Egypt goes back to the year 710 AD[2].Sugar production depended mainly on sugar cane until 1981 when sugar beet was introduced to cover the increasing local demand for sugar. Beet was cultivated as it was not possible to expand the sugarcane plantations which were considered high water consumers in light of the National water policy encouraging water conservation. Cane plantations are concentrated in some areas of Upper Egypt whereby the total amount of cane cultivated in Upper Egypt was about 16 million tons in 2009[3, 4]. The fibrous residue left after sugar canes are crushed to extract their juice is called bagasse. Wet bagasse constitutes about 30% of the cane weight. [5]

On the other hand, wheat is the most important staple crop produced in Egypt. It occupies about 32.6% of the total winter land area and is mostly used to make bread, a very important component of the Egyptian diet. Wheat straw is one of the most important agricultural residues. It is an annually renewable fiber resource that is available in abundant quantity in many regions of the world whereby tons of unused wheat straw residues are generated every year and only a very small percentage has been used for applications such as feed stock and energy production. Straw is similar to wood and could also be considered as a natural composite material. It consists mainly of cellulose, hemicelluloses, and lignin [6].

Among the potential uses of bagasse, incorporation into clay bricks was suggested as it increases the performance of brick, besides eliminating a waste. It is also one of the alternatives to the burning process and cost effective way as the emission from the burning of bagasse would be filtered together with the gases emitted from the brick manufacturing process [7].

Also, production of lightweight clay bricks and blocks with higher thermal insulation properties is possible by using combustible additives in appropriate amounts and particle sizes. One of the materials used for this purpose is polystyrene foam. Each particle whichis dissipated during the firing process leaves behind a cavity, which improves the thermal insulation properties of the brick. Polystyrene foam is thus considered to be a pore forming material in the brick body for reducing thermal conductivity and bulk density of brick which leads to mass reduction of building and improves its resistance to earthquake forces [8].

Kazmi et al [9] stated that the manufacturing of burnt clay bricks using waste materials can reduce the environmental overburden resulting from waste deposition on open landfills and might additionally enhance the brick performance at low manufacturing value In this respect, Junge [8] evaluated the effect of the addition of waste consisting of essential crops: sugarcane and rice in clay bricks manufacturing.

The main objective of the present study is to investigate effect of solid bagasse, wheat straw and polystyrene on the physical, mechanical and thermal insulating properties of burnt fireclay bricks. Bricks were prepared and characterized for elemental composition, bulk density, water absorption, compressive strength and thermal conductivity at (400, 600, 800ºC).

MATERIALS AND METHODS

Materials

1) Clay

Kaolin clay was obtained from Abu Zneima, south of Sinai. It was ground prior to use to pass 35 mesh (417μm) in a laboratory ball mill. Part of it was then fired to 1100ºC for 6 hours to produce grog, while another part was ground to pass 100 mesh screen (147 μm) and was used to induce plasticity

Table 1: X-ray florescence for kaolin sample

SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_3	Na_2O	K_2O	TiO_2	P_2O_5	SrO	Cl	LOI
49.24	33.41	0.33	2.68	0.54	0.12	0.08	1.45	0.33	0.21	0.16	11.35

Chemical analysis of the clay indicates a loss on ignition = 11.35%, which is typical of kaolinitic clays [10].On ILO free basis, silica and alumina constitute more than 93% of the clay mass. This was corroborated by the XRD results which show that clay mainly consists of kaolinite ($Al_2O_3.2SiO_2.2H_2O$) and quartz. (Figure 1)

