PRINT ISSN 1119-8362
Electronic ISSN 2659-1499

Full-text Available Online at
https://www.ajol.info/index.php/jasem
https://www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 28 (9) 2671-2682 September 2024

Feasibility of Utilizing Pulverized Ceramic Wastes as Potential Admixture for an Equimolar Clay-Brick Derivative

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ABSTRACT: The heat-transmuted solid wastes of opalescent structures can be pulverised and recycled entirely for highly developed products. Hence, the objective of this paper was to investigate the feasibility of utilizing pulverised ceramic wastes (CWs) as a potential admixture for fired clay-brick derivative at 950ºC with partial substitution at an equal ratio of clay (CL) and kaolin (KL) for water absorption rate and compressive strength test during loading. Several appropriate standard technics were employed. Results revealed that the sole compaction of ceramic wastes (Cs0) has the lowest strength density of 1.21MPa, compared with the progressive linear density of specimens with the addition of clay compositions as stabilizers. Sp^{10} has a higher resistance of 2.39MPa during compressive loading and a decrease in the quantities of ceramic wastes from Sp^{11-15} caused a low linear strength but an increase in the water absorption rate. Conclusively, ceramic wastes have a positive effect on clay bricks' strength and water absorption when equally substituted with clay compositions. The study provides an avenue for solving ceramic waste disposal challenges and unveils the approach to boost the products of waste recycling industries, enhancing technological and economic growth.

DOI: https://dx.doi.org/10.4314/jasem.v28i9.9

Cite this Article as: AJADI, M. O. (2024). Feasibility of Utilizing Pulverized Ceramic Wastes as Potential Admixture for an Equimolar Clay-Brick Derivative. *J. Appl. Sci. Environ. Manage.* 28 (9) 2671-2682

Dates: Received: 04 June 2024; Revised: 27 June 2024; Accepted: 11 July 2024 Published: 05 August 2024

Keywords: Ceramic Wastes; Compressive Strength; Fired Bricks; Oxide Properties; Water Absorption

Post-consumer wastes are highly generated nonbiodegradable pollutants worldwide, particularly, in most developing countries with low capacities of industrial recycling compared to the level of emission and indiscriminate strewing on the earth's surface. The dissolution of these wastes is difficult due to the heat transubstantiation of the combined chemicals that render the processes into solid-structural wares (Ajadi, 2024). These waste materials are mostly taken to dump sites or landfills (Rodriquez *et al.*, 2019) and significantly pose risks to both ecological niches and the depletion of the environment (Eminov *et al.*, 2023). The alternative usage of these wastes is important for pollution management and environmental safety. However, collection and recycling offer the right ways of managing nonbiodegradable wastes, especially, harnessing their chemical properties for highly developed products (Jock, 2023; Ajadi *et al.*, 2023). Recycling of vitrified waste matters for use in heat resistance or refractory products has huge benefits on environmental sustainability and a positive impact on marketable value-added products, economic interest and niche (Hossain and Roy, 2020). The chemical compositions of waste materials from synthetic or semisynthetic materials, brittle solid structure, thermoplastic polyamide, caoutchouc and opalescent/translucent ceramic wares are suitable for refractory and highly advanced products. To minimize disposal issues of industrial wastes on the earth's surface, alternative functions require urgent attention and environmentally friendly consideration for processes and product

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needs. Ceramics is a fragile solid structural ware of diverse chemical combinations which metamorphose into translucent/opalescent products after vitrification at a high degree of temperature. The structures of opalescent ceramics usually have the visual properties of milky brightness or play of colours on the surface while the translucent ceramics allow light to pass through the structure. The structure of most opalescent ceramic wares is a combination of clayware and vitreous glossy substance (glaze), which renders the clay surface iridescence and impervious to liquid. Glaze is fusion-bonded for gloss-coating the surface of ceramic wares to give the wares strength, non-absorbent, easily cleaned and chemically inert substrates (Andreola *et al.,* 2007; Ajadi, 2019). The glaze on the surface of porcelain is usually composed of four chemical components: silica, alumina, flux and colourant (Kalilu and Ajadi, 2021; Kalilu and Ajadi, 2023). Most utensils such as food dishes, kitchen wares, sanitary wares, floor and wall tiles, and vases are ceramics. Additionally, ceramics serve as highly advanced electrical insulators, heat resistors, parts of aircraft and space shuttles, computer chips and components of machines. Most submarines and blast furnace linings which require high-temperature resistance, chemical reactivity and mechanical stability are made of ceramic composition (Rhode, 1998; Kalilu *et al.,* 2006). Ceramic wastes are undesirable materials from construction and demolition posing a threat to the environment. Ceramic materials generate waste during construction handling, installation, post-consumer use, and demolition and are among the highest generated wastes globally (Belhovehet, *et al.*, 2019; Tikul, 2014). In Nigeria, ceramic tiles are mostly used waste, assembled to form patterns on the floor, while others are generally disposed of as waste on the earth’s surface, leading to landfill occupancy and severe pollution (Tam, *et al.,* 2018).

