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COMPARATIVE ANALYSIS OF INCORPORATION OF DIFFERENT PARTICLE SIZES OF HIGH-LEADED CATHODE RAY TUBE GLASS IN FIRED CLAY BRICKS

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ABSTRACT

End-of-life cathode ray tubes (CRTs) have become global problem in the pool of waste electrical and electronics owing to higher concentration of lead (Pb), and this needs urgent management in an ecofriendly manner. In this study, spent CRT glass was incorporated in clay to make burnt bricks for construction. Samples of CRT glass were collected from technicians' workshops, manually dismantled, pulverized, milled, and sieved into three particles sizes (PS), namely, 0.6mm ≤1.0mm, ≤2.0mm. The metallic composition was determined with Inductive Coupled Plasma- Optical Emission Spectrometric technique (ICP-OES). Each PS was mixed with clay at percentages ranging from 0% as control to 15% CRT and molded using dry compression technique, dried and fired in furnace at 800 0C. Mechanical properties of fired bricks products were assessed including water absorption, linear shrinkage, and compressive strength. The 4wt% CRT-clay composition for ≤0.6mm PS exhibited highest strength with low linear shrinkage and medium water absorption and was selected as optimum composition. Lead (Pb) leachability from fired CRT-glass/clay from the three particle sizes using TCLP and SPLP were within permissible limit of 5.0mg/L set by US-EPA. Lead leachability from raw CRT glass varied according to particle sizes and was for all particles sizes higher in many folds than to EPA limit. From the findings, it can be shown that the optimum composition of less than 0.6mm particle size is of good quality, durable and environmentally safe bricks that can be used for building construction works.

Keywords: Cathode Ray Tube Glass, Incorporation, Fired Clay Bricks, Particle Size.

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1. INTRODUCTION

Management of waste electrical and electronic equipment (WEEE) otherwise called e-waste is a challenge of global concern. E-waste arises from a wide spectrum of electrical and electronic products incorporated with both valuable (e.g. gold, silver, palladium, platinum, etc.) and hazardous substances (e.g. lead-containing glass, mercury, cadmium, batteries, plastics with flame retardants, etc.) with economic potential and deleterious environmental impact, respectively EC (2003), Tsydenovia and Bengtson (2011).

Cathode ray tubes (CRT) was the technology used in most televisions and computer display screens for viewing images in these devices Nnorom and Osibanjo (2010a), Nnorom et al. (2010b). Rapid advances in the 21st century technologies led to the replacement of leaded-CRT-containing televisions and monitors with new products such as Liquid Crystal Display (LCD) and Plasma Display Panel Xu et al. (2012). A typical CRT consists of 85% glass, in which

65% is panel, 30% funnel and 5% neck glass (Yu, et al., 2016), Andreola et al. (2007). A typical CRT computer colour monitor/TV is composed of a plastic casing, a CRT, a deflection yoke, a printed wiring board (PWB), connecting wires, and various types of metals. The CRT contains two types of glass: panel glass and funnel glass. Panel glass is in the front part of the CRT and makes up about two-thirds of its weight. Funnel (cone) glass, which makes up most of the other third, contains about 25% lead (as lead oxide) to shield viewers from the radiation produced by the electron gun. Menad (1999), Andreola et al. (2005), Nnorom et al. (2011). The chemical composition varies between the panel and funnel glass, which need to be treated as lead-free glass and leaded glass respectively Mear et al. (2006). Lead is purposely used in the CRT manufacture in the form of lead oxide used to provide the necessary shielding from x-rays generated within the operating CRT Musson et al. (2000).

Because of the high replacement rate with newer technologies, difficulty in recycling the glass and high disposal cost, CRT glass component of e-waste is gradually becoming a waste of serious global concern. Currently, several studies have been done on sustainable management of CRT glass. Waste CRT glass has been used as raw material aggregate in the production of high strength mortars Maschio et al. (2013), Iniaghe and Adie (2015) as an additive in ceramic industry for the production of high insulating foam glass (Guo et al. (2010), Konig et al. (2015), utilized as substitute for frit in transparent glazes for ceramic tiles with comparable mechanical properties with the standard ones Revelo et al. (2018), as a replacement for river sand in the high-density concrete Zhao and Wei (2011), Zhao et al. (2013). Similarly, feasible studies had been conducted by incorporating cathode ray tube glass in clay bricks and roof tiles Dondi et al. (2009). Furthermore, Guo et al. (2010) observed that high mechanical properties such as compressive strength and bending strength result in the preparation of high strength foam glass-ceramics from waste cathode ray tube as a raw material. This study evaluated the incorporation of CRT-glass of different particle sizes (0.6mm ≤1.0mm ≤2.0mm.) in fired clay bricks with the intention of immobilizing the Pb in the glass.