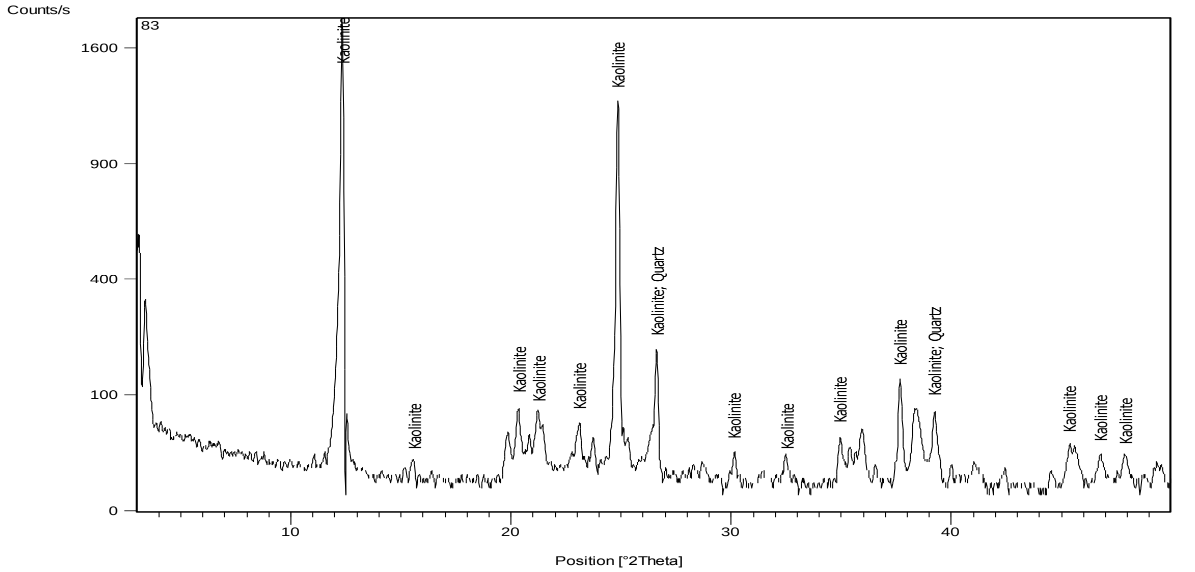

Figure 1: X-ray diffraction for clay sample

2) Bagasse

Sugarcane bagasse waste was collected from juice shops in 10th of Ramadan City which was then sun dried, ground and screened to small particles up to 1 mm size. It is mainly composed of lignin, cellulose, hemicelluloses, fats and silica. Its ultimate composition was established as shown in Table (2).

Table 2: Chemical composition of bagasse

Carbon	Hydrogen	Nitrogen	Phosphorous	Silica -Ash
48.7	4.9	1.3	1.1	44

3) Polystyrene

Polystyrene beads were purchased from Sigma – Aldrich. They passed 6 mesh screens (3.327 mm) and were retained over 10 mesh screen (1.651 mm). The tapped bulk density was determined experimentally to be 0.035 $g.cm^{-3}$.

4) Wheat straw

Wheat straw samples were collected from a farm in 10th of Ramadan city which was then sun dried, ground and screened to small particles up to 1 mm size. It is mainly composed of lignin, cellulose, hemicelluloses, proteins and sugars. Its ultimate composition was established as shown in Table (3).

Table 3: Chemical composition of wheat straw

Carbon	Hydrogen	Oxygen	Silica	Sulfur	Potassium
42–49	5.3–6.2	37–43	1.6	0.66	0.52

5) Control Brick

Ground clay passing 100 mesh screen was mixed mechanically with about 20% water for 30 minutes to produce the brick. After mixing, clay was compacted into 60×60×60 mm^3 steel molds. Following, the brick was dried in the oven with 105°C for 24 hours then fired at 1250ºC for 2 hours. The fired bricks were tested for porosity, bulk density, and water absorption, compressive strength and thermal conductivity. (Figure 2)

6) Sugarcane Bagasse and wheat straw Brick

To produce sugarcane bagasse-polystyrene bricks or wheat straw-polystyrene bricks, the raw materials were first sun dried to negligible moisture content. The wastes were then shredded into smaller pieces of mesh size up to 1mm.Five different percentages of wastes were used which upto5% for each addition together with 0.5% polystyrene by weight. The same drying, firing and testing procedures were applied to the manufactured bricks which were then tested for water absorption, density and porosity. Special shapes of dimensions 230×100×40 mm^3 were used for the thermal conductivity tests.