The chemical properties and heat responsiveness in the first vitrification process make ceramic wastes suitable as materials for refractory products. However, they pose a threat to ecological niches due to their non-dissolution and economic needs. Ceramic wastes are frequently generated waste materials that can be pulverised and utilised for value-added products or utilised as an enhancement in highly resistant products. This utilisation usually creates valuable and eco-friendly products, providing a more sustainable solution (Eminov *et al.,* 2023). They can also be used to increase the strength of tiles, and green mortars, as filler materials in reinforced ceramic products (Ozturk, *et al.,* 2024), enhance the resistance capacity of heat-insulating products made of alumina-rich porcelain (Fassbinder, 2002; Liu *et al.*, 2019), improve reactivity as an aggregate material in building construction (Bhogilal and Tejas, 2018; Siddique, *et al.*, 2019; Huseien, *et al.*, 2020). The utilization of ceramic wastes as the substitution in ceramic productions has a huge potential to replace natural raw materials (Hossain and Roy, 2020) and a partial replacement of clay and kaolin with ceramic waste enhances the strength of the tiles (Ozturk, *et al.*, 2024). More significantly, recycling of ceramic waste is useful for environmental and economic viewpoints (Seo, *et al.,* 2010).

Harnessing ceramic wastes as manufacturing material, particularly, in pulverised form, has been under experimental research over the last decades. Diverse functions and applications have been unveiled in surveyed literature, such as an aggregate in green mortar and an additive material for high-performance ceramics. Premium mechanical traits of clays, limestone filler, fly ash, ground granular blast furnace slag, metakaolin and silica fume enhance the ultra-high-performance of mortar in cementitious technology (Zhang, *et al.*, 2023; Alsalami, and Abbas, 2024; Schmidt, *et al.*, 2018; Lothenbach, *et al.*, 2011). Pulverised glass consists of silicon and calcium with an amorphous structure (Matos and Sousa-Coutinho, 2024). Kelestermur, *et al.,* (2014) carried out a statistical analysis of cement mortars prepared with marble dusts and glass fibre for the improvement of freeze-thaw resistance. The characteristics of ceramic waste material ascertain its usefulness for abrasive products (Huang, *et al.*, 2021), and recycling industrial waste into high-performance ceramics is eco-friendly and significantly provides a sustainable solution (Ashiaf, *et al.*, 2023). Ceramic wastes enhance the mechanical properties and corrosion resistance in concrete structures (Portella, *et al.*, 2006) and provide good strength and long durability as a replacement for cement (Kanaan, *et al.*, 2017; El Dieb and Kanaan, 2018). Hossain and Roy (2020) experimented with the correlation of waste mixture limit, production route and properties of waste derived from whiteware, glass, refractories, oxide and non-oxide ceramics. Silva, *et al*, (2019) examined the rheology, density, water absorption, linear shrinkage and flexural strength of recycled ceramic waste as raw material in sanitary ware production. Rambaldi, *et al.,* (2021) sintered ceramic products of soda-lime cullet mixes and scrap tiles of unfired classification from the industrial ceramic process for experimental examination of a high recycling material in traditional wares. Ozturk *et al*, (2024) affirmed filter-press cake waste as a functional material to improve the mechanical properties and microstructural performance of porcelain tiles. Abrasive materials and concrete are the most viable and economic options for recycling and valorization of ceramic waste (Arias-Ocampo and Rojas-Gonzalez, 2023), and the green development model is a suitable method for the sustainable utilisation of ceramic waste (Gao, *et al.,* 2023). The porcelain microstructures are made of a vitreous phase of mullite reaction between kaolinitic clay raw materials and feldspar and crystalline phases of quartz and feldspar as residual phases (Romero and Pérez, 2015). However, the ceramic wastes could be utilised as a supplementary through collection, recycling, and processing for load-resistant materials of a new ceramic product and enhancement of highly developed products. Several literatures explicate the usefulness of fired porcelain tile wastes of floor and wall, and sanitaryware wastes (Tarhan, 2019; Tarhan, *et al.,* 2016; Elmas, 2019), sanitaryware waste products in porcelain tile production (Tarhan, *et al.,* 2017). The reviewed literature has not been concerned with the utilisation of ceramic wastes in fired clay-brick derivation. This study, therefore, is an investigation on the feasibility of utilization of pulverised ceramic wastes as potential materials for fired clay-brick derivation at 950oC with partial substitution at an equal ratio of clay (CL) and kaolin (KL) for water absorption rate and compressive strength test during loading.

