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Synthesis and Characterization of Clay Brick Using Waste Groundnut Shell Ash

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Abstract

Clay bricks have been made since ancient periods. The higher demand for this brick fails to support the needs. This is because clay is the non-renewable materials. Therefore, new artificial cement blocks have been introduced to satisfy the fast demand in the world. However, the clay bricks are the most eco-friendly and form green environment. Thus, the government, researchers and engineers trying to introduce the clay bricks with the value addition of natural agro waste materials. In one way, these materials improve the physical properties of the clay as well as reduce the environmental pollutions. Our aim at this research was to introduce a green environment clay bricks of value-added Groundnut Shell Ash (GSA) as a partial substitution. Therefore, seven different series of brick were manufactured by applying conventional method, which consists of GSA ratio 0, 2, 4, 5, 6, 8 and 10% of the total weight of the mixture. Each series hold seven brick of dimension (18.5 × 8.5 × 6.5) cm^3. The clay-GSA was mixed well with the addition of sufficient water to form a good workability. These bricks were allowed to dry under sunlight for two days and then baked using the traditional method. The physical properties of the red brick were then determined and compared with Sri Lankan and British Standard Specifications. These physical properties were compared with the commercially available brick made entirely from clay, which is the control brick. From the results, clay-GSA bricks are obviously superior to the clay control-brick, those available in the Eastern region markets.

Keywords: Groundnut Shell Ash; Compressive Strength; Flexural Strength; Water Absorption; Eco-friendly

Introduction

A brick is one of the prime building materials made of clay and burnt in a kiln [1-3]. Still, this brick is manufactured locally and has been emphasized all over the world because of their easy availability and low cost. Brick has been regarded as one of the longest lasting and strongest building material, made from locally available sources, used throughout history. Usual building brick is made of a mixture of clay, which is subjected to a range of processes; differ according to with the nature of the material, the method of manufacture and the character of the ended product [1-3]. The end product is formed in moulds to the desired shape, dried and burned. Burnt brick is usually stronger than sundried brick [2], especially if it is made of clay or clayey material.

The main disadvantage is the environmental impact involved in the manufacturing process of clay brick. To overcome this drawback, a challenge has been made to raise the overall efficiency of clay brick by adding other suitable materials along with clay in the manufacturing process [4-8]. Considering environmental impact and the efficiency, there is a need to find some alternative so as to reduce the impact of the clay brick manufacturing process on the environment [9] and at the same time increase the overall performance of the brick. This research aims to achieve both the mentioned improvements by using admixtures along with clay during the manufacturing process. Certain admixtures are added to increase the bond between the particles and thus increase the strength of the brick. Such admixtures are either cementitious or pozzolanic material. Pozzolanic materials include the traditional lime. The recent non-traditional pozzolanic admixtures are wood ash, sawdust ash and fly ash [10-19]. The second category of admixtures consists of organic matter, such as rice husks, sawdust, coal, etc., which burn out when the bricks undergo firing [20-23]. They regulate the temperature to which the brick is fired during burning, which is of supreme importance. The higher the firing temperature, the higher is the quality of the finished product.

The study was aimed to make the brick of clay mixed with Groundnut Shell Ash (GSA) with various ratios, through the crystallization process. The produced brick should meet the required values of compressive strength, flexural strength and water absorption assigned by the Sri Lankan or British Standard Specifications for load bearing bricks. The produced brick was also aimed to compete with commercial clay brick, which was made under the circumstances of the study, that available in the Sri Lankan market.

Methodology

Materials

Brick Clay: The brick clay was collected from Verpavettuvan, at the depth of 1 to 1.5 m below the earth surface, which is one of the most popular places for clay brick and brick making (located in Batticaloa District, Eastern Province of Sri Lanka). The oxide analyses were carried out for the collected samples by X-Ray fluorescence (XRF), utilizing a Philips PW 780 instrument, with an anticathode container of rhodium of 4 KW, which clearly confirm that the major oxide compositions are silica, alumina, and ferric oxide, are given in Table 1. The higher silica percentage in the clay increases the binding strength, which increases the strength of the clay brick [24].

