SSRG International Journal of Civil Engineering
ISSN: 2348-8352 / https://doi.org/10.14445/23488352/IJCE-V10I1P102

Volume 10 Issue 1, 9-17, January 2023

Original Article

Performance of Perforated Clay Bricks with Charcoal Waste as an Additive

Bayisenge Jean Pierre[1], Isaac Fundi Sanewu[2], Charles Kabubo[3]

[1,2,3]*Department of Civil, Construction and Environmental Engineering, Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya*

Received: 14 November 2022 Revised: 20 December 2022 Accepted: 03 January 2023 Published: 14 January 2023

Abstract *- In Rwanda, the traditional fired solid bricks embody high fuel consumption and quantity of clay during their molding. Traditional solid bricks are also heavy compared to perforated bricks. This study aimed at investigating the performance of perforated clay bricks made of clay soil (CS) mixed with charcoal waste (CW) as an additive. The physical, chemical and mechanical properties of CS mixed with 0, 10, 30, 40 and 50% of CW were determined. The bricks were extruded manually with the inclusion of a varied number of perforations: 4, 8, 12 and 15 number perforations. The chemical analysis included the determination of organic carbon, exchangeable acidity and chemical components (through XRD) in the soil matrix. The chemical analysis depicted an increase in CaO proportions with an increase in charcoal waste content. There was also an increase in the amounts of exchangeable cations. The research found that with an increase in perforations, weight loss is reduced. However, non-perforated bricks depicted the least abrasion resistance, followed by bricks with 4 perforations. As the CW content increased from 0 to 50%, bricks with 15 and 12 perforations displayed the highest abrasion resistance. The research concludes that an increase in charcoal waste led to an increase in the linear shrinkage of clay soil bricks due to increased calcium cations and reduced magnesium cations in the soil. An optimum of 30% of charcoal waste was identified for the linear shrinkage of clay soil bricks. Bricks having 12 perforations and below with 30% charcoal waste additive can be categorized as category I (load-bearing) bricks.*

Keywords *- Brick durability, Charcoal waste, Fired perforated bricks, X-Ray Diffraction.*

1. Introduction

Both the National Energy Strategy and the National Energy Policy in Rwanda state that the potentially serious environmental implications come from the utilization of biomass energy and may not be renewable if not properly managed. In Rwanda, there are many factors of deforestation, like the land clearance for agriculture, tea plantation and construction, but the different report shows that the main cause is charcoal production [1]. It has been found that the use of biomass energy continues to dominate the small sector comprising domestic uses and small industries. This, therefore, necessitates the protection and management of forests and wood plantation so that charcoal production is carried around while ensuring environmental efficiency. In Rwanda, there are 7,000 woodcutters and 8,000 charcoal producers, with a production of around 157,000 tons of charcoal per year [1]. During charcoal production, up to 20% is considered waste. Normally, these wastes are being recovered by producing low-quality briquettes and for some improved domestic cooking practices [1].

Rwanda's current local brick production sector consists of traditional solid bricks pressed from wet soil paste to form regular shapes. However, these bricks have two main drawbacks: they perform poorly when exposed to wet conditions and require firing to enhance their durability. The traditional firing of solid bricks consists of high consumption of fuel-powered wood products.

Clay bricks are among the oldest building materials and the most common construction materials found worldwide. The utilization of agricultural and industrial waste materials has been found to be a practical solution to developing clay brick as a sustainable building material. Research on bricks produced from a mixture of charcoal and clay soils has been done; however, little attention has been paid to finding the performance of perforated clay bricks (PCBs) with charcoal waste as an additive. Previous research has shown that many types of waste are used successfully in brick production, such as coffee waste [2], cigarette butts [3], palm oil waste [4], mosaic vases [5], fly ash [6], and sawdust [7]. The use of these wastes reduces environmental impacts and their elimination. The prime function of these waste materials has been argued to act as a pore former in the clay body [8].

According to [9], when solid clay bricks were mixed with charcoal waste, they obtained an optimum ratio of 60% for energy consumption. Their conclusion indicated that charcoal as an internal fuel reduces external fuel (coal) consumption, reduces pollution emissions, and increases the brick quality in vertical shaft brick kiln (VSBK) outputs. It was achieved without using high internal fuel as compared to the one using charcoal as internal fuel.

The chemical elements composition of clay soil mixed with charcoal waste at different percentages was evaluated to investigate their influence on the different properties of perforated clay bricks and the optimum percentages of the charcoal waste mixture.

Perforated clay bricks are used for the masonry construction industry in some districts of Rwanda due to their good insulation properties and reduced clay consumption. The aim of this research was, therefore, to investigate the performance of perforated clay soil bricks that have varied addition of charcoal waste.

2. Materials and Methods

2.1. Preparation of Raw Materials

The clay soil (CS) used for the research was collected from the quarry zone of Rugeramigozi, located in the Shyogwe sector, Muhanga district, in the Southern province of Rwanda. On the other hand, charcoal wastes (CW) were collected from the charcoal production site located in the Muhanga district. The charcoal waste was obtained from Eucalyptus timber species.