MATERIALS AND METHODS

Figure. 1 summaries the materials' collection, samples' treatment, oxide properties, bricks derivation and analyses of test specimens for shrinkage rate, water absorption, saturation coefficient and compressive strength.

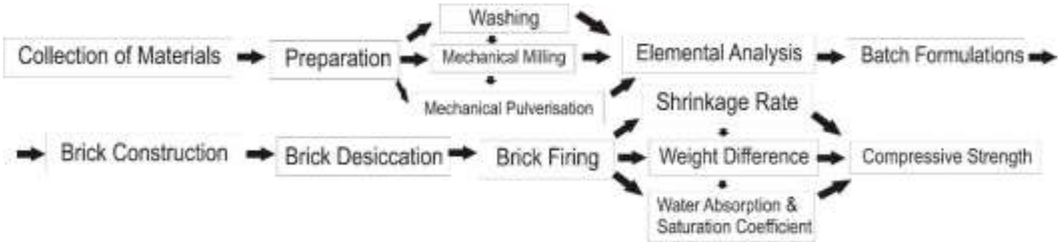

Fig. 1: Materials' Treatment, Bricks' Derivation and Specimens' Analyses

Ceramic wastes (CW) were gathered from dump sites and unearthed from pits' landfill (Plate 1) and clay (CL) of high plasticity and kaolin (KL) were collected from clay pits. The ceramic wastes collected for this study were both glazed and unglazed wares. The soils were 6 6 obtained using ASTM (E1726) and properties characteristics of plasticity and moisture capability. The materials were moved to the Ceramic studio of the Department of Fine and Applied Arts, Ladoke Akintola University of Technology, Ogbomoso as per the ASTM Standard Practice for Preserving and Transporting Soil Samples (D4220-95(07)). The collected wastes (CW) were washed to remove fibre and contaminants (Plate 2), dried and the three materials were mechanically milled (Plates 3-5) with a jar crusher. The jar-crushed samples were distributed over a surface in a layer for constant mass, dried under solar for ten (10) hours and spread at ambient open air for an additional twenty-four (24) hours before being pulverised with pulveriser (Rocklabs, model CRC 3E) to obtain the smallest particle size (Plates 6-7). Typically, these were done for characterization that ascertains the particle-size distribution, samples' composition, material morphology and specimen derivation. Each sample was pulverised at equal density (Kg/m3) for coalescence of the compositions during mixes. The water absorption rate was tested on the specimens' retention capacity using the Differential Immersion Volume (DIV) technique to determine the properties of being a less porous structure. Besides, the test was used to examine the compositional behaviour of the three samples regarding densification and examination of linear shrinkage, boiled saturation and compressive strength.