Compounds (%)	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	TiO_2	P_2O_3	LIO
Present study [25, 26]	63.10	9.23	13.53	5.03	0.02	0.01	1.03	0.02	-	-	8.03
Badr El-Din *et al.* [19]	65.20	7.36	15.26	1.01	0.83	0.08	3.12	0.62	1.92	0.15	6.01

Table 1: The Oxide compositions percentage of Verpavettuvan brick clay

Groundnut Shell Ash (GSA): The groundnut shells were obtained from Puttalam as a waste from a household which uses groundnut for oil and other production. The shells were cleaned and allowed dried in the sunlight of temperature around 40 ^{o}C, consumed in an open climate. The well dried shells were burned in an open environment and allowed to cool. Fine pure ash was sieved and used to manufacture clay bricks. The ash has been protected in fixed glass containers to avert dampness ingestion and other pollution. However, the main aim of the research was to disseminate the knowledge of value addition among the brick production community and introducing the green environment by utilizing the natural agro waste materials. The oxide compositions were investigated by X-Ray fluorescence (XRF), utilizing a Philips PW 780 instrument, with an anticathode container of rhodium of 4 KW and the results tabulated in Table 2 that compared with the previous studies. The specific gravity, bulk density and moisture content of GSA is 2.35, 445 kg.m^{-3} and 1.42 % respectively. These compounds are known to have cement properties that would be beneficiary to the brick to enhance the binding.

Oxide compositions	Present study	T.C. Nwofor and S. Sule. [27]	T.C. Nwofor and S. Sule. [27]	Mara Wazumtu and Egbe-Ngu Ntui Ogork. [28]	Alabadan *et al.* [29]	H. Mahmoud *et al.* [30]
SiO_2	30.16	16.21	16.21	22.00	33.36	26.96
Al_2O_3	6.27	5.93	5.93	2.00	6.73	5.82
Fe_2O_3	2.69	1.80	1.80	5.04	2.16	0.50
CaO	10.2	8.69	8.69	24.10	10.91	9.5
MgO	5.73	6.74	6.74	3.00	4.72	5.60
MnO	-	-	-	0.42	-	0.32
Na_2O	13.27	9.02	9.02	-	25.38	1.15
K_2O	18.95	15.73	15.73	21.90		20.02
TiO_2	2	-	-	1.70	-	0.69
SO_3	5.87	6.21	6.21	1.05	6.40	1.86
CO_3	-	-	-	-	6.02	-
BaO	-	-	-	0.57	-	-
V_2O_3	-	-	-	0.05	-	-
P_2O_5	1.21	-	-	1.08	-	2.00
ZnO	0.5	-	-	0.12	-	-
Cr_2O_5		-	-	0.04	-	-
NiO	-	-	-	0.02	-	-
CuO	-	-	-	0.14	-	-
SrO	0.5	-	-	0.30	-	-
ZrO_2	-	-	-	0.43	-	-
Loss of ignition LOI	2.65	-	-	4.36	-	22.00

Table 2: The Oxide compositions percentage of Groundnut Shell Ash (GSA)

Sample Preparation

Seven different series of brick were manufactured by applying conventional method, which consist of GSA ratio 0, 2, 4, 5, 6, 8 and 10% of the total weight of mixture. Each series hold seven bricks of dimension (18.5×8.5×6.5) cm^3. The clay-GSA was mixed well with the addition of sufficient water to form a good workability (water/clay ratio 0.5 to 0.6). Traditional brick manufacturing method was employed to mix the raw materials. In this study, materials were measured using weighing balance. Then the clay was mixed well with water form a suitable correct plasticity and the workability. After that the GSA was mixed manually with the glue clay while adding water until reach the proper mixing. The GSA mixed clay material was filled in a rectangular wooden mould to get green bricks. The green bricks were protected by sawdust to avoid engaging with other newly prepared clay bricks. These green clay bricks were subjected to direct air dry under sunlight of temperature around 35 °C for a week. The sundried clay bricks were burned in a brick kiln of temperature range 600 °C to 850 °C, which is the industrial scale manufacturing process of fired clay bricks in the Eastern region of Sri Lanka. The burning process was continuously carried out for two days and kept about one week. The properties of the fired bricks were analyzed.

Analysis of bricks

The mechanical and physical properties of the produced brick were analyzed which were namely; density, compressive strength, flexural strength and water absorption. The experimental methods and the analysis of results were done in accordance with Sri Lankan, British and Indonesian Standard Specifications, SLS, BS and SNI respectively which are similar to ASTM C67-05 [31].

Particle size analysis: Particle analysis can be done by different size of sieves, but here this test was not done, because the aim of the research was to disseminate the knowledge to the local markets and improve the self-employment of the local community.

