EXPLOITATION OF RICE AGRICULTURE WASTES IN CLAY MASONRY UNITS PREPARATION

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ABSTRACT

This paper deals with the exploitation of both rice husk and straw as partial constituents in the fabrication of clay masonry units. This allows for using harmful wastes that were otherwise burnt besides lowering the amount of clay used in brickmaking. Clay was mixed with different percentages of each waste and water was added in a suitable amount to produce mixes that were molded and dried. Drying shrinkage and green compressive strength were determined for these dry samples. The firing of the dried samples was then carried out at temperatures ranging from 700 to 800ºC with a one-hour soaking time. The following properties were investigated as a function of both firing temperature and percent waste added: loss of ignition, firing shrinkage, cold and boiling water absorption, saturation coefficient, apparent porosity, bulk density, and compressive strength. The properties of masonry units produced by firing at 700ºC and containing 3% of either waste were in good agreement with ASTM C 62 specifications for clay made bricks.

Keywords: clay masonry units, agriculture wastes, rice husk, rice straw.

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1. INTRODUCTION

Agricultural and industrial wastes are byproducts that often represent a major threat to the environment due to the increase in their amount and their diversity which affect environmental sustainability. Also, capitalization of wastes is difficult because of their variety, as well as unknown possible variations in their properties over time [1-5].

The increase in the amount of waste is strongly linked to the increase in world population which jumped from 6.8 billion in 2009 to 7.7 billion in 2019 and is estimated to reach an estimated 9.7 billion by the year 2050 [6]. Several schemes were suggested to overcome the problem of waste in general and agricultural waste in particular. This latter type cannot easily be recycled and the need for reuse in other applications is often necessary. One such field of application lies in sustainable construction materials aiming at designing green buildings. This may partially relieve the economic strains facing the construction industry as well as the production of conventional building materials [7, 8].

Investigating the reuse of agricultural waste generally aims at reaching an eco-friendly, cleaner environment besides seeking socio-economic solutions to get rid of these wastes.

In this connection, the building industry in general, and brick making, in particular, offers an excellent sink for a large variety of agricultural waste, particularly in third-world and South East Asian countries owing to the huge amounts of generated waste [9-11].

Much work has been devoted to the use of agricultural waste in the production of fired clay bricks with special emphasis on the effect of such addition on their properties such as water absorption, bulk density, and compressive strength.

Guna *et al*. [12] researched the effect of adding ground nut shells and rice husks on the properties of fired clay bricks. Waste polypropylene was also added in different amounts to increase thermal insulation. Flexural strengths up to 37.6 MPa were achieved. Also, Maheswari *et al*. [13] found that it was possible to add up to 20% rice husk in clay bricks to obtain bricks with reasonable strength upon firing at some undetermined temperature. The authors however relied on comparing their results to Standards on IS 2386–Part III (1963). They considered therefore that reaching a compressive strength of 4.49 MPa was sufficient strength. These findings are not compatible with the more recent ASTM C 62 which requires a minimum of 8.7 MPa for normal-duty bricks [14].

Luna-Cañas *et al.* found that the addition of 10% of cocoa shell and 90% of clayey soil did not affect the compressive strength, flexural strength, and durability of resulting bricks whose mechanical properties were suitable for use as secondary raw materials in brick production [7].

To investigate the production of clay bricks containing lower doses of rice straw ash and sugar can bagasse ash, mixes containing these wastes were molded, sun-dried, and fired at 800ºC for 36 hours [15]. The authors failed to attain however the minimum compressive strength stipulated by ASTM C 62. On the other hand, Heniegal *et al.* [16] studied the possibility of incorporating rice straw, sugarcane bagasse, and wheat straw ashes with 50% water sludge in clay brick mixes. They fired the molded samples at 900ºC and determined the properties of the fired bricks produced. They claimed that the values of flexural strength were within the range allowed by standards without, however, referring to the relevant standard. The compressive strength, a major requisite, was not determined.

The addition of sugar bagasse and wheat straw up to 5% with 0.5% polystyrene beads by weight to brick mixture lowered its density and improved its insulating properties [17]. Also, Kazmi *et al*. [18] used waste sugarcane bagasse and rice husk ashes with clay to prepare fired bricks with elevated compressive strength and high durability. The use of rice straw was also researched by a few authors lar in unfired brick making whereby a compressive strength of 2.8 MPa was reached by Dawood *et al.* [19].

The present paper aims at reducing agriculture waste impact, specifically rice husk and straw by finding appropriate socio-economic solutions. The extent of using such wastes in fired brick making was governed by its abiding to ASTM C 62 Standards [14].

2. EXPERIMENTAL WORK

2.1. Raw Materials

Two types of raw materials were utilized in this research: The first consists of desert clay, which is mainly used in the fired clay brick industry, obtained from Upper Egypt (Beni–Sweif). The second consists of rice husk and rice straw wastes, obtained from rice farming in Lower Egypt (Nile Delta region).

2.2. Characterization of Raw Materials

The aforementioned raw materials were subjected to the following analyses:

2.2.1 Chemical analysis

X–ray fluorescence spectrometry (XRF) is a type of elemental analysis that detects several elements presence with their concentration in the sample. The elements with atomic numbers exceeding 8 can be detected at levels of a few mg/kg (ppm). Recent wavelength dispersive spectrometers (WDXRF) improvement allows for determining ultra-low atomic number elements including (O). XRF analyses were worked on AXIOS, analytical 2005, Wavelength Dispersive (WD-XRF) Sequential Spectrometer.

2.2.2 Determination of free silica

In this method, the combined silica, within the clay minerals is liberated as silicic acid and is accordingly dissolved in a hot sodium hydroxide solution. The quartz "free silica" remains as a residue [20]. This method is more efficient than that consisting of using boiling concentrated sulfuric acid.

2.2.3 Determination of organic matter

Organic matter removal was carried out using chemical reagents a familiar pretreatment method to analyze the phases present in soil [21]. The organic matter chemical destruction is also utilized to uncover mineral surfaces for subsequent sorption experiments [22, 23] and to assess organically bound metals [23].

2.2.4 Mineralogical analysis

XRD (X–Ray diffraction analysis) is used for the qualitative analysis of phases existing in the sample rather than its chemical components. Samples were analyzed using a Bruker D_8 Advanced Computerized X-Ray Diffracto-Meter with mono-chromatized Cu K_α radiation. Standard diagnostic treatments such as those set out in Bindley and Brown [24-26]. The diffraction pattern is used to identify the specimen's crystalline phases [27].

2.2.5 Thermal analysis (DTA and TGA)

The three main thermo–analytical techniques are thermo-gravimetric analysis (TGA), differential thermal analysis (DTA), and derivative thermo-gravimetric (DTG). These terms were first adopted by the international confederation for thermal analysis [27]. The apparatus used is a Universal V4-7A, TA apparatus at a heating rate of 10ºC.min^{-1}, in nitrogen flow.

2.2.6 Screen analysis

The grain size distribution for both of clay and rice wastes was determined according to the sieving procedure described by ASTM D 422 [28], using standard sieves which are in compliance with ASTM E 11 [29]. The reported cumulative analyses are represented on a semi-logarithmic graph.

2.3. Experimental Procedure

2.3.1 Preparation and formation of brick samples

Clay masonry brick mixes were prepared by adding rice wastes to clay, the percentage added of rice wastes ranging from 0% to 35% (by weight), in 5% increments, so that eight samples were made from each rice straw and rice husk separately. These mixtures were mixed on a dry basis for 10 minutes in a laboratory drum mixer. The body formation of bricks was carried out as follows:

a) Cubic brick samples of 50×50×50 mm^3 were molded by semi-dry pressing using a laboratory hydraulic press under uniaxial pressure of about 8MPa with 20% water as binder.
b) Brick samples were dried in three steps in a laboratory muffle dryer: First, at a temperature of 50ºC for 24 hours, then the temperature was increased to 80ºC for another three hours, and finally at 110ºC for three hours.
c) Each sample is composed of three test specimens, which were tested to take the average of results.