Plate 1: Ceramic wastes in dump sites

Plate 2: Submerged wastes

Plate 3: Collected Clay

Plate 4: Jar Crushed Waste

Plate 5: Jar Crushed Kaolin

Plate 6: Pulverised Ceramic Waste

Plate 7: Pulverised Kaolin, Ceramic waste and Clay

The particle size density (PSD) of the samples was determined using the Laser method and the size distribution was presented in Table 1. Table 1 above highlights the particle size distribution of each particle. The densification characteristic was ascertained by measuring the materials' density, firing shrinkage and water absorption. The specimens' density and water absorption by capillary actions and pore formations were determined according to ASTM C373-88. The porosity was determined by the percentage of water absorption through pore-formation areas and the performance characteristic of the surface tension of each specimen. The oxide properties of the pulverised samples were characterized by a tandem accelerator machine using Particle induced X-ray Emission (PIXE). However, the samples' mixes were measured at dry phase based on their weight (Plate 8) and homogenised in Jar mill machine (G90, GE: 1880913) on batch constituents of 100% ceramic wastes as a control sample (CS^0) and subsequently substituted at 5% disparities of 5-75% with an equal ratio of clay (CL) and kaolin (KL) in each of the specimens (SP^{1-15}) for examination of physical, chemical and morphological characterisations of the ceramic waste's performance on the shrinkage capacity, water absorption and strength at 950°C firing temperature.

Table 1. Particle size distribution of Ceramic wastes, Clay and Kaolin after Mechanical Pulverisation

Materials	**Ceramic wastes**	**Clay**	**Kaolin**
Density (Kg/m^3)	3110	3110	3110

Table 2: Batch Constituents of the Specimens

Specimens	**Cs^0**	**Sp^1**	**Sp^2**	**Sp^3**	**Sp^4**	**Sp^5**	**Sp^6**	**Sp^7**	**Sp^8**	**Sp^9**	**Sp^{10}**	**Sp^{11}**	**Sp^{12}**	**Sp^{13}**	**Sp^{14}**	**Sp^{15}**
Ceramic wastes	100	95	90	85	80	75	70	65	60	55	50	45	40	35	30	25
Clay	-	2.5	5	7.5	10	12.5	15	17.5	20	22.5	25	27.5	30	32.5	35	37.5
Kaolin	-	2.5	5	7.5	10	12.5	15	17.5	20	22.5	25	27.5	30	32.5	35	37.5

All formulations were applied in specimens after malleably mixed with water, including the control specimen as described in Table 2. The specimens were made from a metal mould of fifty millimetres in width by a hundred millimetres in length and thirty millimetres in thickness (50 x 100 x 30mm^3) with a manual compacted machine (Plate 9). The bricks were inscribed with the numeric number of specimen's compositions and the water dehydration of each composition was monitored at intervals of two (2) hours under ambient temperature in the studio. The diminutive ceramic waste quantity in the compositions at 75% suggests the ineffectiveness of this material in further mixtures. This may not have a significant influence on the further compositions with a higher percentage of clay and kaolin. In addition, the rationale for these multiple specimens is to validate the suitable composition during compressive strength.

Plate 8: Measurement of samples for batch Compositions With Electronic Scale Model BL 20001

Plate 9: Manual Compaction of Clay-Brick

Plate 10: Clay-Brick with Numeric Inscription

However, the bone-dry specimens were stacked in a kiln with a 950ºC pyrometric cone at the spy-hole beside the door for the heat assessment and cone reactions in the kiln chamber. The specimens were fired after the kiln had been sealed off with gas until the temperature in the chamber reached 950ºC and ascertained through the bent cone. The specimens were off-loaded for the examination of shrinkage rate, water absorption capacity, saturation coefficient, weight differences and compressive strength. All the specimens were tested for shrinkage rate using ASTM C62-09 (ASTM C62 2006). The shrinkage capacity of each specimen was measured in millimetres (mm) to ascertain the percentage of decreasing rates in the length and diameter at the leather-hard phase and after firing. To reach the leather-hard phase, the specimens were exposed to ambient air in the studio for 24 hours for easy handling and measurement without deformation. The shrinkage rate was determined as shown in Equation (1):

Initial Length at leather-hard = (*ILL)* after 24 hours at room temperature
Length after firing = (*LAF)*
Loss capacity differences = (*LCD)*
Loss percentage capacity = (*LPC)*
That is: $\frac{ILL-LAF}{ILL} \times 100$ (1)

Weight differential analysis was done by determining water dehydration at the leather-hard phase and kiln-fired phase. The weight of each specimen was measured at leather-hard and after firing in kilograms (kg) with a digital electronic scale (model: BL20001) and the probe specimens were ascertained as shown in Equation (2):

Initial Weight at leather-hard = (*IWL)*
Weight after firing = (*WAF)*
Weight differential result = (*WDR)*
Weight differential percentage = (*WDP)*
That is: $\frac{IWL-WAF}{IWF} \times 100$ (2)