The CS and CW were covered in carrier bags to reduce moisture loss. The clay soil was sieved to achieve consistency in the particle sizes. The materials were further dried using an electric kiln for 24 hours at a sustained temperature of 105 °C. The CW was added to CS at dosages of 0%, 10%, 30%, 40% and 50%.

Clay soil bricks were molded mechanically with the introduction of perforations (Fig. 1). Clay soil bricks of size 210 x 100 x 66mm were molded. Perforations were of size 23 x 14 x 66mm in accordance with [10] and [11]. The number of perforations varied from 0, 4, 8, 12 and 15. This was equivalent to 0%, 6.15%, 12.30%, 18.45% and 25%, respectively, of the whole molded clay soil bricks.

(a) Mechanical molds **(b) Molded clay soil bricks**

Fig. 1 Molding of perforated bricks

Different properties of clay soil (CS) mixed with charcoal waste (CW) and their related perforated bricks were determined, including linear shrinkage, loss of weight, water absorption, compressive strength and durability. All tests (chemical, physical and mechanical) were done in laboratories at Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya.

2.2. Chemical Analysis for CS and CW mixtures

2.2.1. Organic Carbon in Clay Soil Mixed with Charcoal Waste

In determining the organic carbon in clay and charcoal waste, the Walkley-Black method was used. Representative samples ground and those which passed through a 0.5mm sieve were considered. The samples were oxidized using chromic acid in the presence of sulphuric acid. The percentage of organic carbon was determined from equation 3.1. A multiplying factor of 1.72 was used to convert organic carbon to organic matter.

$$Organic\ carbon\ (\%) = \frac{\{me(k_2Cr_2O_7) - me(FeSO_4)\}0.003 * 100 * f}{oven\ dry\ weight(g)} \ldots\ldots equation\ 3.1$$

Where;

$f = 1.33$ correction factor

me – normality of solution used (ml)

2.2.2. Exchangeable Acidity in Clay Soil Mixed ith Charcoal Waste (Titration Method)

Exchangeable acidity was determined using the titrimetric method (standard method) according to the routine methodology adapted from [12]. Primarily, the exchangeable acidity (Al^{3+}, H^{+}) was determined by titration of 25 mL potassium chloride (KCl) extract with 0.025 mol L^{-1} sodium hydroxide (NaOH), using 1g L^{-1} phenolphthalein as an indicator (titration from colorless to pink). Then, the concentration of Al^{3+} was obtained by back-titration of the same KCl extract previously used after the acidification with a drop of hydrogen chloride (HCl) and the addition of 40 g L^{-1} sodium fluoride (NaF), with 0.025 mol L^{-1} HCl (titration from pink to colorless).

2.2.3. X-ray Diffraction (XRD) Analysis

The samples were milled using a grinding mill before placing them in a jar. The samples were ground to particles of size 10 µm. The grinding action enabled the homogenization of the particles. The samples in powder form were placed in glass slides before loading them in a D2 PHASER XRD machine. The concentrations of different elements were measured after evaluating the X-ray intensities at the given wavelengths of the elements in the XRD machine recorded as electronic signals. A search of the International Centre for Diffraction Data (ICDD) standard database of X-ray diffraction patterns enabled quick phase identification for the crystalline samples.

2.3. Loss on Ignition (LOI) in Samples

Clay and charcoal waste samples which had been oven dried at 105 °C, were weighed and placed in a crucible. The samples were then placed in an oven and heated to 470 °C. Equation 3.2, as specified in [13], was used to determine the LOI.

$$LOI\ (\%) = \frac{(L-M)}{(L-J)} * 100 \dots \dots equation\ 3.2$$

where,

J - weight for the container

L - weight for container plus dried raw material at 105 °C

M - the weight of the container plus raw material fired at 470 °C

2.4. Particle Size Distribution

The particle size distribution for clay soil and charcoal waste was determined according to [14]. The soil and charcoal waste were passed through a series of stacked sieves with a pan at the lowest level. The sieves were shaken mechanically, and whatever was retained on the sieves was weighed. The particles that passed through a sieve size of 0.075mm were subjected to hydrometer analysis in accordance with [14].

2.5. Clay Soil Bricks Bulk Density

All test specimens were dried at 105 ºC for 24 hours to ensure total moisture loss and then fired to a temperature of 910 ºC using an electrical furnace. The weight was measured using an electronic weighing machine. Their corresponding weights after firing was measured and recorded as W_f. The specimens were allowed to cool before immersing in water. The bricks were fully submerged, and their soaked weight was measured suspended in air and recorded as W_a. They were then suspended in water in a beaker, one after the other, using a sling, and their respective suspended weight was measured and recorded as W_w. The bulk density was calculated using equation 3.3 and examined, referring to [27].

$$BD = \frac{w_f}{w_a - w_w} \dots \dots equation\ 3.3$$

2.6. Loss of Weight and Water Absorption

Three bricks were randomly selected from molded bricks containing different CW proportions. They were dried in a kiln at a temperate of 105 ºC for 24 hours. The bricks were weighed (W_1) and fired in a furnace to 910 ºC before re-weighing (W_2), according to [13]. The bricks were then submerged in a water bath at a temperature of 27º +/- 2 ºC for 24hrs. They were weighed (W_3) after air dying for 3 minutes. Equations 3.4 and 3.5 were used to determine weight loss and water absorption, respectively.