2. MATERIALS AND METHODS

2.1. SAMPLE COLLECTION

Eight samples of obsolete coloured television CRTs of different brands were obtained from scrap shops in Ibadan metropolis, Nigeria (Figure 1). These were dismantled manually into their various components. The glass components were further dismantled into panel, neck, and funnel. The funnel, neck, and frits components with higher concentration of Pb and classified as hazardous materials were crushed manually and pulverized into particles sizes ranging from less than 0.6mm-2mm using a locally fabricated hammer mill with stainless steel crushers. The pulverized CRT was sieved using 0.6mm, 1.0mm and 2.0mm BS sieve mesh sizes to obtain the three particles' sizes. The brick clay sample was obtained from an artistic shop in Ibadan. The clay was air-dried, crushed, and sieved to fine powdered form. The raw clay and CRT glass were characterized using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) to determine the elemental composition of the raw materials.

Figure 1 Cathode ray tube from Television

2.2. MIX PROPORTION CRT GLASS-TO-CLAY

The sample cylindrical test probes with 25mm internal diameter, 3.0mm thick and. height 45mm were made from CRT- glass/ clay of different proportions as indicated in Table 1. Five different mix proportions were prepared for each size by incorporation of pulverized CRT into 0% (100% clay), 2%, 4%, 6%, 10% and 15% CRT –glass replacement.

Table 1 Mix Proportions for Clay and CRT-Glass

CRT Composition (%)	Weight of Clay (g)	Weight of Glass (g)	Volume of water (mL)	CBR Maximum Force (Kilonewton, KN)
0	34	0	8.2	0.42
2	33.3	0.7	7.4	0.44
4	32.6	1.4	7.2	0.52
6	32	2	7	0.6
10	30.6	3.4	6.8	0.46
15	28.9	5.1	6.4	0.66

2.3. PREPARATION OF SAMPLES

Seven replicate samples were prepared for each composition and for each particle size giving a total of 126 test probes for all the six compositions and three particles' sizes (Table 1). Clay and CRT glass were premixed for 1-2 minutes continuously to obtain uniform and homogenized sample composition. Then, appropriate quantity of water (Table 1) was added to the mixture to enhance compactness when moulding. The water was carefully sprinkled on the mixture on varied quantity based on percentage composition of the raw materials. Quantity of water was observed to reduce with increase in CRT-glass addition. Each wetted and homogenized mixture was kneaded using lightly lubricated cylindrical iron mould and compacted using ELE International multiplex 50CBR machine to give a cylindrical test probe that assumed the shape of the mould of dimension 25mm internal diameter, 3.0mm thick and. height 45mm. The force used varied between 0.42 – 0.66 N/mm^2. After moulding, the test probes were removed from the mould and weighed while the diameter and length were also measured. This process was repeated to make all the test probes. After moulding, all the test probes were oven dried at 105 ^{0}C for 24 hours after which all water was judged to have evaporated. The dry test probe was muffled in an AAF 1100 Carbolite Electric Furnace reaching an elevated temperature of 800 ^{0}C. The temperature of the furnace rose from room temperature to maximum temperature of 800 ^{0}C in approximately 2 hours and was maintained for one hour before cooling to room temperature overnight.

2.4. ANALYSIS OF MECHANICAL PROPERTIES OF FIRED TEST PROBES

In each of these analyses, five replicate samples were used.