The water absorption capacity of the test specimens was determined through liquid porosity and surface pore formations. The process was carried out in ASTM specifications of 12 hours cold water immersion and 2 hours immersion of boiling test (ASTM C62 2006). The water absorption involved the initial weight of dry mass in the air of fired specimens and measured in kilogram (kg) before the 12 hours of immersion. The weight of each specimen was measured immediately after immersion to determine their differences and the was calculated as shown in statistical Equation (3):

Initial Dry Mass = *(IMA)* after firing
Mass After Drenched = *(MAD)* after 12 hours
Absorption Capacity Volume = *(ACV)*
Absorption Capacity in Percentage = *(ACP)*
That is: $\frac{IMA-MAD}{IMA} \times 100$ (3)

The saturation coefficient was equally examined on the test specimens after thorough desiccation of the water absorption test of the specimens. All the test specimens were drenched in a pot with continuous boiled water for 2 hours of equal gas burner regulation. This test was used to ensure that all the surface capillaries, voids and pore formations in the specimens were penetrated with water during immersion in the vapour form. After 2 hours of water boiling, the specimens were permitted to cool for 12 hours in submerged water before being measured immediately for statistical calculation of the water saturation coefficient. The saturation coefficient was determined as shown in Equation (4):

Weight of Dried Specimen = *(WDS)* at thorough desiccation
Weight of Saturated Specimen = *(WSS)* after 2 hours in boiled water
Absorption Capacity Volume = *(ACV)*
Absorption Capacity in Percentage = *(ACP)*

$$\text{That is: } \frac{WDS - WSS}{WDS} \times 100 \qquad (4)$$

The compressive strength of the specimens was examined in their maximum resistance to the break. The test was done with digital powered universal testing machine (Model Instron 3369K1781) and the parametric average of all specimen measurements are anvil height of 14.95000mm, thickness of 149.04000mm, and width of 45.05000mm. The measurement was done to determine weight against the compressive strength (MPa) which was examined as shown in Equation (5):

$$\text{Compressive strength (MPa)} = \frac{Force\ (N)\ or\ Load}{Area\ (M^2)}$$

$$\text{Pascal (Pa)} = \text{N/M}^2 \qquad (5)$$

RESULTS AND DISCUSSION

Oxide Properties of Pulverised Ceramic Wastes and Other Raw Materials: The oxide properties (wt.%) of the ceramic wastes and other raw materials results from Particle Induced X-ray Emission are presented in Table 3.

Table 3. Oxide analysis (wt.%) of the raw materials and the waste

Oxides	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**P_2O_5**	**K_2O**	**CaO**	**TiO_2**	**Fe_2O_3**	**ZrO_2**	**ZnO**	**Sb_2O_5**	**SrO**	**Total**
Kaolin	4.96	5.24	17.24	58.72	0.08	10.37	0.27	-	0.12	0.01	0.09	2.92	0.07	100
Clay	1.06	1.48	6.04	81.46	0.18	1.74	0.49	0.53	6.45	0.09	0.21	0.42	0,12	100
Ceramic Wastes	4.75	0.75	19.6	69.5	0.12	1.9	0.85	0.59	1.53	0.01	0.20	0.12	0.07	100

From the results in Table 3, the percentage of Al_2O_3 in ceramic wastes will decrease the excess amorphous silica in the matrix at the temperature of 950ºC (Peter and Iberg, 1978; Convile and Lee, 2005). The major elements in the three samples are silicon, aluminium, sodium, potassium, magnesium, and iron while molybdenum, strontium, zirconium, zinc, and phosphorus are minor in the compositions. Other elements traced in the materials were titanium and calcium and the percentage of iron (Fe_2O_3) in clay enhanced the malleability of the test specimens in terms of stickiness, plasticity and stabilization. However, plasticity index >20 is not suitable for brick compacted manually (Walker, 1995).

Properties' Characterisation of Test Specimens: The major characteristics that ascertain the quality and durability of fired bricks in civil structures are shrinkage rate (SR), water absorption capacity (WAC) and compressive strength (CS) (Adie and Osibanjo, 2013). The results of the compacted specimens after kiln firing at 950ºC showcase the usefulness of ceramic wastes on these mechanical parameters with positive results at certain parametric mixtures. However, the results of the structural properties of each specimen which include shrinkage rate, weight difference, water absorption capacity, saturation coefficient and compressive strength are presented below.