2.3.2 Testing of green samples

a) Determination of linear drying shrinkage for prepared samples

Based on ASTM C 326 [30], linear shrinkage of unfired and fired brick produced was measured for different preparation conditions. The following expression was used to evaluate the linear drying shrinkage (LDS):

$$LDS\% = \frac{L_w - L_d}{L_w} \times 100 \quad (1)$$

Where: L_w is the wet length (mm)
L_d is the dry length (mm)

b) Determination of compressive strength

Flatwise specimens of unfired and fired brick were subjected to uniaxial compressive loading at a uniform rate for more than 1 or 2 minutes [31]. If the load at failure is W (N) and the cross-sectional area normal to loading direction is A (mm^2), then the compressive strength σ (MPa) can be calculated from:

$$\sigma = \frac{W}{A} \quad (2)$$

2.3.3 Firing of brick samples

Formed bricks were fired at three different temperatures (700, 750, and 800) ºC, for one-hour soaking time and a total firing time of 3 hours in a laboratory muffle furnace.

The dimensions and weight of the formed bricks, before and after firing, were determined using a vernier caliper and a digital balance respectively.

2.3.4 Testing of fired brick samples

a) Loss in weight on firing

This test is done to measure the impurities lost or moisture quantity when the sample is ignited under the firing conditions according to ASTM D 7348 [32].

b) Linear firing shrinkage (LFS)

Linear firing shrinkage of each specimen was determined after firing the specimen at different temperatures according to ASTM C 326 [30].

c) Sintering properties

These properties were measured by determination of cold and boiling water absorption, saturation coefficient, porosity, and bulk density, which were measured, calculated, and reported according to ASTM C 373 [33].

- Boiling water absorption (BWA), expressed as a percent, was determined using the expression:

$$BWA\% = \frac{m_b - m_d}{m_d} \times 100 \quad (3)$$

Where m_b is the mass of the specimen soaked with water after boiling (g)
m_d is the mass of dry specimen (g)

- Cold water absorption (CWA), expressed as a percent, was determined using a similar expression:

$$CWA\% = \frac{m_c - m_d}{m_d} \times 100 \quad (4)$$

Where m_c is the mass of the specimen soaked with cold water (g)
m_d is the mass of dry specimen (g)

- Saturation coefficient (SC) is the ratio between CWA and BWA. It was determined using the expression:

$$SC = \frac{m_c - m_d}{m_b - m_d} \quad (5)$$

- Apparent porosity (P), expressed as a percent, was calculated using the aforementioned values of m_d and m_b and the bulk volume was determined geometrically using the Vernier caliper:

$$P\% = \frac{m_b - m_d}{V_b \times \rho_{water}} \times 100 \quad (6)$$

- Bulk density (ρ_b) was obtained as the ratio between the dry mass and bulk volume:

$$\rho_b = \frac{m_d}{V_b} \quad (7)$$

d) Compressive strength

The compressive strength of fired clay bricks is determined as that of green clay bricks [28].

3. RESULTS and DISCUSSIONS

3.1. Raw Materials Characterizations

3.1.1 Chemical analysis

Silica and alumina mainly constitute the backbone of clay besides having free silica as a normal impurity in clays while for rice husk and straw, the absence of any appreciable amounts of alumina infers that most of the silica present will be in the free form as shown in Table-1.

Table-1. Chemical analysis of raw materials.

Constituents, Wt. (%)	Desert Clay	Rice Husk	Rice Straw
SiO_2	43.08	13.28	7.57
Al_2O_3	16.54	0.22	0.13
$Fe_2O_3^{tot.}$	8.08	0.57	0.6
TiO_2	0.91	0.08	0.07
MgO	1.38	0.13	0.19
CaO	9.00	0.77	1.16
Na_2O	3.40	0.06	0.24
K_2O	1.29	2.22	3.90
P_2O_5	0.18	0.26	0.12
SO_3	1.91	0.33	0.36
SrO	0.16	0.02	0.02
Cr_2O_3	0.02	———	———
MnO	0.03	0.06	0.11
ZrO_2	0.07	———	0.004
Co_3O_4	0.02	———	———
ZnO	0.01	———	———
CeO_3	0.04	———	———
NiO	0.01	0.02	0.01
CuO	0.01	0.01	0.01
Nb_2O_3	0.01	———	———
Rb_2O	0.01	———	———
Cl	0.59	0.41	1.43
Br	———	0.01	0.01
L.O.I	13.26	81.75	84.07
Total	**100.01**	**100.2**	**100.004**

The relatively elevated figure of LOI for clay is due to the dehydroxylation of kaolin following the reaction:

$$Al_2Si_2O_5(OH)_4 = Al_2Si_2O_7 \text{ (meta-kaolin)} + 2H_2O$$

This is besides the decomposition of calcium carbonate and possible hydrated iron oxides present in the material.

On the other hand, the large LOI observed for both rice wastes is due to the devolatilization of lignosulfonate components such as hemicellulose, cellulose, and lignin [34, 35].

3.1.2 Free silica and organic matter content

The organic matter content of clay is relatively low, so the loss of ignition (LOI) while that of rice straw and husk is considerable as observed in Table-2. The percent organic matter in both wastes is about 14% short of the total LOI, presumably due to the loss of moisture besides organic matter [34, 35].

Table-2. Free silica and organic matter in raw materials.

Component \ Raw Material	Desert Clay	Rice Husk	Rice Straw
Organic Matter, %	5.07	68.7	70.56
Free Silica, %	22.82	12.00	7.80

3.1.3 Mineralogical analysis

The XRD pattern for clay reveals the presence of two types of clay namely, kaolinite ($Al_2Si_2O_5(OH)_4$) and montmorillonite ($Al_2Si_4O_{10}(OH)_2$), besides quartz (SiO_2), calcite ($CaCO_3$) and soda feldspar - albite - ($Na_2Al_2Si_6O_{16}$) which is in good agreement with the chemical analysis of clay reported in Table-1.

It seems also that the main peaks of Fe_2O_3 (hematite) occurring at $2\theta = 49$ and for magnetite ($2\theta = 35$) may well have been masked by the multitude of peaks present in that zone as illustrated in Fig. (1).

On the other hand, the XRD pattern for both rice husk and straw were very similar exhibiting three diffuse peaks at $2\theta \approx 16°$, 22.3° and 35° corresponding to the presence of KCl. These results reveal the absence of crystalline quartz which, if present would have shown a marked peak at 26.3° [34, 35].

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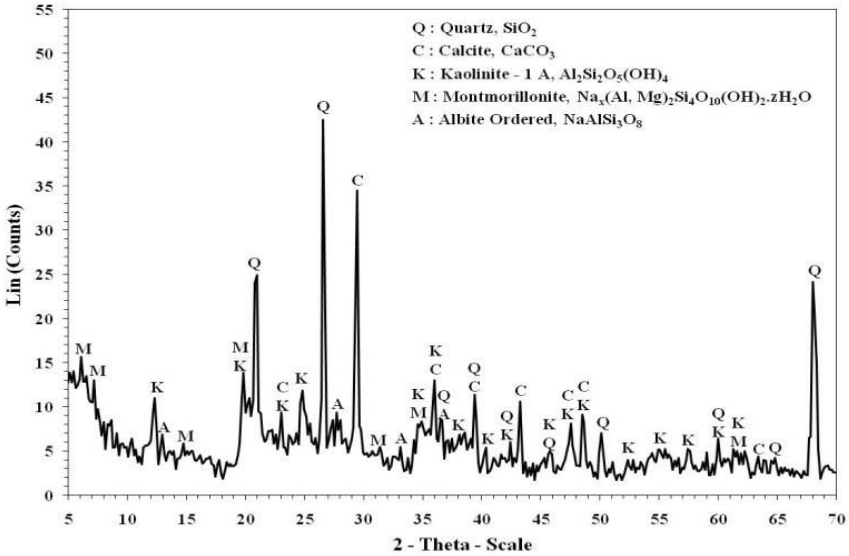

Figure-1. XRD pattern for desert clay.