1) Linear Shrinkage: The linear shrinkage was determined by measuring the length and diameter of the test probes before and after firing. The formula for calculating Linear shrinkage was:

$$\text{Linear shrinkage} = \frac{Length\ before\ firing - Length\ after\ firing}{Length\ before\ firing} \times 100$$

2) Water Absorption: Water absorption capacity of the test probes was done in two ways according to ASTM specifications. They were 24 hours cold immersion and 5 hours boiling test. The 24-hour cold immersion method involved taking the weight of the test probes before soaking in cold water and after soaking and determining the difference. Water absorption was calculated thus:

$$\text{24hours soaking} = \frac{Mass\ after\ 24hours\ soaking - Dry\ mass\ in\ air}{Dry\ mass\ in\ air} \times 100$$

The 5-hour boil water absorption test was carried out on the test probes after 24-hour cold immersion test. The test probes were boiled in hot water for a period of 5 hours, a test that ensures that all the channellings that were not filled with water during immersion would be as water penetrated the material in the vapour form. The samples at this stage were allowed to cool for 24 hours to room temperature. This water absorption was calculated as follows:

$$\text{5hours boiling} = \frac{Saturated\ mass\ after\ 5hours\ boil - Dry\ mass\ in\ air}{Dry\ mass\ in\ air} \times 100$$

3) Bulk Density: This was done by determining the mass of each test probe in an analytical balance, the diameter and length of the probes were determined with micrometre gauge and ruler respectively while exterior volume was measured by attaching test probes to rope string and submerged in water inside a measuring cylinder filled to a known mark operates based on the Archimedes principle. The volume of displaced water in the container is recognized as suspended mass of the test probes. These were removed from water and lightly blotted with dried-cotton cloth to get rid of water at the surface and the saturated mass was determined on analytical balance after 5 hours boil. The exterior volume and bulk density were thus calculated as:

Exterior volume = suspended mass after 5hours boil – saturated mass after 5hours boil

$$\text{Bulk Density} = \frac{Dry\ mass\ in\ air}{Exterior\ volume}$$

4) Compressive Strength: The compressive strength is the maximum resistance of the fired test probe to a gradually increasing load (force) applied at a right angle to the bearing surface of the clay products. Compressive strength was carried out using ADR Touch 2000 standard compression machine. The formular for calculating the compressive strength was:

$$\text{Compressive strength } (N/mm^2) = \frac{Maximum\ Load\ by\ the\ machine}{Cross-sectional\ area\ of\ the\ specimen}$$

2.5. ACID DIGESTION METHOD (EPA3050B)

Total recoverable metals were determined using the EPA 3050B method Silva et al. (2013), Olubanjo et al. (2015). It is a very strong acid digestion that will dissolve almost all metals that could become environmentally available. The process of acid was carried out by taking 1.000g of the sample and added into a polypropylene digestion tube and 10 mL of 1:1 HNO_3(70.5% Analar grade) was added to make the slurry, covered, and transferred to water bath and was heated to about 95±5 ∘ C and refluxed for 15minutes without boiling. This sample was allowed to cool, then 5.mL concentrated nitric acid was added, heated for 30 minutes, and later allowed to cool. More of 5 mL concentrated nitric acids were added at a time until no more brown fumes were generated. Afterwards, the sample was allowed to cool and 10 mL aliquot of 30% hydrogen peroxide was added, and this was heated for 2 hours without boiling. Again, 5 mL of concentrated HCl (35.4% Analar grade) was added and heated for another 15 minutes. The sample digest was allowed to cool, filtered through a Whatman No 1 filter paper and the filtrate was collected in a 100 mL standard flask and made up to the mark with distilled water. The sample filtrate was analysed for Pb using Buck Scientific 205 Atomic absorption spectrophotometer (Buck Scientific, Inc, East Norwalk, Ct., USA). This was repeated for all samples and blanks.

2.6. TOXICITY CHARACTERISTICS LEACHING PROCEDURE (TCLP) METHOD

The TCLP test was conducted on the fired materials to evaluate the level of immobilization of Pb in the glassy lattice of the fired product. This leaching test was carried out following the EPA 1311 (EPA (1996) designed to simulate land fill condition. Twenty grams (20g) of the crushed particles were taken into the polypropylene extraction vials and leached with 400 mL of the extraction fluid which comprised acetic acid and sodium hydroxide solution at pH 4.92. The mixtures were agitated for 18 hours on a locally fabricated rotary shaker at 30±5rpm. The mixtures were filtered after shaking and Pb was determined using calibrated Buck Scientific 205 flame atomic absorption spectrophotometer ((Buck Scientific, Inc, East Norwalk, Ct., USA).