Shrinkage rate: Figure 2 summarises the shrinkage rate of the test specimens (initial length at leather-hard and length after kiln fired), shrinkage capacity difference (mm) and shrinkage capacity percentage (%). The volume of shrivelled differences were the determining factors for the shrinkage rate which was examined through the initial and retained size of each sample after kiln firing.

All the specimens were approximately measured hundred (100) millimetres at leather-hard. The shrinkage differences were calculated through arithmetic subtraction of length after firing *(LAF)* at 950ºC from the initial length at leather-hard *(ILL)* in the diameter of all specimens (mm) *(i.e. ILL – LAF = SRD).* The shrinkage capacity in percentages (*SRP%*) was established through the multiplication of shrinkage rate difference (*SRD*) with hundred (100) divided by the initial length at the leather-hard of the specimens (*ILL*). From the result in Figure 2, ceramic wastes reduced the shrinkage level of the compositions in proportional decrease with substituted materials and it is linearly evidenced in the mixed samples with water retention capacities. Beal *et al*, (2019) submitted that shrinkage is a significant property of clay brick and the higher the shrinkage, the tendency of stress, cracks and breaks results as water vaporizes during dry out and firing, consequently, shrinking the brick. Similarly, it is observed that the linear reduction in shrinkage of compositions is by the study of Zhao *et al*, (2013) and this is a function of a proportional decrease in the content of ceramic wastes in clay bodies.

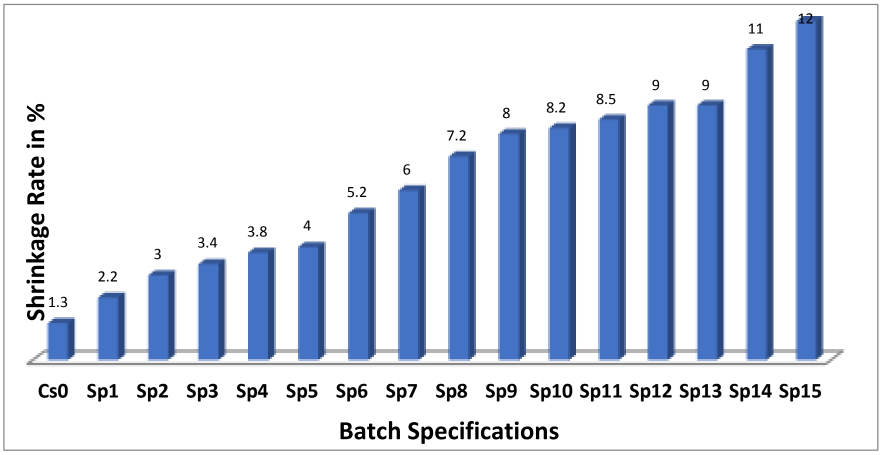

Fig. 2: Percentage of Shrinkage Rate of the Test Specimens

Weight Differential Analysis: Table 4 identifies the weight differential properties of the test specimen at kilogram (kg) with (initial weight at leather-hard and weight after kiln fired), weight differential result (kg) and weight differential percentage (%).

Table 4: Weight Differential Analysis of Test Specimens

Specimens	**Cs^{0}**	**Sp^{1}**	**Sp^{2}**	**Sp^{3}**	**Sp^{4}**	**Sp^{5}**	**Sp^{6}**	**Sp^{7}**	**Sp^{8}**	**Sp^{9}**	**Sp^{10}**	**Sp^{11}**	**Sp^{12}**	**Sp^{13}**	**Sp^{14}**	**Sp^{15}**
Leather-hard (kg)	0.65	0.67	0.70	0.71	0.71	0.72	0.71	0.71	0.69	0.68	0.68	0.67	0.68	0.65	0.65	0.66
After Firing (kg)	0.54	0.57	0.58	0.58	0.58	0.58	0.58	0.56	0.54	0.53	0.54	0.53	0.53	0.51	0.51	0.52
Differential (kg)	0.11	0.10	0.12	0.13	0.13	0.14	0.14	0.15	0.15	0.15	0.14	0.14	0.15	0.14	0.14	0.15
Differential (%)	16.9	14.9	17.1	18.3	18.3	19.4	19.7	21.1	21.7	22.1	20.6	20.9	22.1	21.5	21.5	22.7