$$Loss\ of\ weight = W_2 - W_1 \dots \dots equation\ 3.4$$

$$WA = \frac{W_3 - W_2}{W_2} * 100 \dots \dots equation\ 3.5$$

2.7. Linear Shrinkage

The test specimens were dried in a furnace for 24 hours at 105 ºC before their dimensions (length, breadth and height) were measured using a vernier caliper. The dimensions were recorded as dry length (L_D) and then fired in a furnace to a temperature of 910 ºC. The bricks were cooled to room temperature, and their measurement was recorded as fired length (L_F). For each sample, 3 specimens were measured, and the averages of the dimensions were used to calculate the linear shrinkage (L_S) using equation 3.6, according to [11].

$$L_S = \frac{L_D - L_F}{L_F} * 100 \dots \dots equation\ 3.6$$

2.8. Compressive Strength

The compressive strength is the only mechanical property used in the brick specification; it is the failure stress measured normally to the bed face. The perforated clay bricks were tested wet. The load was applied at a rate of 0.05N/mm^2/s until the bricks failed after the maximum compressive load of the bricks was recorded. The compressive strength (Cs in MPa) was computed using equation 3.7, in which P is the maximum compressive load of the bricks and A (mm^2) is the surface area in contact with the platen. The test was carried out according to [16] and [17].

$$C_s = \frac{P}{A} \dots \dots equation\ 3.7$$

2.9. The Durability of Perforated Clay Bricks

Through the abrasion test, each brick sample was weighed before the test was conducted. The sample brick was placed on a flat horizontal table top secured against sliding as prescribed in [18]. The top side of the sample was given 50 strokes of a wire brush, after which the sample was re-weighed, and the depth of abrasion measured and recorded. The abrasion value (α) was computed by equation 3.8, in which w_1(weight before abrasion) and w_2(weight after abrasion). The tests were carried out according to [19] and [18].

$$\alpha(\%) = 100\,(\frac{w_1 - w_2}{w_1}) * 100 \ldots\ldots equation\ 3.8$$

3. Results and Discussion

3.1. Particle Size Distribution

The particle size distribution for the clay soil (Fig. 2) indicates that with the addition of charcoal waste, the percentage of particles passing a sieve reduced considerably beyond 30% of addition. However, from the results, as shown in Fig. 2, the particle distribution does not change considerably with the addition of charcoal waste. This was in agreement with the findings of [20]

3.2. Chemical Characterization

As shown in Table 1, the chemical analysis showed that Iron Oxide (Fe_2O_3) was not detected (ND). The dominant oxides in charcoal waste are silicon dioxide and aluminium oxide (Table 1). According to [21], this described the soil matrix as of clean alluvial clay type. The proportion of CaO increased with charcoal waste content. It could have an effect on the compressive strength of the bricks as it contributes to cementing properties of the clay matrix.

It was noted from the chemical results that as the CW was increased, the calcium cation increased while the magnesium cation reduced. As it has been argued by [22] that there is a positive correlation between the clay plasticity index and the type and concentration of the exchangeable cations in the soil system. The calcium cations led to the coagulation of soil particles and helped to displace water. The high plasticity with an increased dosage of CW could have contributed to higher linear shrinkage experienced with the bricks beyond the 30% addition of CW.

3.3. Loss on Ignition

As indicated in Table 1, the loss on ignition reduced with an increase in the percentage dosage of charcoal waste. The research found that, as the percentage of charcoal waste was added, the more the presence of organic carbon was observed. This could have been the contributing factor to the reduction in loss of ignition. Therefore, it indicates less ash in pure charcoal compared to the CS and CW mix samples.