2.7. SYNTHETIC PRECIPITATION LEACHING PROCEDURE (SPLP) METHOD

The SPLP was carried out according to EPA 1312 EPA (1996) method. The extraction fluid consisted of two acids mixture prepared by mixing sulphuric (H_2SO_4) acid and nitric acid (HNO_3) in the ratio of 6:4 (w/w) to mimic rainwater in case the fired products were exposed to it. Twenty grams each of the fired products were weighed after crushing into polypropylene extraction vessels and 400 mL (indicating a 1:20 ratio) of the SPLP extraction fluid were added and corked. Agitation was done as for TCLP for 18 hours at 30±5rpm and the leachate were filtered and analysed as in TCLP.

2.8. QUALITY CONTROL/ASSURANCE PROTOCOL

Adequate precautions and quality assurance procedures were maintained to ensure valid and reliable results. Samples were handled with care from the primary source, dismantling stage and stored in a clean washed sack. All plastic containers, glassware and grinders used were thoroughly washed, rinsed in distilled water, and soaked in dilute Analar grade nitric acid (70.5%) overnight, rinsed with distilled water and air-dried before use. Sample preparations were done in a clean environment to avoid cross-contamination even at analysis stage and replicate samples were made for the test probes. All chemicals used were of Analytical grade: HNO_3 (70.5%), HCl (35.4%), H_2O_2 (30%), H_2SO_4 (98.0%), glacial acetic acid (99.85%) and reagents were prepared using distilled water. Reagent blank determinations were carried out to check analyte impurities in the reagents Instruments were calibrated with standard solutions of analyte before analysis. Check standard was run after every ten samples injections

3. RESULTS AND DISCUSSION

3.1. CHEMICAL CHARACTERIZATION OF RAW MATERIALS

Table 2 Characterization of Raw Clay and CRT (mg/kg)

Elements	Clay	CRT
Calcium	159	857
Magnesium	661	230
Potassium	86.8	208
Sodium	393	485
Manganese	98.5	81.2
Iron	289	215
Copper	12	8.97
Zinc	85.7	87.8
Boron	953	1410
Phosphorus	296	221
Aluminum	851	635
Sulphur	37	27.6
Silicon	2210	1650
Arsenic	0.6	0.45
Vanadium	8.16	8.36
Lead	BDL	11600

BDL - Below Detection Limit

The level of elemental composition of the raw clay and CRT glass were presented in Table 2. The major constituents that made up the clay were Silicon, calcium, boron, and aluminium while the minor constituents were sodium, potassium, zinc, iron, phosphorus, lead and manganese. Some of the elements occurred at trace level such as vanadium, Arsenic, and copper. Elemental composition of CRT glass consisted of Silicon as a result of amorphous silicate salt of the glass which will be a good binder with clay-CRT glass admixture, calcium, boron and aluminium resulting from its mineral contents.

3.2. TECHNOLOGICAL PROPERTIES OF THE TEST BRICKS

The partial substitution of clay with waste CRT glass had puzzling effects on the mechanical properties of the clay bricks depending on both the composition and the granulometric characteristics of the clay Dondi et al. (2009). Mechanical tests of bricks are imperative tool for assessing the degree of maturation and structural properties of brick bodies and the properties include total linear shrinkage, water absorption capacity, compressive strength, bulk density, saturation coefficient among others.

Linear Shrinkage

The results of total linear shrinkage of CRT glass incorporated in clay bricks obtained from drying and firing at temperature of 800^{0}C for the three particle sizes of less than 0.6mm, 1.0mm and 2.0mm are presented in Table 3. Beal et al. (2019) reported that linear shrinkage is an important property of clay bricks while high linear shrinkage could cause cracks, stress and breaks the brick as water evaporates the bricks during drying and firing as a consequent of shrinking of the clay bricks. From the result, it can be shown that the minimum average shrinkage was observed at 2% (3.53±1.42), 4% (3.87±1.58) and 6% (5.99±0.17) in the particle size of less than 1.0mm, 0.6mm and 2.0mm respectively. The highest average shrinkage was exhibited in the 15wt% (7.43±1.46) of less than 1.0mm particle size with reduction from the control value. Evidently, the trend of shrinkage in the clay products was irregular across the three particle sizes because of factors like position of material in the furnace during firing, firing temperature and dry compression process effect during moulding among others Adie and Osibanjo (2013). It is observed that the average total linear shrinkage of all CRT incorporated clay bricks within the whole range of the particle sizes were below the control (100%) clay sample with average shrinkage of 8.05±1.31wt%. Reduction in the linear shrinkage of the current study is in accordance with the study by Zhao et al. (2013) and this is a function of proportional decrease in particle size and content of glass in clay bodies.