3.1.4 Thermal analysis

Figure-2a shows the TG–DTG patterns obtained on heating clay. The early endothermic losses before 120ºC are due to the elimination of moisture amounting to about 10% of the initial mass. A small DTG peak shows at about 250ºC, presumably due to the oxidation of organic matter. The two subsequent losses starting at about 400ºC and ending at about 640ºC are due to the dehydroxylation of montmorillonite and kaolinite respectively. The final weight loss above 800ºC relates to the decomposition of calcite. The total weight loss, excluding moisture, amounts to about 12%, a figure close to the LOI value previously reported for clay.

On the other hand, the TG–DTG trace of rice husk (Figure-2b) shows a loss of moisture of about 9.3% followed by a loss of organic matter ending at about 400ºC amounting to 59.3%. The total loss is short of 70%, a figure lower than that predicted by XRF which may be due to incomplete drying of the XRF sample before analysis. The two main peaks observed ending at about 370ºC relate to the devolatilization of hemicellulose, cellulose, and lignin [34, 35].

As for rice straw (Figure-2c), the same pattern was obtained except for two: First, the total loss in weight amounted to about 86%, a figure close to the LOI obtained on chemical analysis. Second: A third peak was observed on DTG with a peak at about 820ºC, accompanied by a weight loss of about 9% at the end of the peak at 860ºC. This peak is presumably due to the combustion of biochar left after the devolatilization of lignocellulosic organic matter and the calcination of minor amounts of calcium carbonate and volatilization of KCl.

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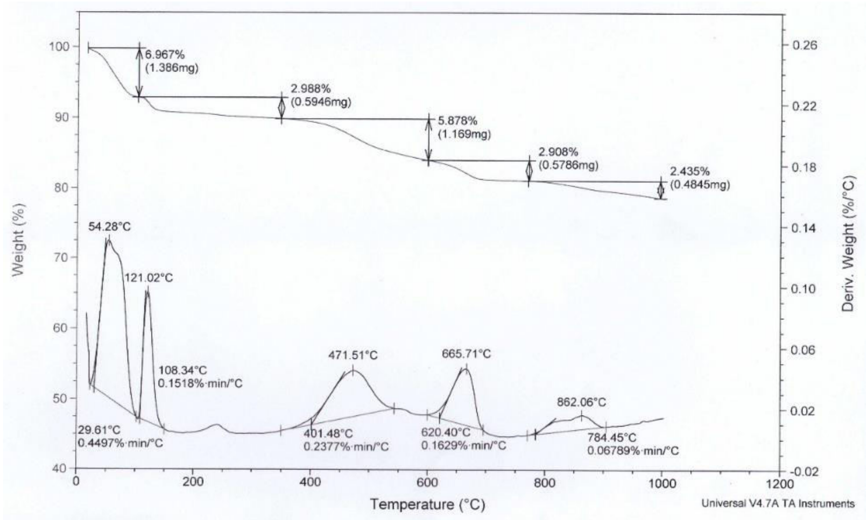
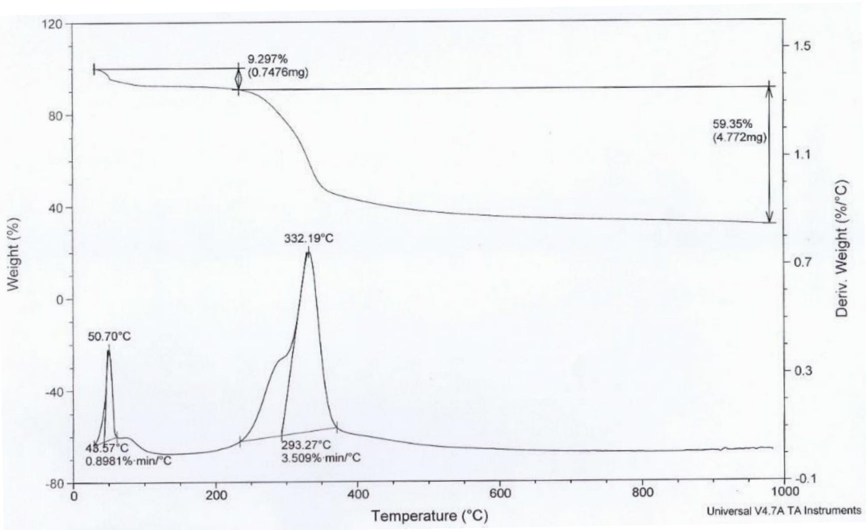
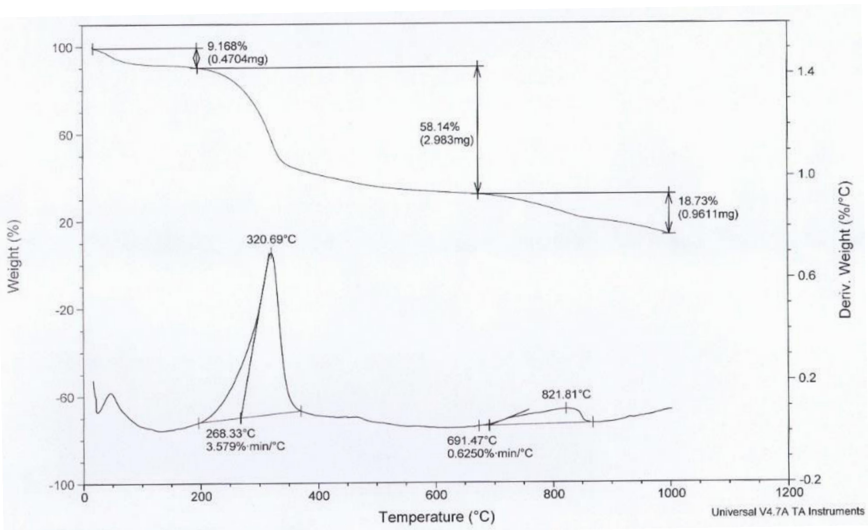


(a)



(b)



(c)

Figure-2. TG - DTG pattern for raw materials used; (a) Desert clay, (b) Rice husk, and (c) Rice straw.

3.1.5 Screen analysis

The cumulative plots of the three raw materials show that while clay particles are the finest, those of rice straw are coarser and rice husks particles are the coarsest among the three materials as is clear in Figure-3a.

On the other hand, differential analysis (Figure-3b) reveals bimodal distributions for both rice wastes. Even clay exhibits a second small peak at about 0.4 mm which can be explained as that behavior is associated with the presence of hard silica particles which exist as fine quartz in the case of clay, while present in amorphous forms in rice wastes. This observation agrees with the presence of the second peak in both rice husks and straw at the same particle size of about 0.4 mm. The higher silica content of rice husks seems to be responsible for the more pronounced bimodal character of the distribution.

Also, the median particle sizes of raw materials are calculated. It is 0.09 mm for desert clay, 0.22 mm for rice husks, and 0.12 mm for rice straw.

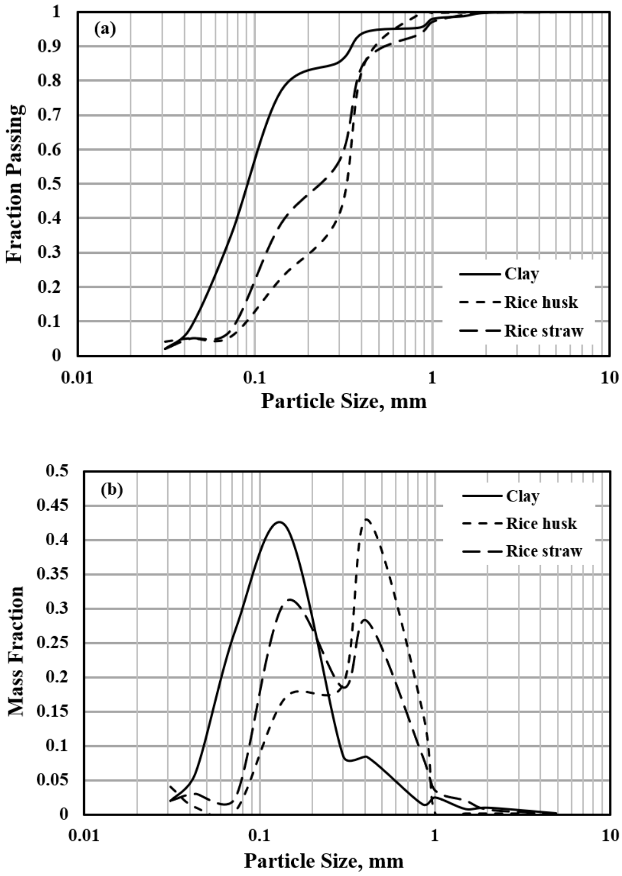


Figure-3. Screen analysis of raw materials used: (a) Cumulative analysis, and (b) Differential analysis.