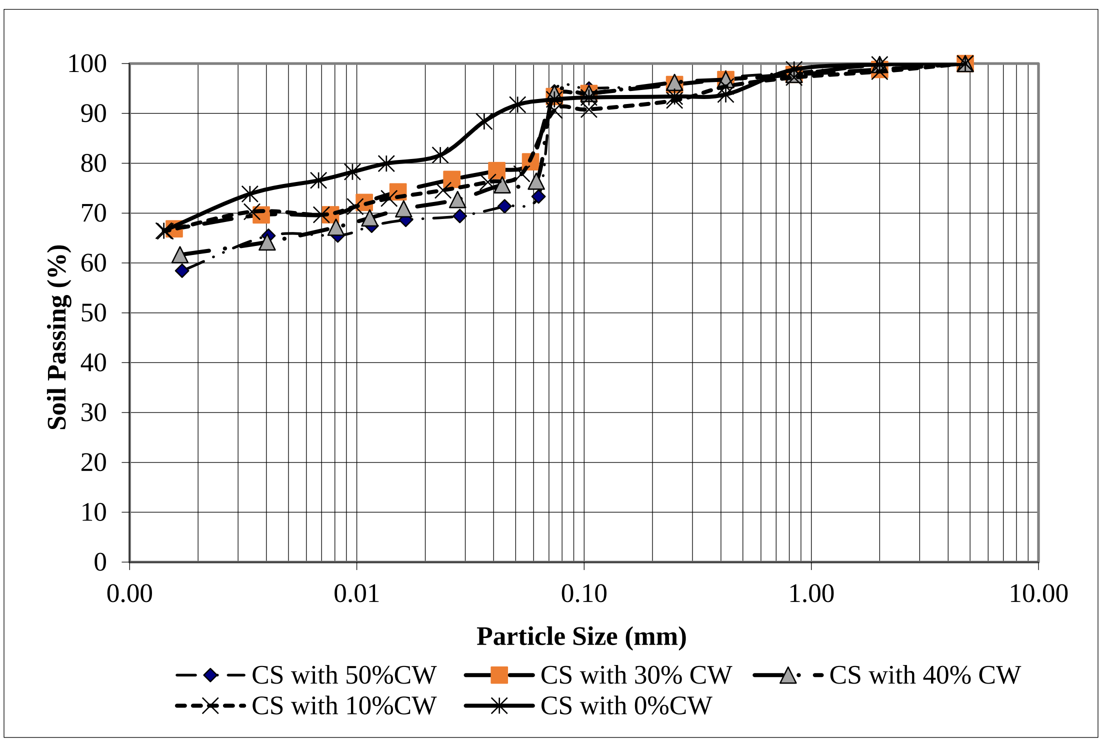

Fig. 2 Particle size distribution for clay soil mixed with charcoal waste

Table 1. Chemical properties of clay soil with charcoal waste

Parameter	Charcoal waste content				
	0 %	**10 %**	**30 %**	**40%**	**50%**
Calcium oxide (CaO), %	0.250	0.804	1.455	3.209	4.137
Magnesium Oxide (MgO), %	6.563	1.783	ND	ND	ND
Aluminum Oxide (Al_2O_3), %	27.843	28.826	28.454	26.195	22.199
Silicon Dioxide (SiO_2), %	61.122	63.404	63.599	63.826	63.866
Iron Oxide (Fe_2O_3), %	ND	ND	ND	ND	ND
Potassium Oxide (K_2O), %	0.983	1.402	1.659	2.228	2.774
Sodium Oxide (Na_2O), %	ND	ND	ND	ND	ND
Magnesium (mg/kg)	17.455	14.595	6.721	3.681	2.667
Potassium (mg/kg)	14.249	25.630	39.747	60.749	72.954
Calcium (mg/kg)	20.035	34.520	56.437	86.705	101.231
Iron (mg/kg)	1.054	1.728	1.926	2.333	3.194
Chlorine (%)	0.018	0.057	0.146	0.251	0.258
Organic carbon (%)	6.652	9.524	13.969	16.024	18.600
LOI (%)	99.348	90.744	86.080	84.001	81.400
Exchangeable acidity	0.60	0.15	0.10	0.20	0.10
$Mg^{(2+)}$ (mg/kg)	17.455	14.595	6.721	3.681	2.667
$Ca^{(2+)}$ (mg/kg)	20.035	34.520	56.437	86.705	101.231
Exchangeable cations -Na (meq/100g)	0.15	0.80	0.30	0.44	0.50
Exchangeable cations -K (meq/100g)	0.39	2.53	1.55	1.92	2.31
Exchangeable cations Ca (meq/100g)	1.01	4.15	1.77	1.82	2.14
Exchangeable cations-Mg (meq/100g)	1.22	3.52	1.44	1.40	1.43