The measurement of each of the test specimens was taken in kilograms (kg) for examination of air and heat reactions to the weight and strength. Differential results were determined by mathematical differentiation in the value of weight decrease through subtraction of initial weight at leather-hard (kg) from the weight after firing (kg) which gives the weight differential result (*i.e. IWL – WAF = WDR*). The difference the weight was manifested in the percentage of ceramic wastes and the increase in the weight differential percentage (*WDP %*) is linearly evidenced in the reduction of ceramic waste quantity. In addition, the surface smoothness of fired clay bricks determines water sorption and morphological depth influences the durability of the fired clay-bricks. Based on these results, the increase of kaolin and clay in the mixtures influenced the weight of the test specimens by increasing the mass and differentially, ceramic wastes reduced the weight units. These may have significantly influenced the test specimens' performance during water absorption and compressive strength.

Water Absorption Capacity: The water absorption properties were performed on resistant capacity and amount of water permitted through the open porosity and capillary actions of test specimens after water absorption and saturation coefficient.

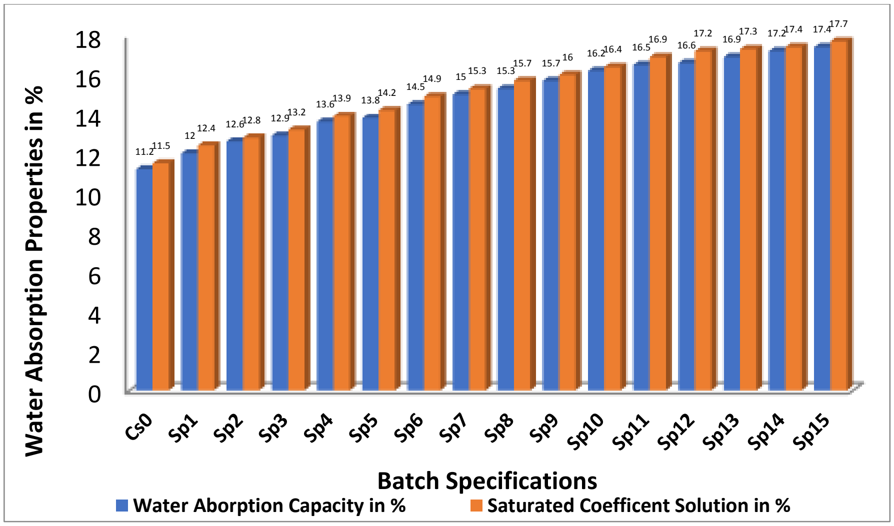

Fig. 3: Water Absorption and Saturation Coefficient Properties of the Test Specimens

The correlation coefficient in the absorption chart (figure 3) indicates that the decrease in ceramic wastes' quantity increases total porosity amounts with 11.2 – 17.4% of water absorption rate and 11.5 – 17.7% of saturation coefficient. This reveals that the wastes solidified against liquid with positive effects on the surface properties of the test specimens. As can be deduced from the results, an increase in quantities of clay compositions absorbed higher water which shows lower resistance to movement of water and greater interconnectivity of voids and pores which may equally occur during the compaction process. It was also observed that the compositions of the used clays are capable of being adsorbed or accumulated when compacted as a solid structure. This result can be improved by increasing the kiln temperature of this experiment to 1100ºC for better interfacial zone between ceramic wastes and clay compositions. NIS 978:2017 (2017) recommended that the water absorption rate of sandcrete block types should not exceed a maximum of 12% for durability. Increasing ceramic waste content in the specimens reduced the water sorption and low porous structure (Silva, *et al.*, 2019) and this result is compatible with the log-normal distribution function and the studies of Adie, *et al*, (2022), Portella, *et al.*, 2006 and Abdeen and Shihada (2017). The trend of water absorption properties and saturation coefficient results are compatible. The impact of variation and increased in clay and kaolin mixed brought an increase in water sorption through the voids and pores in the surface. The variation equally shows a progressive pattern with the decrease in resistance to water absorption compared to compositions with a higher percentage of ceramic wastes. However, particle size density (PSD) affects the water absorption properties of fired brick and the pulverised density of each particle enhances the brick's strength (Ajadi, 2024; Adie, *et al.*, 2022). The three materials are in equal particle size and variation in water absorption can only be linked to properties of the pulverised materials, selected temperature and manufacturing process of the bricks.