3.2. Unfired Brick Samples Characterizations

3.2.1 Drying shrinkage (DS)

The addition of any of the two rice wastes decreases the linear drying shrinkage. It also seems that the effect of adding rice straw is more pronounced than that of rice husks, which is clear in Figure-4. This behavior is due to the presence of a higher level of silica in husks compared to straw which could be responsible for that effect because of the non-plastic properties of silica [36–40].

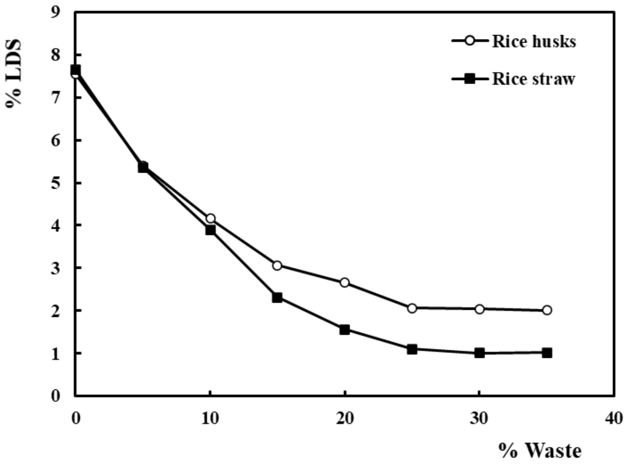


Figure-4. Effect of waste addition on linear drying shrinkage.

3.2.2 Green compressive strength

Addition of rice waste to clay results in a severe loss of green strength as shown in Figure-5. This is due to the decreased cohesion between particles following diminished shrinkage.

This figure also shows that the effect of either waste on strength is practically the same, the strength decreasing from about 4.5 MPa for bricks formed without any addition down to about 0.5 MPa as the percent rice waste reaches 20%. Further addition does not have any more effect on the weakened bricks [36–40].

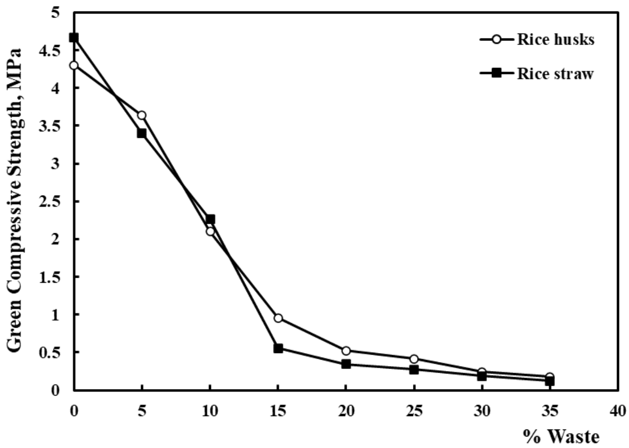


Figure-5. Effect of waste addition on green compressive strength.

To emphasize the fact that the drop in strength is primarily due to low drying shrinkage, a plot was performed between green dry strength and percent volume drying shrinkage. This plot is shown in Figure-6 and reveals the increasing trend between the two variables. Here also, it is clear that there were no appreciable

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differences between the effects of drying shrinkage on green strength in any of the two wastes investigated [36-40].

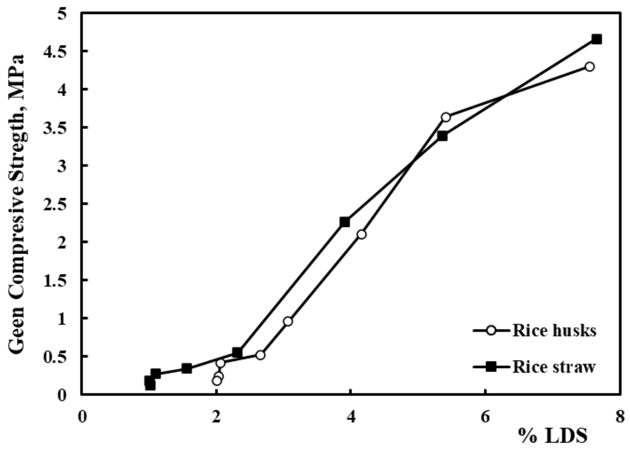
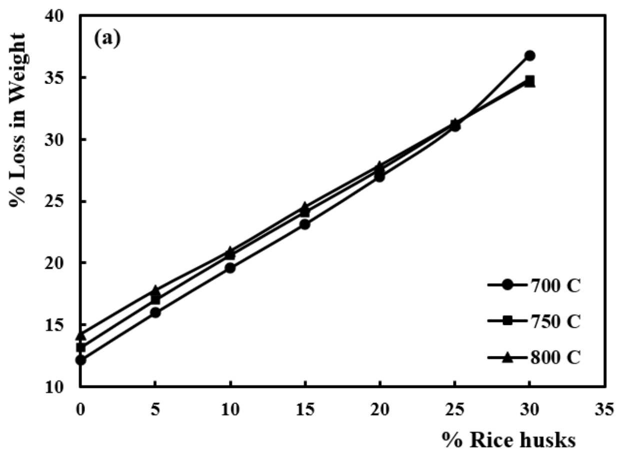


Figure-6. Dependence of green strength on the percent linear drying.

3.3. Fired Brick Samples Characterizations

3.3.1 Loss in weight on firing

The loss on firing for different samples was studied as a function of waste content and firing temperature. As evidenced by Figure-7, the loss linearly depends on the percent waste added. The nearest results for LOI are those recorded at 800ºC since LOI is determined at 1000ºC. Figure-7a reveals that the loss in weight in the case of adding rice husks did not practically depend on the firing temperature while it is clear from Figure-7b that the dependence is more pronounced in the case of adding rice straw. This is related to the presence of calcium carbonate in the straw (Figure-2c) that starts decomposition above 700ºC. That is why the curves corresponding to 750ºC and 800ºC show a slightly higher weight loss [36–40].



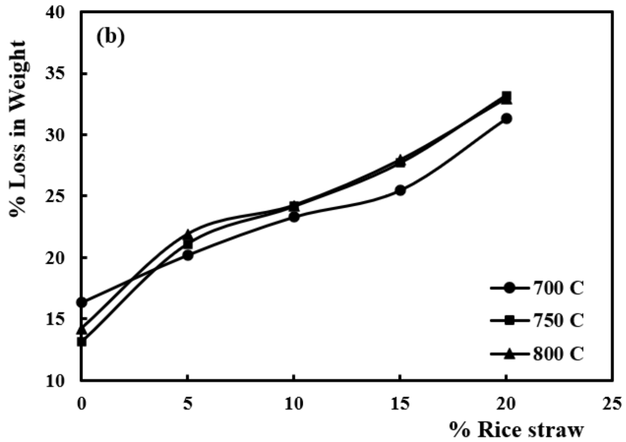


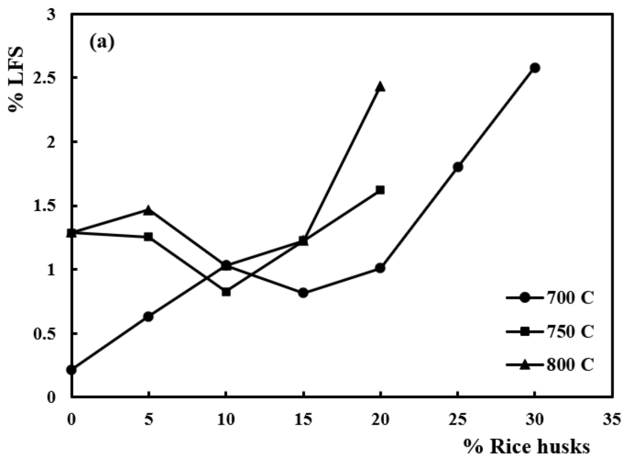
Figure-7. Effect of percent rice waste on the loss in weight on firing; (a) Rice husk, and (b) Rice straw.