Density (ρ) analysis: Density is defined as the ratio between the dry mass and the volume of the clay brick, quantifying the quantity of clay found in the volume. It is evident from the definition; higher value is the denser brick and evidently enhanced its mechanical and durability properties. Literature shows that the typical value of the apparent density of the normal fired clay brick range from 1200 to 2200 kg. m^{-3} [32]. To determine the average densities, mass, length, width and the height of the brick was measured using mechanical balance and Vernier calliper of sensitivity 0.1 g and 0.01 mm respectively. In each series, three bricks were recorded and average densities were calculated using equation (1).

$$\text{Density} = \text{Mass} / \text{Volume} \tag{1}$$

Water absorption analysis: Water absorption analysis was done to determine the water absorption property of the fired clay bricks. Three bricks from each percentage of GSA addition were analyzed. Initially, the bricks were kept under the sunlight of temperature of 35 °C to 40 °C for one day and the dry weight of the bricks were measured. Then the bricks were immersed into water of temperature of 20 °C to 23 °C for one day. Wet bricks were allowed to settle down for few Water absorption analysis was done to determine the water absorption property of the fired clay bricks. Three bricks from each percentage of GSA addition were analyzed. Initially, the bricks were kept under the sunlight of temperature of 35 °C to 40 °C for one day and the dry weight of the bricks were measured. Then the bricks were immersed into water of temperature of 20 °C to 23 °C for one day. Wet bricks were allowed to settle down for few minutes after taken out form the tank and the wet weight of each brick was measured. Water absorption percentage was calculated using equation (2), and the average values were calculated.

$$\text{Water absorption} = \frac{\text{Wet weight of the brick -Dry weight of the Brick}}{\text{Dry weight of the Brick}} \text{X } 100\% \tag{2}$$

Compressive Strength (*CS*) analysis: Compressive strength analyses were done using Universal Testing Machine available in the Department of Physics, Eastern University, Sri Lanka. The testing procedure was performed according to the Sri Lankan Standards 39: 1978 [37], which is similar to ASTM C67-05 [31]. Initially, the brick surfaces were smoothen to get smooth parallel surfaces to form a good surface contacts between the brick and the two pressing discs fitted in the machine. The brick setup for measurement is shown in Figure 1. The compressive strength of bricks was measured with the help of a pressure gauge of sensitivity 2 kg.cm^{-2} attached to the Universal Testing Machine. The maximum force applied to just break the brick (or force at failure), width, and length of the block were recorded. Three bricks from each set were measured and the average compressive strength was determined using equation (3) and compared with the Sri Lankan standards.

$$\text{Compresive Strength} = \frac{\text{Force at failure}}{\text{Width of the brick} \times \text{ length of the brick}} \tag{3}$$

Flexural Strength (*FS*) analysis: Three-point bending test were done using Universal Testing Machine available in the Department of Physics, Eastern University, Sri Lanka according to the Sri Lankan standards Sri Lankan Standards 39: 1978 [37] to determine the flexural strength of the bricks which is similar to ASTM E72-15 [33-35]. Before the test, the brick surfaces were smoothen to get smooth parallel surfaces to form a uniform contacts between the brick and the three wedges in the machine. The brick setup for measurement is shown in Figure 2. The flexural strength of bricks was measured with the aid of a pressure of sensitivity 2 kg.cm^{-2} attached to the Universal Testing Machine. The applied force at failure and the other physical parameters of the brick were recorded to determine the flexural strength with the aid of equation (4). Three bricks from each set were measured and the average flexural strength was determined and compared with the Sri Lankan standards.

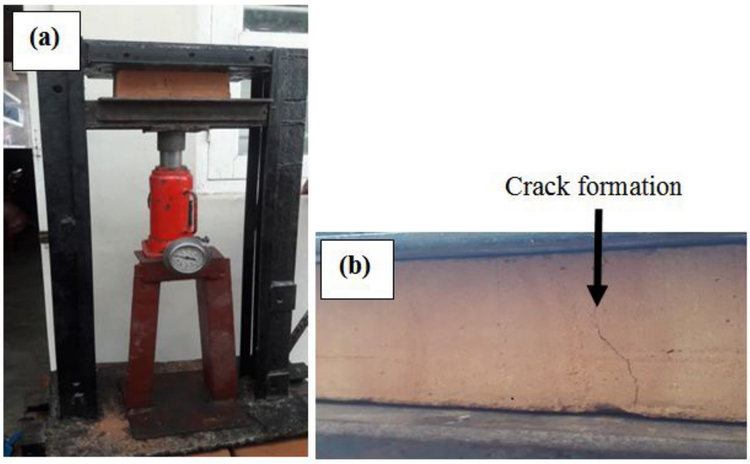

Figure 1: (a). Aarrangement of sample for compressive strength analysis and (b) Formation of crack indicates the force at failure

$$\text{Flexural Strength} = \frac{3 \times \text{Applied force at failure} \times \text{distance between line of fracture and the nearest wedge}}{2 \times \text{width of the brick} \times (\text{height of the brick})^2} \quad (4)$$