Compressive Strength: Figure 4 shows the compressive strength test results of the test specimens with composition of ceramic wastes, kaolin and clay at different ratios. The compressive strength indicates low results with the sole composition of ceramic wastes as a control sample (Cs^0) and an increase with a decrease in the content of ceramic wastes because of an increase in malleable materials and loss of ceramic waste quantities from the mixtures during shearing.

The results indicate that the sole compaction of ceramic-wastes (Cs^0) has the lowest strength density of 1.21MPa, in comparison with the progressive linear density of specimens with addition of clay and kaolin as stabilisers. Specimen 10 (Sp^{10}) has a higher resistance of 2.39MPa during compressive loading and an increase in the combination of clay and kaolin volume from 50% upward (Sp^{11-15}) caused a low linear strength and weaken the interfacial zones of the specimens. Sp^{10} demonstrated that ceramic wastes have a significant impact on compressive strength of fired clay bricks and can be reused for environmental sustainability (Fassbinder, 2002; Liu, *et al.*, 2019; Hossain and Roy, 2020). Although the wastes have a low strength when solely used, the trend of results in the chart assured appreciable improvement in the workability and durability of the material when properly mixed with clay and kaolin. The loss of strength at 5-25% (Sp^{1-5}) of equal kaolin and clay mixtures identified the importance of plasticity of clay as a stabiliser in the fired clay-brick compositions

(Ozturk, *et al* 2024). The results corroborate (Bhogilal and Tejas, 2018; Siddique, *et al.*, 2019; Huseien, *et al.*, 2020) submissions that ceramic wastes improve reactivity as an aggregate material in the brick derivation.

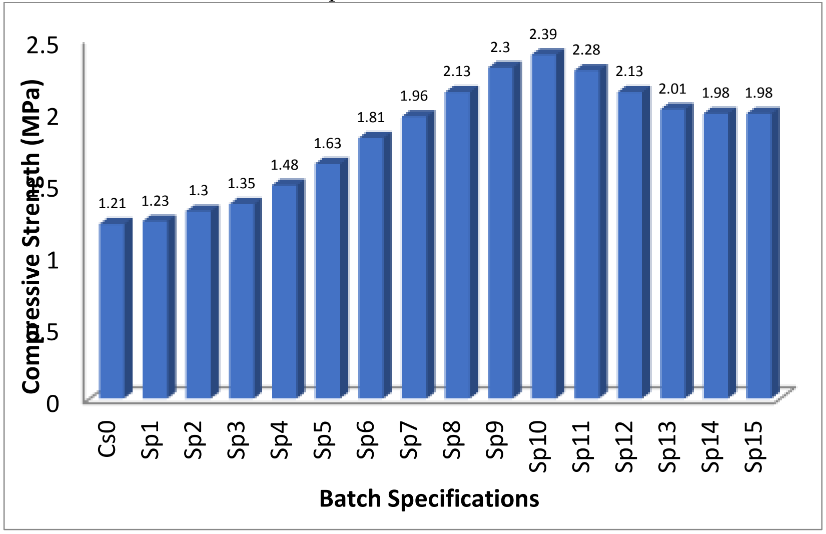

Fig. 4: Compressive Strength of Fired Brick Specimens

Conclusion: The properties' characterisation of ceramic wastes as material for fired clay bricks were examined through shrinkage rate, water absorption rate and compressive strength test. The examination was to reduce these wastes impact in landfilled pits and promote reuse and recycling practices for environmental sustainability. The study has provided good information on oxide properties of ceramic wastes and significantly unveiled the wastes as material that can reduce the shrinkage level of clay-brick and reveal the positive effect of ceramic wastes on fired clay bricks' strength and water absorption rate when proportionally substituted with clay materials. However, the study provides an avenue for solving heat-transmuted ceramic waste disposal challenges and unveils the potential to boost the products of waste recycling industries, enhancing technological and economic growth. Finally, it contributed to the knowledge of ceramic waste properties and established invaluable reference materials for the recycling practice and scholarship.

Declaration of Conflict of Interest: The author declares no conflict of interest.

Data Availability Statement: Data are available upon request from the author or corresponding author.

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