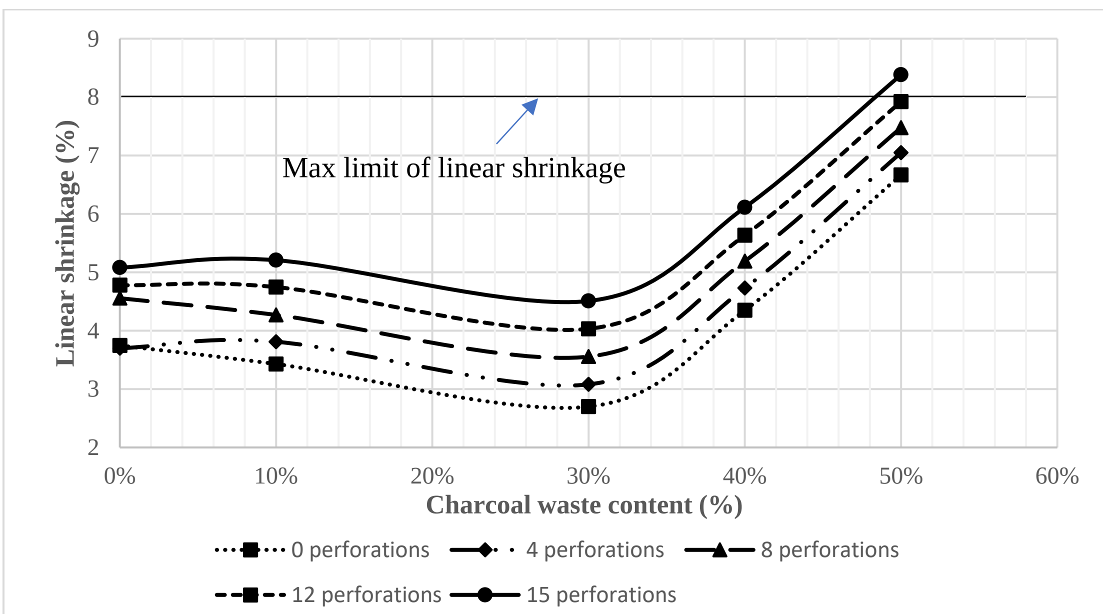

Fig. 3 Clay soil with charcoal waste bricks linear shrinkage

3.4. Bricks Linear Shrinkage

The bricks experienced a decrease in linear shrinkage with an increase in charcoal waste content up to 30% of CW (Fig. 3). Beyond the optimum value of 30%, an increase in CW led to an increase in linear shrinkage. As urged by [23], the increase in linear shrinkage could have been contributed by additional unburnt charcoal waste, which occupied spaces in the soil leading to the linear reduction in drying. It was experienced irrespective of the number of perforations in the bricks—usually, a good quality brick exhibits shrinkage below 8% [24]. The research found that with the exception of bricks with 15 perforations, all other bricks recorded linear shrinkage below 8% with up to 50% CW addition. This indicated that they were bricks of good quality.

3.5. Loss of Weight and Water Absorption

The bricks' water absorption capacity increased with an increase in CW content (Fig. 4). This observation corresponds well with the findings of [25] that wood ash increases porosity in a clay mass, thus increasing water absorption. The high content of CW introduced high porosity that caused water absorption by capillary by the bricks. However, there was a general reduction of water absorption with an increase in the number of perforations. This observation can be associated with the reduction of solid mass, thereby reducing the amount of water absorbed. The bricks' water absorption capacity is greater than the recommended by [11], [16], and [17] for Engineering bricks (Class 'B's should be ≤ 7%) and Dampproof course (Class 'A's should be ≤ 4.5%). The bonding of the bricks with mortar is, however, compromised when the bricks absorb too much water.

It was observed that with an increase in perforations, weight loss is reduced. However, there was no significant change in weight loss with an increase in CW percentages (Fig. 5). The research deduced that an increase in perforations led to lightweight bricks, which tend to suffer less weight loss and absorb low amounts of water. This is associated with efficient fire transfer through the perforations, and the presence of CW reduces the weight, which acts as an internal fuel that accelerates the firing.