Figure 2: Clay bricks samples after firing

Testing methods

Water absorption, porosity and bulk density of fired samples were determined using the hot test piece boiling water method [11].

Cold crushing strength was determined according to ASTM C133 – 97 [12].

Thermal conductivity of fired samples was measured method described by ASTM C-182 [13].

The properties of the prepared bricks were compared to class C-32 insulating firebricks with bulk density not exceeding 1250 $kg.m^3$ according to ASTM C155-97 [14].

RESULT AND DISCUSSION

Porosity, Bulk Density and water Absorption

Water absorption, bulk density and apparent porosity were measured by using water absorption method. Addition of either bagasse or wheat straw with 0.5% PS resulted in an increase in porosity and water absorption as evidenced in Figures (3) and (4).

On the other hand, these additions were associated with an expected corresponding decrease in bulk density of the produced bricks. (Figure 5).

It is worth noticing that in all three related properties, there is a radical change in the value of the investigated property as the waste content increases from 0 to 1%. The subsequent variation in the value of the dependent variable is then much less pronounced. For example, while the percent porosity increased from 30% to 45% as the bagasse content in the brick was increased from 0 to 1%, it reached 53.3% as the percent bagasse was increased to 5%.

As for bulk density, none of the obtained values fulfilled the requirement of C-30 insulating bricks of maximum bulk density of 1.03 $g.cm^{-3}$. The maximum value allowed for C-32 bricks being 1.25 $g.cm^{-3}$, Figure 5 shows that it takes adding 5% of either type of waste to obtain density values below that limit.