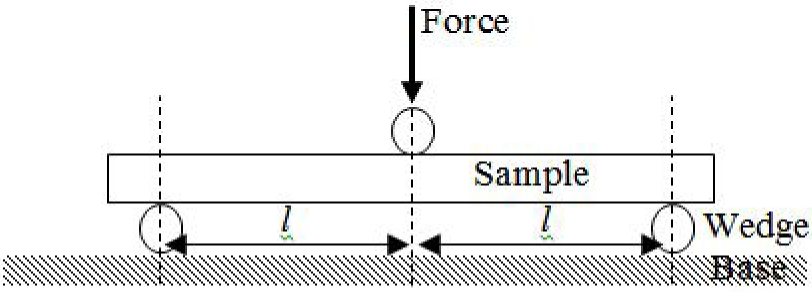

Figure 2: Arrangement of sample for flexural strength test

Results and Discussion

Density Analysis

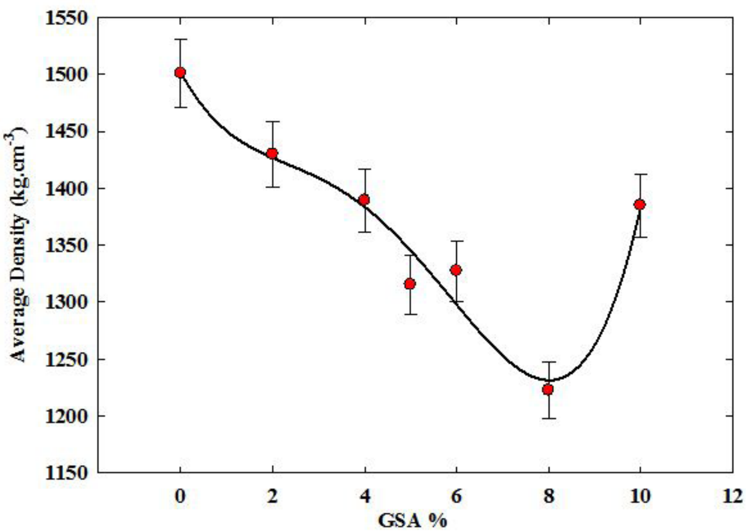

Figure 3: Average density of the GSA-Clay bricks as a function of GSA%

As shown in Figure 3, the average density of the brick smoothly decreases with increase GSA percentage up to 8% of GSA. The decreasing behavior can be attributed to coating of the clay by the GSA that result to large particles with larger voids and less density [16] or the baking temperature [36]. The researcher [36] reveal that density increases with increasing temperature to the certain limit. According to his [36] statement, density of the clay brick increase from 1800 kg.m^{-3} to 2200 kg.m^{-3} while increasing baking temperature from 900 °C to 1100 °C respectively, which is decreasing form from 2200 kg.m^{-3} to 2000 kg.m^{-3} while increasing the baking temperature from 1100 °C to 1200 °C. The effect could depend on the type of the chemical and physical behavior of the clay material.

Not only that this effect is unlike related to normal clay brick due to the mixing of GSA. The formation of the pores could be ascribed to the presence of unstable organic compounds in the GSA that burnt off during the firing process. However, the reduction in density is a useful outcome that revealed the potential use of the fired clay bricks as light-weight building materials. Low weight or density has immeasurable advantages such as diminish structural weight, easier management; low costs with transport and environmental friendly. Not only have that in production side more number of bricks can be manufactured per ton of natural agro wasted materials. These bricks can be replaced for standard bricks in most applications, except when bricks of superior strength are required and depend on architectural needs.

As per BS 3921:1982, the minimum density of the normal fired clay brick is 1300 to 2200 kg.m^{-3} [17,35]. Minimum average density of 1250 kg.m^{-3} can be observed at 8% followed that, it shows a sharp increase. The increasing behavior, GSA > 8% may be due to high compact between the materials and less voids presents in the brick. Therefore, the 8% GSA mixed fired clay brick is most suitable for construction.