3.3.2 Firing shrinkage (FS)

Firing shrinkage is mainly due to the sintering process that is activated by the presence of pores and elevated temperatures. That is why it is expected that an increase in waste content will generate porosity assisting in the start of the sintering process.

In the case of rice husks, it is almost fully decomposed at 400ºC (Figure-2b) and the presence of waste will enhance the sintering process resulting in an increase in shrinkage with increased waste level (Figure-8a). The effect of temperature is limited compared to that of percent waste which seems to regulate the firing shrinkage [36–40].

A similar situation was found when rice straw was added. The results are represented in Figure-8b.



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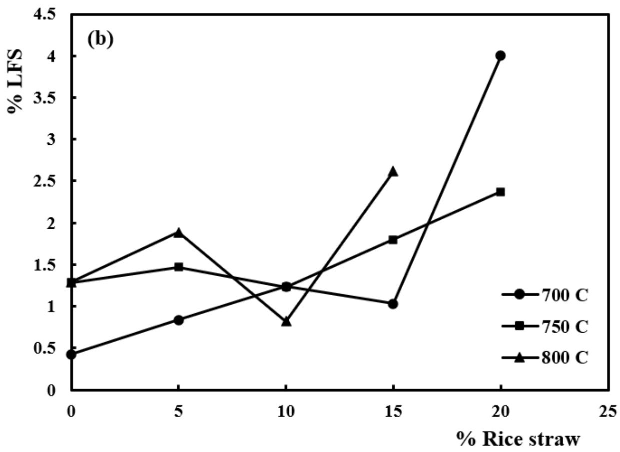
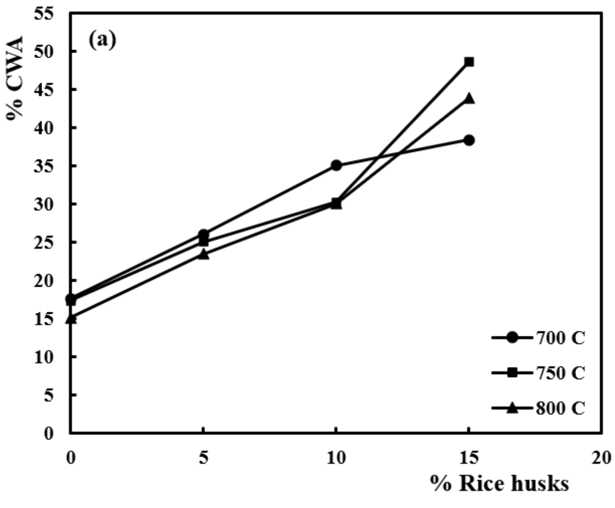


Figure-8. Effect of rice wastes addition on linear firing shrinkage; (a) Rice husks, and (b) Rice straw.

3.3.3 Water absorption

(a) Cold water absorption (CWA)

Tests for cold water absorption were conducted for samples fired at the three prefixed temperatures and with waste addition levels reaching 20%. The results for rice husks and rice straw-containing samples are presented in Figure-9. In either case, firing temperature does not seem to have any serious effect on the results whereas there is an almost linear relation between the proportion of added waste and water absorption [36–40].



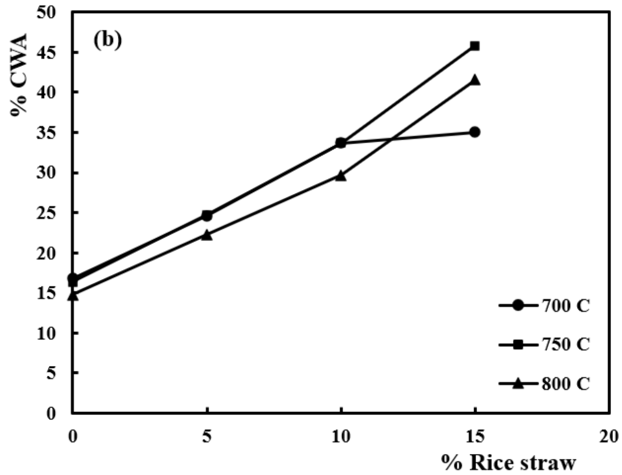


Figure-9. Effect of rice wastes addition on percent cold water absorption (CWA) (a) Rice husks, and (b) Rice straw.

(b) Boiling water absorption (BWA)

As expected, the values of BWA were higher than the corresponding values for cold water. This can be explained as entrapped air in the smaller pores being expelled by boiling and allow to hot water to penetrate these pores as illustrated in Figure-10 [36–40].

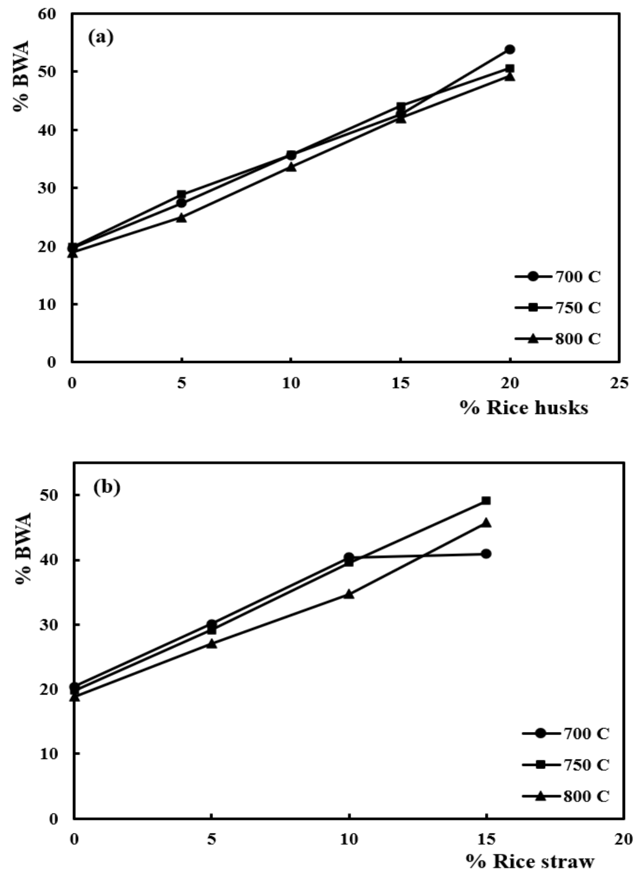


Figure-10. Effect of rice wastes addition on percent boiling water absorption (BWA); (a) Rice husks, and (b) Rice straw.

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3.3.4 Saturation coefficient (SC)

As previously explained a high saturation coefficient implies that the amount of water absorbed does not depend on whether it is cold or boiling because of the large pore size. A small coefficient will correspond to more micropores. Due to the nature of rice husks, the pores formed upon firing will be relatively large; increasing in total volume as the percent waste is increased. Once more the firing temperature is almost irrelevant. This is revealed in Figure-11 [36–40].