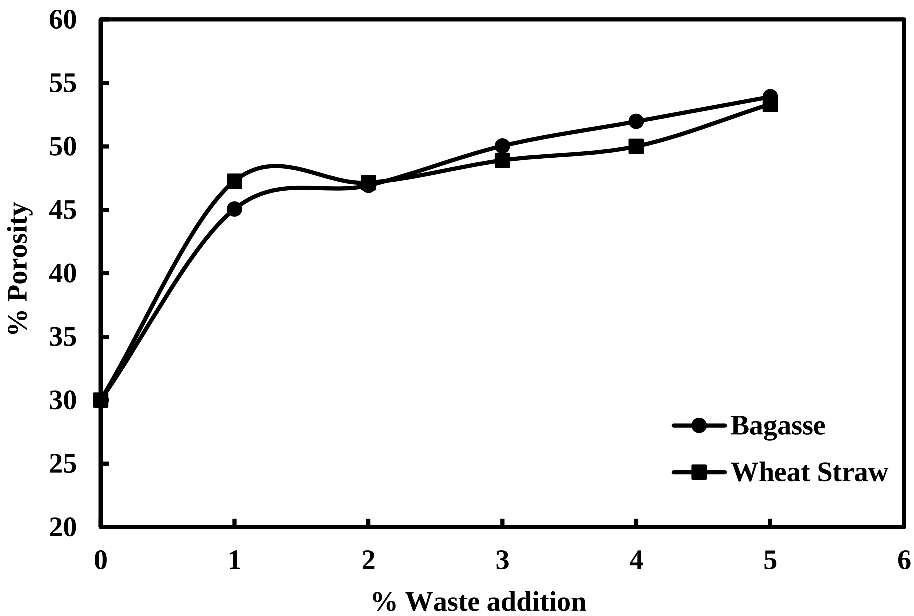

Figure 3: Effect of Percent bagasse and wheat straw on Porosity

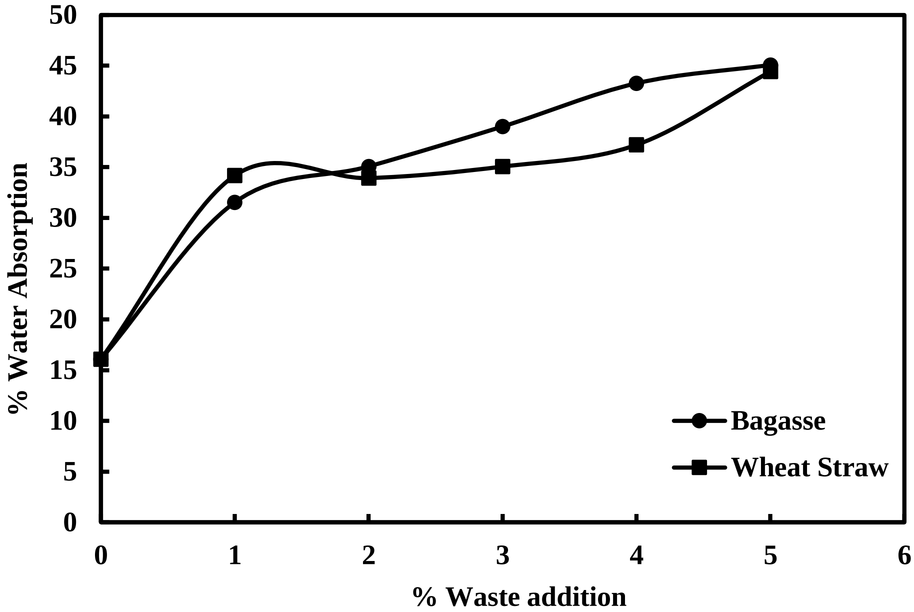

Figure 4: Effect of Percent bagasse and wheat straw on Water Absorption

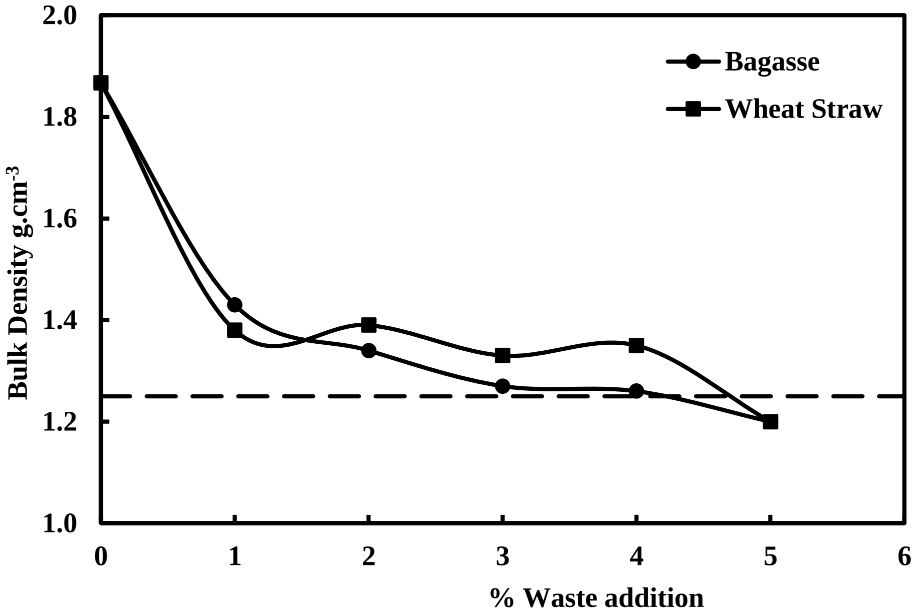

Figure 5: Effect of Percent bagasse and wheat straw on Bulk density

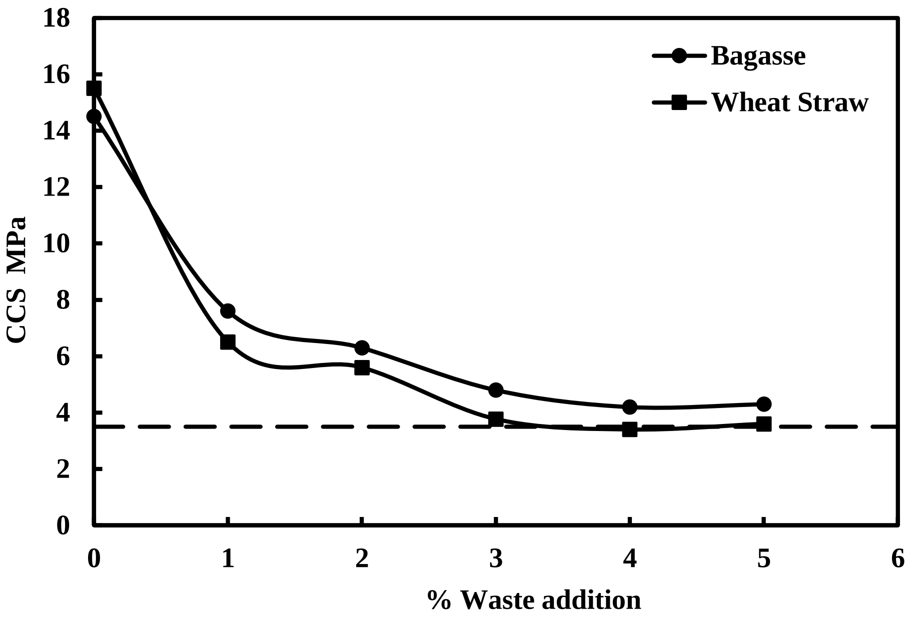

Figure 6: Effect of Percent bagasse and wheat straw on Cold Crushing Strength

Cold Crushing Strength

Cold crushing Strength (CCS) was determined for all bricks and the results exhibited in Figure 6. As the minimum limit required by ASTM C155-97[14] is 3.5 MPa, it appears from that figure that all samples containing bagasse displayed higher values including the 5% sample; while the value obtained on adding 5% wheat straw was marginal.

Thermal conductivity

Thermal conductivity obviously represents a major property to be reckoned with on testing insulating fire bricks. This property was determined for all prepared bricks samples at 400, 600 and 800ºC.

Following ASTM C155-97, the values of thermal conductivities for C-32 type bricks should not exceed 0.49, 0.5 and 0.51 $W.m^{-1}K^{-1}$ at 400, 600 and 800ºC respectively. Figures 7 and 8 shows the results obtained on determining thermal conductivities of bagasse and wheat straw containing bricks respectively at all three temperatures. For all percentages waste investigated, including the sample with no waste, the values of thermal conductivity did not exceed the standard values.