Water absorpation analysis

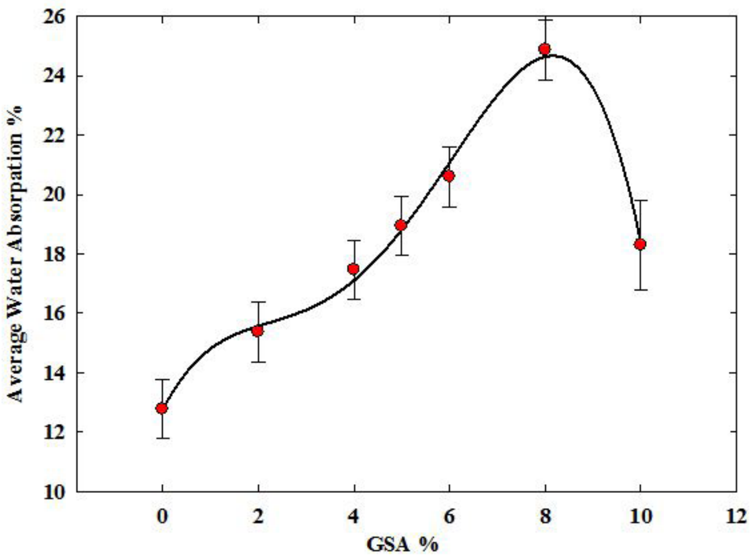

Figure 4: Average water absorption of the GSA-Clay bricks as a function of GSA%

Water absorption property can be used as one of an indicator to analyse the quality of the sample. Figure 4 portrays the change of the average water absorption for the fired clay brick as a function of GSA%. The average water absorption increases sharply with increasing the GSA%. It shows a maximum absorption ≈ 24% at 8% GSA, followed that it decreases sharply. This indicates that GSA plays a major role in clay-GSA mixture. According to the results, the bricks $5 \leq$ GSA% < 10 , satisfy recommended value of 20% as per the Indonesian Standard SNI 15-2094-2000 [14] and all the bricks, satisfy recommended value of 12% as per the British Standard BS 5628: Part 1:2005 [15] which lie within the standard values. The change in the behaviour depends on porosity. This is depends on effect of firing temperatures that ensures the completion of the crystallization process and closes the open pores in the sinter, as well as the effect of the soft nature of the GSA particles, which severely decreases the open pores and significantly reduces the water absorption.

Compressive strength analysis

Compressive strength determines the potential for application of the bricks. Compressive strength is usually affected by the porosity, pore size, and type of crystallization. It is usually defined as the failure stress measured normal to the bed face of the brick. The compressive strength analysis results are shown in Figure 5. The compressive strength of the 0% GSA clay brick is 120 kg.cm^{-2} and the GSA above 0% clay brick ranged between 70 and 170 kg.cm^{-2}. The compressive strength decreases up to 2% and then shows a maximum of 170 kg.cm^{-2} at 4%, followed that it gradually decreases up to 8% and increase with increasing the GSA%. The increase in the compressive strength is due to higher percentage of SiO_2 that stabilise the clay material. Therefore, 4% GSA is the maximum optimal dosage and a suitable agent to stabilize the strength of the brick clay.

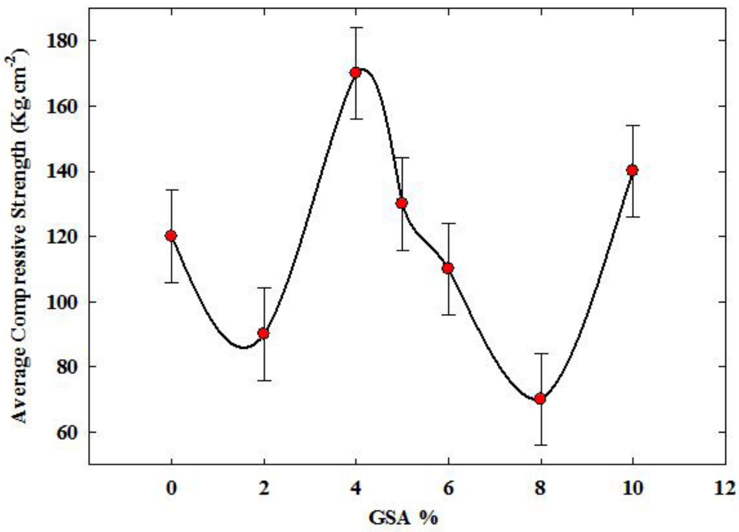

Figure 5: Average compressive strength of the GSA-Clay bricks as a function of GSA%