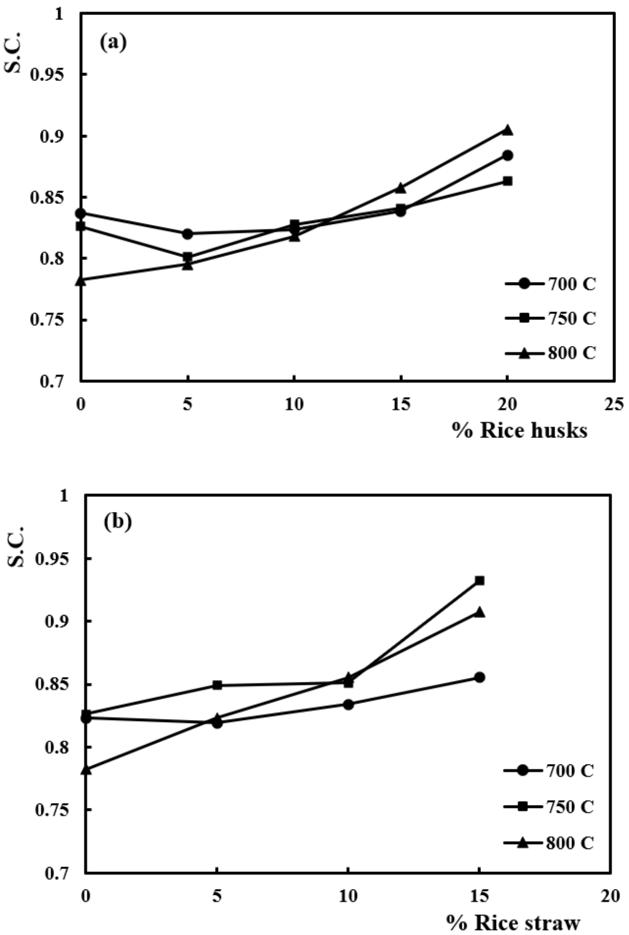


Figure-11. Effect of rice wastes addition on saturation coefficient (SC); (a) Rice husks, and (b) Rice straw.

3.3.5 Apparent porosity (P)

The apparent percent porosity represents the available open surface pores that are available for any fluid absorption. The normal trend of porosity curves is usually in harmony with water absorption curves. As shown in Figure-12a, an increase in percent rice husks increases porosity while an increase in temperature tends to decrease porosity as some open pores get closed by the start of the sintering process. A similar trend was observed in determining the porosity of samples containing rice straw. The effect of temperature and addition level is shown in Figure-12b [36-40].

A relation between apparent porosity and water absorption seems evident. This is clear from Figure-13 where a plot of percent BWA and apparent porosity is illustrated for rice husk.

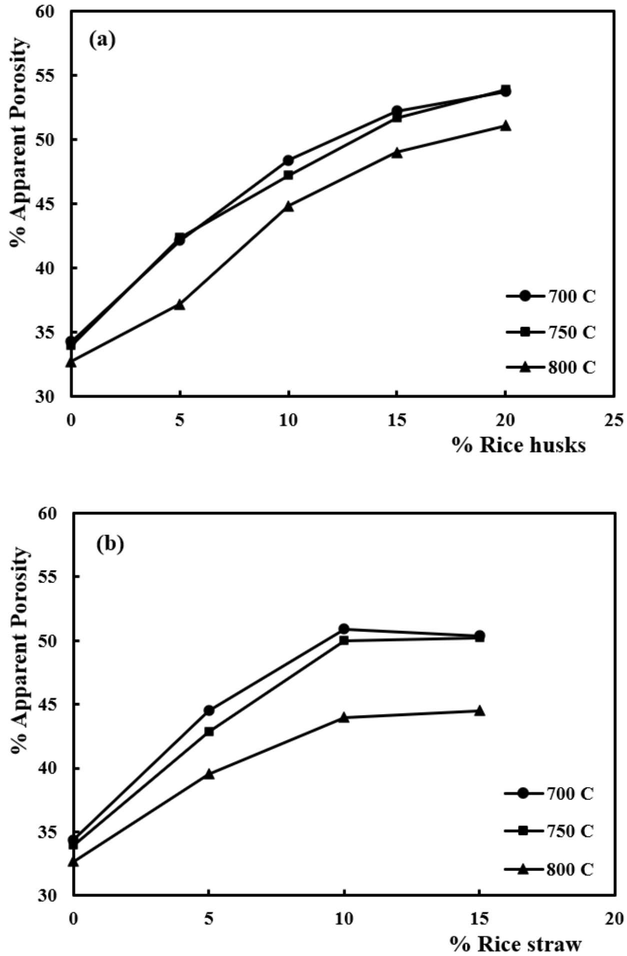


Figure-12. Effect of rice waste addition on apparent porosity (P); (a) Rice husks, and (b) Rice straw.

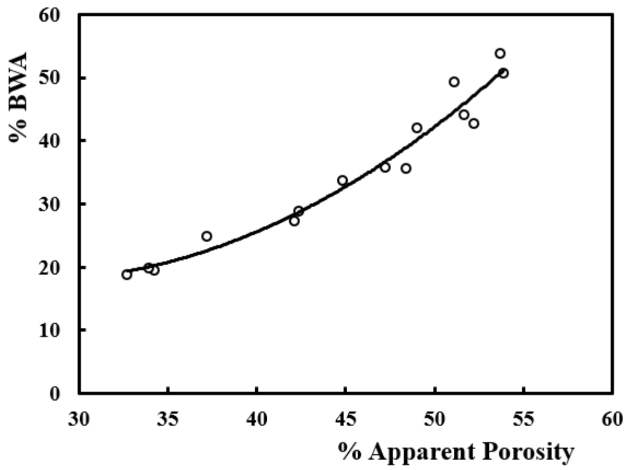


Figure-13. Relation between BWA and apparent porosity for rice husk samples.

3.3.6 Bulk density (ρ_b)

The bulk density (ρ_b) of a brick is related to its total fractional porosity (ε) by the expression:

$$\rho_b = \rho_p(1 - \varepsilon) \quad (8)$$

where: ρ_p is the powder density (true density) of the material.

Consequently, the bulk density is expected to decrease with increasing temperature and an increase in waste content. This is effectively the case as shown in Figure-14a which displays an almost linear relation between bulk density and temperature and percent rice husk added.

To decide about the possibility of having any closed porosity, the following analysis was set:

Let ε_o and ε_c be the open (apparent) and closed porosities respectively so that the total porosity: $\varepsilon = \varepsilon_0 + \varepsilon_c$. Equation (8) can be rewritten as follows:

$$\rho_b = \rho_p(1 - \varepsilon_c) - \rho_p.\varepsilon_o \quad (9)$$

A plot of bulk density against apparent porosity should yield a straight line of slope = ρ_p, the true density of the material, and intercept = $\rho_p(1 - \varepsilon_c)$. This way, the fraction of closed porosity can be deduced. This plot reveals the presence of three straight lines at each firing temperature. Their slopes and intercepts were determined and the results are summarized in Table-3. It can be deduced from that table that the proportion of closed pores indeed increases with increased firing temperature as evidence of initial sintering.

As for samples to which was added rice straw, the almost linear dependence of bulk density on the percent waste added was independent of temperature (Figure-14b). When it was attempted to correlate bulk density to apparent porosity to deduce the percent closed pores present at each temperature, the linearity of the obtained curves was questionable. This has led to ignoring this attempt.

Table-3. Estimation of closed porosity.

Temperature, ºC	700	750	800
Slope	–3.0975	–3.188	–3.413
Intercept	2.828	2.808	2.820
Closed Porosity, %	9.51	13.5	21

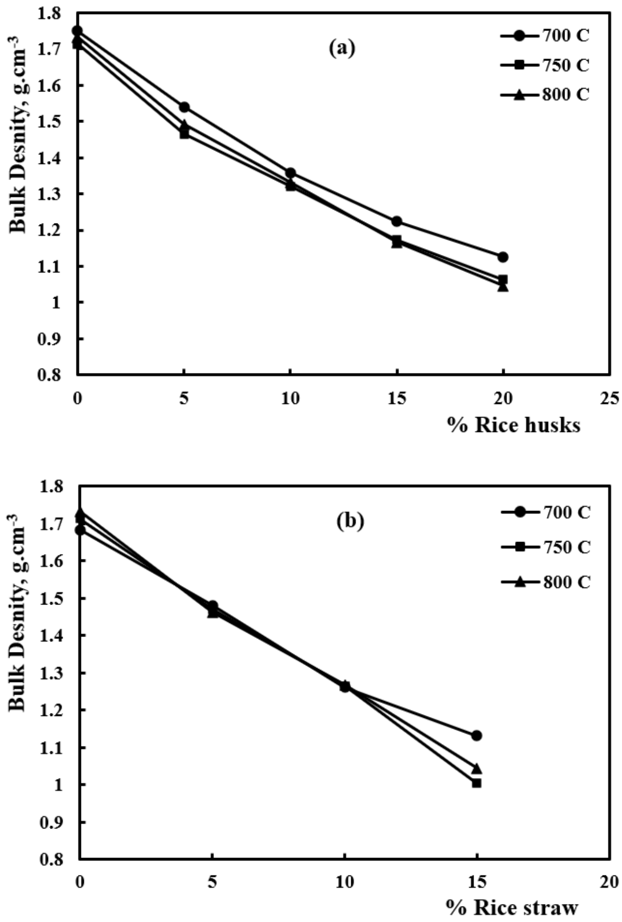


Figure-14. Effect of rice wastes addition on bulk density (BD); (a) Rice husks, and (b) Rice straw.