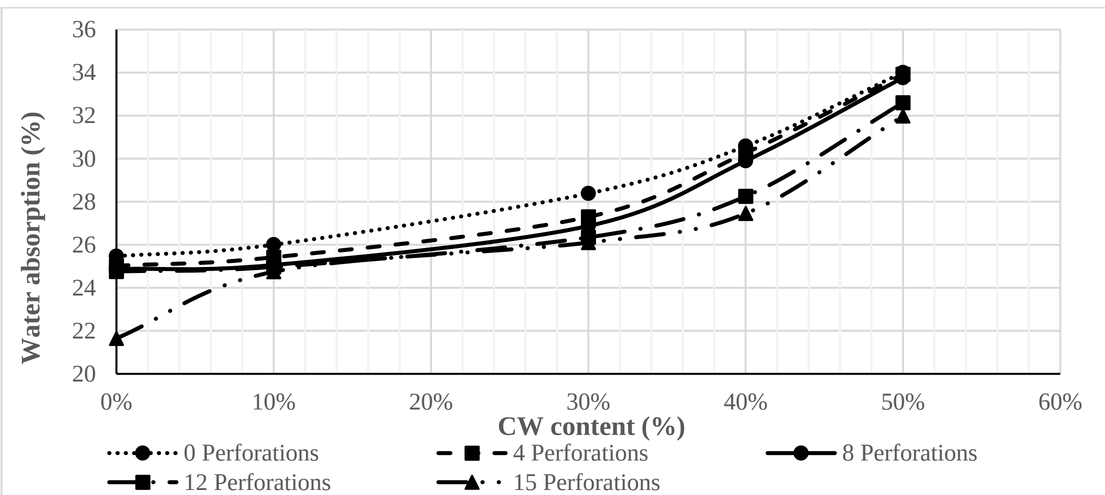

Fig. 4 Bricks water absorption

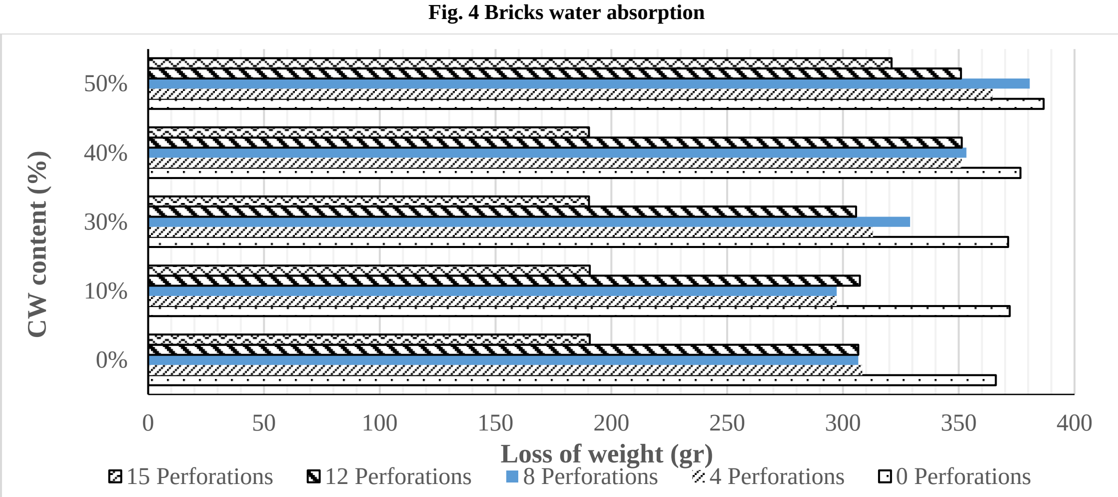

Fig. 5 Loss of weight

3.6. Durability

Fig. 6 shows that at 0% CW, bricks with no perforation had the least abrasion index, followed by bricks with 4 perforations (0.05%). As the CW content increased from 0 to 50%, bricks with no perforations experienced an 85.19% increase in abrasion, while those with 4 perforations had an 82.14% increase in abrasion index. Bricks with 15 and 12 perforations displayed the least abrasion indices, increasing CW to 50%, at 42.11 and 45.45%, respectively. It can be deduced that clay bricks with 12 and 15 perforations produce better durability as the CW content increases.

3.7. Compressive Strength and Bulk Density

The bricks compressive strength decreased with an increase in CW and the number of perforations. According to [26], the bricks can be classified under category I (load bearing) with a minimum compressive strength of 7N/mm^2 (Fig. 7).

With the increase in CW, there is a decrease in bulk density. Moreso, with the increase in the number of perforations, the bricks experienced a decrease in bulk density (Fig. 8). An optimum value of 30% CW was achieved with the exception of bricks with 12 perforations.