The effect of firing temperature on compressive strength may be attributable ensures the completion of the crystallization process, closes the open pores in the sinter, and, consequently, increases compressive strength of the crystalline aluminosilicate brick. Recrystallization after dehydroxylation of water molecules, hence other parameters affects the process of dehydroxylation may cause to strength reduction, when GSA > 4%. The dehydroxylation temperature increases with the increase of water pressure. While the effect of the flabby nature of the GSA particles, which severely increases the open pores in the sinter on decreasing compressive strength is much significant than that of reducing silica content. As a result, increasing GSA ratio generally decreases the open pores in the clay-GSA sinter and, consequently, increases the compressive strength. The plasticity variation indicates that the water content increase with increase of GSA. Hence these factors may be a root for the reduction of strength, when GSA > 4%.

Flexural strength analysis

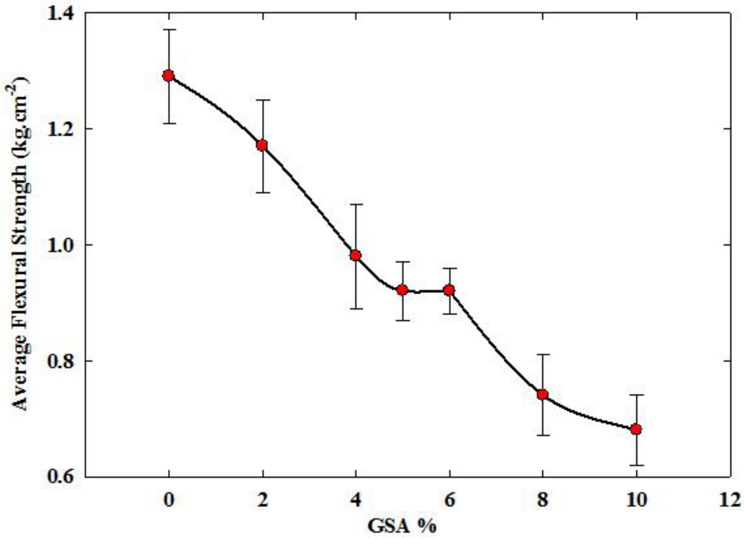

Figure 6: Average flexural strength of the GSA-Clay bricks as a function of GSA%

From Figure 6, it can be clearly seen that when increases the GSA% flexural strength decreases significant. However, it shows a step like behavior in between 4 to 6% GSA. Maximum strength of 1.3 $kg.cm^{-2}$ is obtained for 0% GSA, which is higher than the conventional brick 2.89 $MN.m^{-2}$ and minimum strength of 0.50 $kg.cm^{-2}$ is obtained for 10% GSA.

Conclusions

From various physical properties studies performed by doping different percentage of GSA, it could be concluded that partial replacement of GSA improves the physical properties of the fired clay bricks within the limit of experimental error.

The results obtained from this analysis revealed that replacement of 4% GSA provides optimum values in the compressive strength and the physical properties are given as follows: The average density 1400 $kg.m^{-3}$ was recorded and satisfy the requirements as per BS 3921: British standard specifications for brick clay which stated the minimum density of 2000 $kg.m^{-3}$. According to the results, all the brick, satisfy recommended water absorption value of 20% as per the Indonesian Standard SNI 15-2094-2000 and 12% as per the British Standard BS 5628: Part 1:2005 which lie within the standard values. The maximum compressive and flexural strength 170 kg.cm^{-2} and 1.00 kg.cm^{-2} were recorded respectively. According to the BS 3921, compressive strength of the fired clay brick should be greater than 50.98 kg.cm^{-2}. For a single story building minimum compressive strength should be within the range 10 to 50.98 kg.cm^{-2} and recommended by the building authorities.

The new born clay bricks are not suite for high strength external construction; because their low strength and the wet environments will be affect the structural integrity. However, the bricks reduce the overall weight of the building due to low density and weight. Thus, the bricks can be used for interior wall partitions and decorations.

This new clay bricks can be manufactured on site itself, low cost, semi labour skills and local economy will flourish. Not only has that by introducing the use of locally available natural agro waste materials directed to ecological structure.

Therefore, 4% GSA could be suggested for use in enlightening the physical properties of the fired clay bricks than the conventional fired clay brick.

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