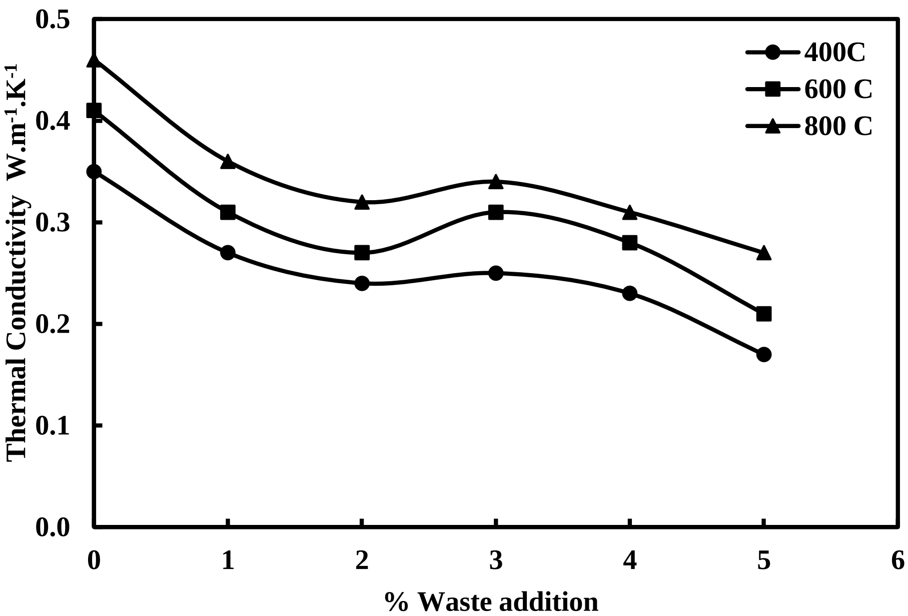

Figure 7: Effect of Percent bagasse on Thermal conductivity

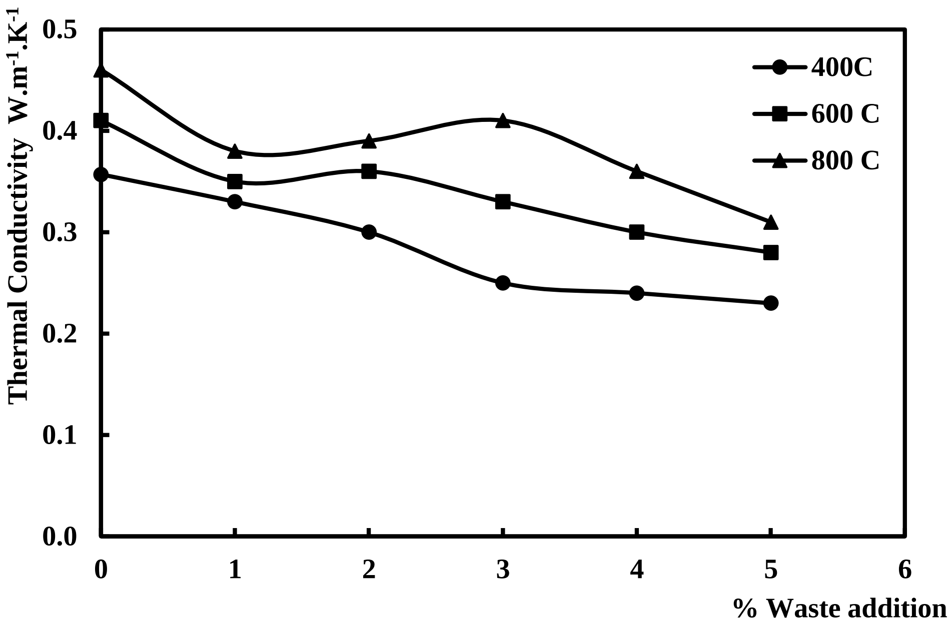

Figure 8: Effect of Percent wheat straw on Thermal conductivity

CONCLUSION

The present investigation was concerned with utilization of two types of vegetable waste (Bagasse and wheat straw) with 0.5% polystyrene into fired clay bricks to act as pore formers to produce lightweight bricks. Tests showed that by increasing the percentage wastes with fixed polystyrene foam additive, the percent porosity, percent water absorption increased entraining a decrease in bulk density while the cold crushing strength decreased accordingly. These additions were also accompanied with increased thermal conductivities.

Results proved that adding 5% bagasse with 0.5% polystyrene beads results and firing for 2 hours at 1250ºC produced bricks abiding by ASTM standards for C-32 type insulating fireclay bricks. On the other hand, the addition of 5% wheat straw, despite fulfilling the density and thermal conductivity requirements, resulted in marginal values for cold crushing strength. The results are summarized in Table 4.

Table 4: Properties of 5% waste + 0.5% PS insulating firebricks

Composition	Density $g.cm^{-3}$	CCS MPa	$K_{800°C}$ $W.m^{-1}.K^{-1}$
5% Bagasse + 0.5% PS	1.2	4.3	0.27
5% W.S. + 0.5% PS	1.2	3.55	0.31
Standard values	1.25 max	3.5 min	0.51 max

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