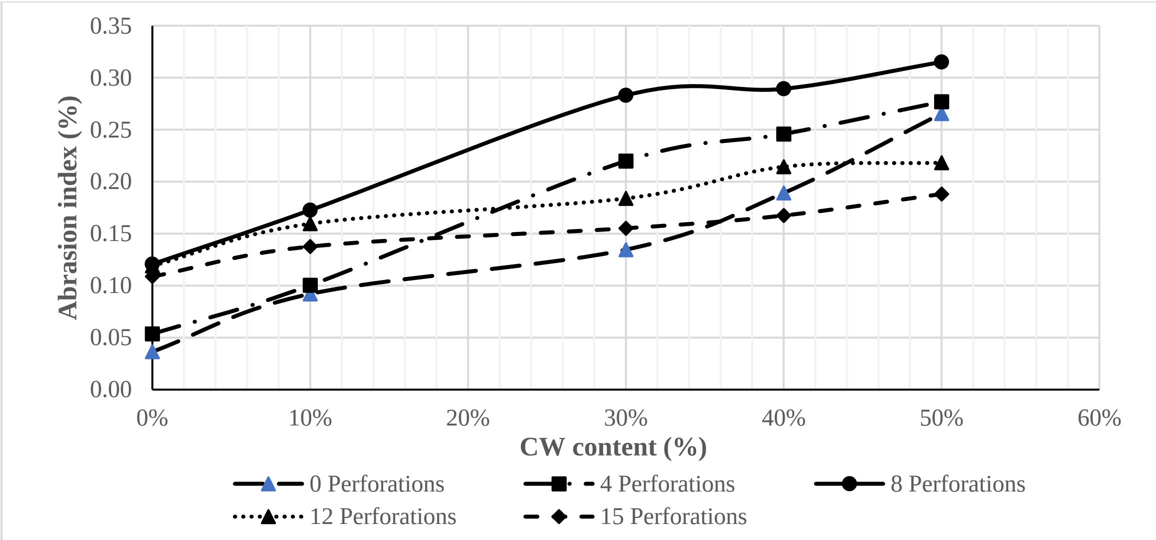

Fig. 6 Abrasion index for clay soil bricks

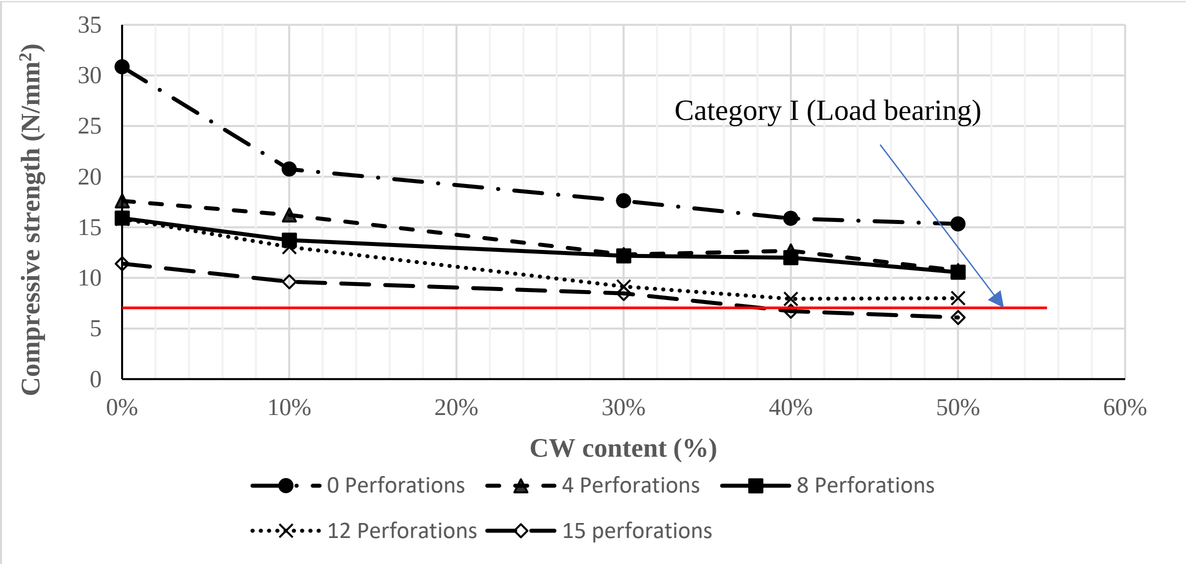

Fig. 7 Perforated clay bricks' compressive strength

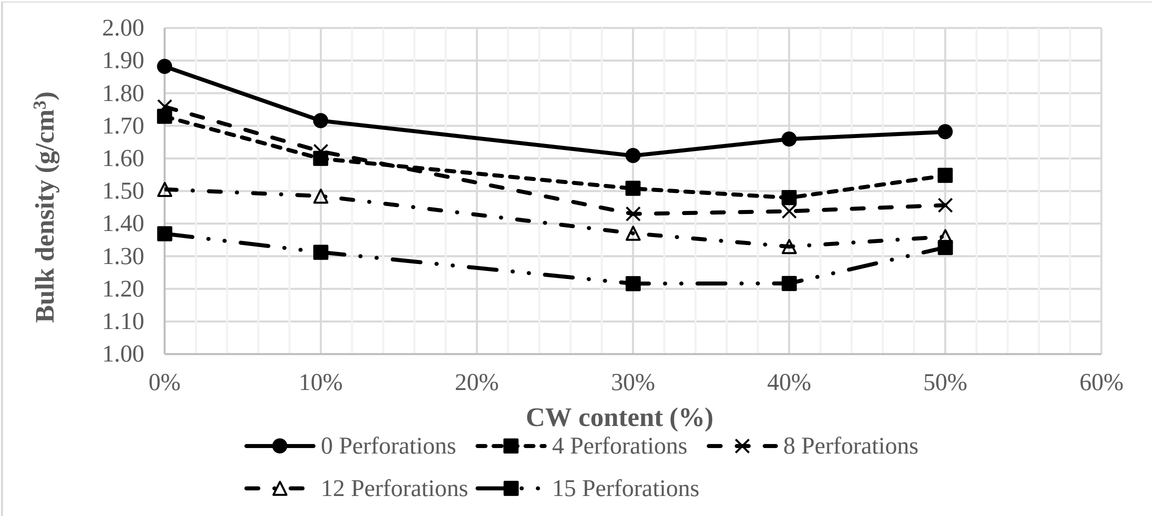

Fig. 8 Perforated cay bricks bulk density

4. Conclusion

This research aimed to find the performance of perforated clay soil bricks with charcoal waste as an additive. The following conclusion can therefore be drawn from this study:

- The increase in charcoal waste led to an increase in linear shrinkage of clay soil bricks due to the increase of calcium cations and reduction of magnesium cations in the soil. An optimum of 30% of charcoal waste was identified for the linear shrinkage of clay soil bricks.
- An increase in the number of perforations reduces the water absorption capacity of bricks; however, they don't meet the code requirement.
- An increase in the number of perforations and charcoal waste result in higher abrasion of clay soil bricks. However, beyond 8 perforations amount of abraded material reduces due to the effectiveness of burning the bricks.
- Bricks having 12 perforations and below with 30% charcoal waste additive can be categorized as category I (load-bearing) bricks.

References

[1] K. Fabien "*Charcoal Value Chain and Improved Cookstove Sector Analyses*" Courtney Blodgett, p. 48, 2010

[2] A.A. Kadir, H.H. Jamil, and A.S. Abdul Rahim, "Leachability of Fired Clay Bricks Incorporating with Sludge Waste from Mosaic Industry," *Materials science forum*, vol. 803, pp. 233-238, 2014. *Crossref*, https://doi.org/10.4028/www.scientific.net/MSF.803.233

[3] Abbas Mohajerani, and Aeslina Abdul Kadir, "Effect of Heating Rate on Gas Emission and Properties of Fired Clay Bricks and Fired Clay Bricks Incorporated With Cigarette Butts," *Applied Clay Science*, vol. 104, pp. 269-276, 2015. *Crossref*, https://doi.org/10.1016/j.clay.2014.12.005

[4] Kadir Aeslina Abdul Kadir, Nur Azian Mohd Zahari, and Noor Azizi Mardi, "Utilization of Palm Oil Waste into Fired Clay Brick," *Advances in Environmental Biology*, vol. 7, no.12, pp. 3826-3834, 2013.