3.3.7 Compressive strength

When the mean compressive strength of three specimens was calculated for each percent of rice husks or straw added, it was evident that strength did not depend on the firing temperature but exclusively on the percent waste added Figure-15a. In this Figure, it was clear that there is an exponential decay following the addition of rice husk to clay [36–40]. The equation deduced for that decay takes the form:

$$\sigma = \mathrm{A}e^{-kx} \quad (10)$$

Where A and k are constants depending on firing temperature having the values shown in Table-4, while x is the fraction of waste addition.

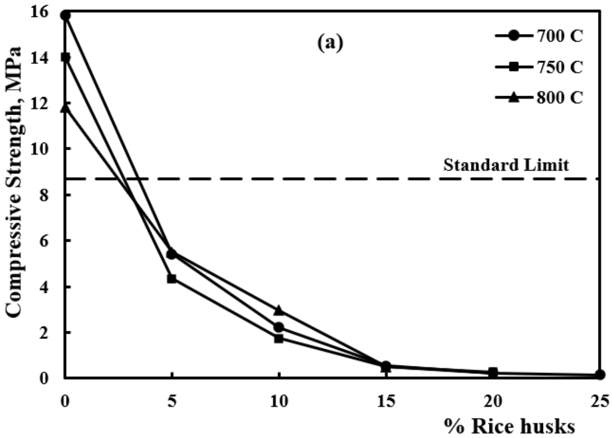
Table-4. Values of constants in strength - percent waste relations.

Temperature, ºC	Rice husks		Rice straw	
	A	*x*	*A*	*x*
700	12.21	0.177	14.27	0.256
750	12.69	0.201	14.44	0.294
800	14.67	0.208	14.47	0.309

The coefficient of the exponential term denotes the strength of waste-free samples, while the negative power indicates the speed of decay. It is therefore clear that the strength of waste-free samples and the strength decay rate increased with increased firing temperature [36-40].

As for the results obtained on adding rice straw, they were more or less close to the previous results as can be seen from Figure-15b.

It is to be noticed that the minimum allowable strength for clay bricks according to ASTM C 62 is 8.7 MPa for normal duty bricks [14]. This can only be achieved with no more than 3% of either waste on firing at 700ºC.



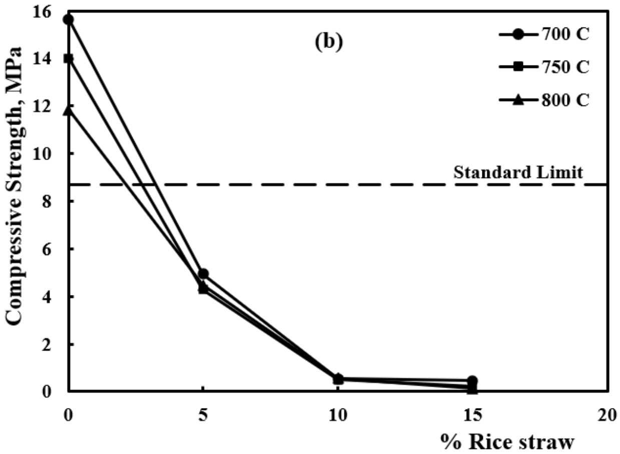


Figure-15. Effect of rice waste addition on compressive strength; (a) Rice husks, and (b) Rice straw.

3.4. Comparison with ASTM Standards

A comparison of specifications of fire bricks obtained by adding 3% of either waste on firing at 700ºC with standards is illustrated in Table-5. This comparison shows that the minimum required strength is exceeded and the bulk densities of the prepared bricks are lower than the recommended value by 11.7% and 15% for rice husks and rice straw-based bricks respectively.

Table-5. Comparison of the properties of prepared bricks with standards.

Property	Brick with 3% husk	Brick with 3% straw	Normal Duty
Compressive strength, MPa	9.0	9.0	8.7
Cold water absorption, %	≈ 20	≈ 24	No upper limit
Boiling water absorption, %	24.2	26.3	No upper limit
Saturation coefficient	0.83	0.82	No upper limit
Bulk density, kg.m^{-3}	1590	1530	1800^{+}
+ Maximum recommended value.			

3.5. Preliminary Simple Economical Assessment

Clay brick's annual production in Egypt is about 6 billion bricks per year [41], with standard dimensions of 250 × 120 × 60 mm^3 consuming around 2.88 million tons of clay each year. Using rice wastes as ingredients in clay bricks will reduce the amount of consumed clay.

The use of 3% rice waste will result in reducing the amount of clay consumption by about 86400 tons. As one ton of clay costs around $1.25 the use of rice wastes shall save around $108,000 per year in the bricks production from raw materials; also, it shall assist in the safe disposal of around 86400 tons of rice wastes every year. Besides the negative environmental impact associated with burning these wastes, any alternative solution involving dumping is estimated to cost about $ 2 per ton, amounting to an annual spending of about $170,000 Accordingly, the suggested technique will economize about $280,000 annually.

Another indirect benefit stemming from the use of 3% rice waste is the reduced density of the produced brick: A standard brick of bulk density 1800 kg.m^{-3} weighs about 3.2 kg. A 3% waste addition reduces this figure to about 2.8 kg. This reduction has a positive impact on the number of bricks that can be truck loaded as this will increase by about 15%, entraining a corresponding economy in transportation. Also, this will reduce the energy consumed in the vertical lifting of bricks to upper levels.

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4. CONCLUSIONS

From the previous results, the following conclusions could be drawn:

a) Recycling of rice husks and straws reduces the harmful effect of disposal of these wastes since farmers usually tend to burn these wastes as the most economical way for disposal which causes huge environmental and health problems. Additionally, it would be more beneficial to utilize such waste in producing bricks since they are priceless raw materials which decrease the cost of raw material.
b) The addition of any of the two rice wastes decreases the linear drying shrinkage, although the effect of adding rice straw is more pronounced than that of rice husks presumably due to the presence of a higher level of silica in husks compared to straw.
c) The green strength suffered a severe loss with adding rice waste, due to the decreased cohesion between particles following diminished shrinkage.
d) LOI in the case of adding rice husks did not practically depend on the firing temperature while the dependence is more pronounced in the case of adding rice straw.
e) Both CWA and BWA display the same behavior up to waste addition levels reaching 20%.
f) Firing temperature does not have any serious effect on water absorption as there is an almost linear relation between the proportion of added waste and water absorption.
g) Regarding Saturation Coefficient, the pores formed upon firing are relatively large in the case of rice waste addition which decreases the SC.
h) The results reveal that the dependence of apparent porosity on the addition level of waste is much higher than on firing temperature.
i) The bulk density decreases with an increase in rice husk or straw content. This decrease is almost independent of firing temperature.
j) The compressive strength decreases with increasing both rice husk and straw content with limited influence of firing temperature.

REFERENCES

[1] Barbut M., Bucur R. D., Cimpeanu S. M., Paraschiv G., Bucur D. 2015. Wastes in building materials industry (http://creativecommons.org/licenses/by/3.0).

[2] Maraveas C. 2020. Production of sustainable construction materials using agro-wastes. Materials. 13(26).

[3] El‑Mekkawi S. A., Sebaei A. S., Amin Sh. K. 2022. Green waste recycling of peanuts highly contaminated with aflatoxins in clay brick manufacturing. Bulletin of the National Research Centre. 46(91): 1-15.