[5] A.S.A. Rahim, H.H. Jamil, and A.A. Kadir, "Leachability of Fired Clay Brick Incorporating with Sludge Waste from Mosaic Industry," *Material Science Forum*, vol. 803, pp. 233-238, 2015.

[6] Kae Long Lin, "Feasibility Study of Using Brick Made from Municipal Solid Waste Incinerator Fly Ash Slag," *Journal of Hazardous Material*, vol. 137, no. 3, pp. 1810-1816, 2006. *Crossref*, https://doi.org/10.1016/j.jhazmat.2006.05.027

[7] Banhidi Viktor, "Enhancement of Insulating Properties of Brick Clay by Renewable Agricultural Wastes," *Processing and Applications of Ceramics*, vol. 2, no.2, pp. 75-79, 2008. *Crossref*, http://dx.doi.org/10.2298/PAC0802075B

[8] P Chindaprasirt et al., "*Eco-Efficient Masonry Bricks and Blocks: Design, Properties and Durability*," Elsevier, 2015

[9] Sanu Babu Dangol, S. Adhikari and R.M. Byanju, "Use of Charcoal as Internal Fuel in Vertical Shaft Brick Kiln", Remtech Symposium Compendium, vol. 3, pp. 22-25, 2013.

[10] BS EN 771-1, Specification for Masonry Units – Clay Masonry Units. BSI, 2003.

[11] BS 3921, Specification for clay bricks. BSI.

[12] E.O. Mclean, "Aluminium in Methods of Soil Analysis," *America Science Agronomy*, Madison, Wisconsin, pp. 978-998, 1965

[13] BS 1377-3, Methods of Testing Soils for Civil Engineering Purposes, Chemical and Electro-Chemical Tests, British Standards Institution, 2 Park Street, London, 1990.

[14] BS 1377-2, Methods of Testing Soils for Civil Engineering Purposes, Classification Tests, British Standards Institution, 2 Park Street, London, 1990.

[15] Prashant Modi, and Aarif Jamal, "Geochemical Characterisation of Coal with Special Reference to Thermal Industries of Dhanpuri Open Cast Project, Sohagpur Coalfield, Madhya Pradesh, India," *International Journal of Engineering Trends and Technology*, vol. 68, no. 4, pp. 36-42, 2020. *Crossref*, https://doi.org/10.14445/22315381/IJETT-V68I4P207S

[16] Rwanda standard, RS 359, 2009.

[17] KS EAS 54, Burnt Building Bricks – Specification, 1999.

[18] AASHTO - T 96-02, Standard Method of Test for Resistance to Degradation of Small Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine, Washington D.C. USA, 2010.

[19] BS EN 7721-1, Methods of Test for Masonry Units, Determination of Compressive Strength, British standards, 2011.

[20] Uzoma Darlington Chima, Gabriel A. Adedeji, and Kingsley O. Uloho, "Preliminary Assessment of the Impact of Charcoal Production on Physico-Chemical Properties of Soil in Rivers State, Nigeria," *Ethiopian Journal of Environmental Studies and Management*, vol. 6, no. 3, pp. 286 – 293, 2013. *Crossref*, http://dx.doi.org/10.4314/ejesm.v6i3.9

[21] Chellasamy Manoharan et al, "Characteristics of Some Clay Materials from Tamilnadu, India, and Their Possible Ceramic Uses," *Ceramica*, vol. 58, no. 347, pp. 412-418, 2012. *Crossref*, http://dx.doi.org/10.1590/S0366-69132012000300021

[22] Kent J. Schwieger, "*The Influence of Cation Exchange and Electrolyte Concentrations Upon the Atterberg Limits*," Masters Thesis. 5721, 1965.

[23] Oladunni Oyelola Alabi, Miracle Adegun, and Temitope Olatunji, "Chemical Characterization of Ijapo Clay and its Additives Towards Production of Refractory Bricks," *Indian Journal of Engineering*, vol. 17, no. 48, pp. 342 – 350, 2020.

[24] Brick Industry Association (BIA, Technical Notes 9-Manufacturing, Classification, and Selection of Bricks Manufacturing: Part 1, vol. 14, 2004.

[25] Anuwat Srisuwan et al., "Preparation and Properties of Fired Clay Bricks with Added Wood Ash," *Journal of Metals, Materials and Minerals*, vol. 30, no.4, pp. 84- 89, 2020. *Crossref*, http://dx.doi.org/10.14456/jmmm.2020.

[26] Kenya standard DKS 2801-1, Specification for Clay Masonry Units. Kenya Bureau of Standards

[27] BS 1377-1, Methods of Testing Soils for Civil Engineering Purposes, General Requirements and Sample Preparation, British Standards Institution, 2 Park Street, London, 1990.