[4] Ghoneim S. A., Abadir M. F., Ghoneim I. M., Amin Sh. K. 2020. The Use of Tannery Solid Waste in the Production of Building Bricks. International Journal of Applied Engineering Research. 15(9): 891-905.

[5] El-Naggar K. A. M., Amin Sh. K., El-Sherbiny S. A., Abadir M. F. 2019. Preparation of Geopolymer Insulating Bricks from Waste Raw Materials. Construction and Building Materials. 222: 699-705.

[6] Worldometers.info, World Population Clock: 7.7 Billion People 2019 Worldo meters, Worldometers.info. 2019. Available online: https://www.worldometers.info/world-population/ (accessed on 20 November 2019).

[7] Luna-Cañas L. M., Ríos-Reyes C. A., Quintero-Ortíz L. A. 2014. Recycling of agro-industrial solid wastes as additives in brick manufacturing for the development of sustainable construction materials. DYNA. 81(188): 34-41.

[8] Madurwar M., Ralegaonkar R., Mandavgane S. 2013. Application of agro-waste for sustainable construction materials: A review. Constr. Build. Mater. 38: 872-878.

[9] AbdulKadir A. K., 2012. An overview of wastes recycling in fired clay bricks" International Journal of Integrated Engineering. 4(2): 53-69.

[10] Rautray P., Roy A., Mathew D. J., Eisenbart B. 2019. Bio-Brick - Development of sustainable and cost-effective building material. International Conference on Engineering Design, Iced19, 5-8 August 2019, Delft, the Netherlands.

[11] Wahab R. A. A., Zakri F. A. A., Sokri N. K. N., Farhana N. A. 2020. Physical and mechanical properties of fired clay bricks substituted with agricultural waste. 4th International Sciences, Technology & Engineering Conference (ISTEC), Zurich.

[12] Guna V., Ilangovan M., Rather M. H., Giridharan B. V., Prajwal B., Krishna, K. V., Venkatesh K., Reddy N. 2019. Groundnut shell/rice husk agro-waste reinforced polypropylene hybrid biocomposites. J. Build. Eng., 27: 100991.

[13] Maheswari A. U., Varma D. R., Srivalli G., Raju N.R., Santosh V.S. 2020. Utilization of rice husk in the production of red clay bricks. IJCRT. 8(4): 2320-2882.

[14] ASTM C 62 / 2017. Standard Specification for Building Brick (Solid Masonry Units Made from Clay or Shale), Annual book of American Society for Testing of Material (ASTM), U.S.A. 4(5): (June 2022).

[15] Saleem M. A., Kazmi S. M. S., Abbas S. 2017. Clay bricks prepared with sugarcane bagasse and rice husk ash - A sustainable solution. MATEC Web of Conferences, 120, 03001.

[16] Heniegal A. M., Ramadan M. A., Naguib A., Agwa I. S. 2020. Study on properties of clay brick incorporating sludge of water treatment plant and agriculture waste. Case Studies in Construction Materials. 13: e00397.

[17] Hassan A. M., Abadir M. F., Moselhy H. 2018. Use of agricultural waste in the preparation of insulating fireclay bricks. International Journal of Applied Engineering Research. 13(12): 10819-10825.

[18] Kazmi S. M. S., Abbas S., Saleem M. A., Munir M. J., Khitab A. 2016. Manufacturing of sustainable clay bricks: Utilization of waste sugarcane bagasse and rice husk ashes. Construction and Building Materials. 120: 29-41.

[19] Dawood A. O., Mussa F. I., Al-Khasraji H. A., AbdulSada H. A., Yasser M. M. 2021. Investigation of compressive strength of straw reinforced unfired clay bricks for sustainable building construction. Civil and Environmental Engineering. 17(1): 150-163.

[20] Trostb L. J., Wynne D. J. 1940. Determination of quartz (free silica) in refractory clays. Journal of the American Ceramic Society. 23(1): 18-22.

[21] Kahle M., Kleber M., Torn M. S., Jahn R. 2003. Carbon storage in coarse and fine clay fractions of illitic soils. Journal of the American Soil Science Society. 67: 1732-1739.

[22] Gee G. W., Bauder J. W. 1986. Particle-size analysis in A. Klute (ed.) Methods of soil analysis, Part (1): SSSA and ASA, Madison, WI. 383-411.

[23] Jardine P. M., Weber N. L., McCarthy J. F. 1989. Mechanisms of dissolved organic carbon adsorption on soil. Journal of the American Soil Science Society. 53: 1378-1385.

[24] Brindley G. W., Brown G. 1980. Crystal structures of clay minerals and their X–ray identification", Mineral. Soc. London S. p. 485.

[25] Moore D. M., Reynolds R. C. Jr. 1989. X–ray diffraction and the identification and analysis of clay minerals. Oxford, New York, Oxford University Press. p. 332.

[26] Wilson Editor M. J. 1989. A handbook of determination methods in clay mineralogy. Blackie, USA, Chapman and Hall. New York. p. 308.

[27] ICDD. 1993. Mineral powder diffraction file data book. (Sets 1-42), Pennsylvania, USA.

[28] ASTM D 422 / 2017. Method for particle-size analysis of soils. Annual book of American Society for Testing of Material (ASTM), U.S.A., 4(8): (March 2022).

[29] ASTM E 11 / 2020. Specifications for wire-cloth sieves for testing purposes. Annual book of American Society for Testing of Material (ASTM), U.S.A. 14(2): (July 2022).

[30] ASTM C 326 / 2018. Standard test method for drying and firing shrinkages of ceramic white ware clays. Annual book of American Society for Testing of Material (ASTM), U.S.A. 15(2): (April 2022).

[31] ASTM C 67 / 2021. Standard test methods for sampling and testing brick and structural clay tile. ASTM annual book, U.S.A. 4(5): (June 2022).

[32] ASTM D 7348 / 2021. Standard test methods for loss on ignition (L.O.I) of solid combustion residues. Annual book of American Society for Testing of Material (ASTM), U.S.A. 5(6): (September 2022).

[33] ASTM C 373 / 2018. Standard test method for water absorption, bulk density, apparent porosity, and apparent specific gravity of fired white ware products. Annual book of American Society for Testing of Material (ASTM), U.S.A., 15(2), (April 2022).

[34] Sakhiya A. K., Baghel P., Pathak S., Vijay V. K. 2021. Effect of process parameters on slow pyrolysis of rice straw. Proceedings IEEE.DOI 10.1109/ICUE49301.2020.9306945

[35] Hafez A. I., Khedr M. M. A., Amin Sh. K., Sabry R. M., Osman R. M. 2016. Utilization of Agricultural Residues of Rice Cultivation in Manufacturing of Light Fired Clay Bricks. Research Journal of Pharmaceutical, Biological and Chemical Sciences (RJPBCS). 7(4): 2588-2600.

[36] Selem N. Y. S., Amin Sh. K., El-Sherbiny S. A., Abadir M. F. 2015. Effect of Fineness of Homra (Clay Brick Dust) on the Properties of Geopolymer Bricks Produced from Slaked Lime. International Journal of Applied Engineering Research. 10(3): 6077-6087.

[37] El-Naggar K. A., Abadir M. F., Amin Sh. K., Ahmed M.M., El-Sherbiny S.A. 2015. Recycling of Landfill Waste in the Manufacture of Building Bricks. International Journal of Scientific and Engineering Research (IJSER). 6(11): 1217-1223.

[38] Amin Sh. K., Sibak H. A., El-Sherbiny S. A., Abadir M.F. 2016. An Overview of Ceramic Wastes Management in Construction. International Journal of Applied Engineering Research. 11(4): 2680-2685.

[39] Amin Sh. K., El-Sherbiny S. A., Abo El-Magd A. A. M., Belal A., Abadir M. F. 2017. Fabrication of Geopolymer Bricks Using Ceramic Dust Waste. Construction and Building Materials. 157: 610-620.

[40] Amin Sh. K., Ashmawy N. M. F., Abadir M. F. 2022. The use of tannery waste in the preparation of clay roof tiles. Construction and Building Materials. 325(126393): 1-10.

[41] Annual bricks production in Egypt. 2017. https://gate.ahram.org.eg/News/1648162.aspx.