Table 3 Total linear shrinkage of the particle sizes

Composition (%)	0		2		4		6		10		15	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
<0.6mm	8.05	1.31	4.57	1.14	3.87	1.58	7.07	1.14	5.92	0.08	4.58	1.82
<1.0mm	8.05	1.31	3.53	1.42	5.39	3.85	6.55	0.19	5.88	0.18	7.43	1.46
<2.0mm	8.05	1.31	6.03	0.2	6.99	5.35	5.99	0.1	6.03	0.25	6.15	0.1
n = 5												

Apparent Porosity and Bulk Density

Apparent porosity is the degree of open pores that were present in clay-CRT products which largely related with bulk density and water absorption. Variations of apparent porosity and bulk density values for the percentage compositions of the particle sizes were presented in Table 4 and Figure 1 respectively. Obviously, the immobilization of waste CRT glass in the clay bricks influences the porosity and bulk density of the clay bricks. Greater porosities were generally achieved as the proportions of the glass were increased across the three particle sizes in agreement with the study by Beal et al. (2019), but decreased down the trend as more waste CRT glass was added. From the result in the Table 4, he averages apparent porosity of 2wt% CRT-clay composition of the particle sizes was in the order of 17.1±0.87 < 20.4±0.92 < 20.4±0.40 in comparison with 18.2±0.18 of control clay sample value. The larger particle size of CRT glass incorporated in the clay bricks of similar content imparted porosity on the test probes which gave rise to higher water absorption and commensurately decreased the bulk density of the brick as established on Figure 2. Conversely, the various proportion of the CRT glass in the bricks of the same particle size from 2-6wt% of the three particle sizes, with exception of 2.0mm particle, have higher apparent porosity than the control sample. While the 10-15wt% with slight reduction which is an indicator of more compaction within the structure of the brick. Similarly, the lowest value of apparent porosity was obtained at 15wt% of particle size 2.0mm and the highest porosity was obtained at 2wt% of 1.0mm particle size which implies that the content composition and particle size of the CRT glass in clay are determinant factors of apparent porosity and water retention capacity.

It has been emphasized that bulk density is related to apparent porosity and water absorption that determine the durability of the bricks. As shown in the Table 5, the bulk density decreased with increasing amount of waste CRT glass, although irregular in pattern, with concomitant increase in open pores and absorption of water which infiltrates into the porous channel in the bricks exerted by the glass. Abdeen and Shihada (2017) reiterated that density of clay brick depends on the specific gravity of the raw materials, method of manufacturing and degree of burning. The bulk density of waste CRT glass in clay bodies were in the range of 1.67-1.73g/cm^3, 1.66-1.71g/cm^3 and 1.67-1.73g/cm^3 for the less than 0.6mm, 1.0mm and 2.0mm particle sizes respectively. This has shown slight reduction in the bulk density of all the compositions in the three particle sizes from the control sample of 1.74g/cm^3 value. In the same vein, the resultant effect of particle size on the bulk density contributed no any measurable change has also shown with the composition. Consequently, the addition of finer CRT glass relatively improves the bulk density as compared to coarse particle sizes as presented in Figure 2. Raw clay type and manufacturing process affect brick bulk density which could vary between 1500-2400kg/m^3 (1.5-2.4g/cm^3) as the minimum requirement for fired clay products in Adie and Osibanjo (2013) for building purposes. The density of bricks influences the weight of fired bricks and the variations in weight have implications on structural, acoustical, and thermal design of the construction wall Grim (1996).

Table 4 Apparent Porosity of the three particle sizes

Composition (%)	0		2		4		6		10		15	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
<0.6mm	18.2	1.89	17.1	0.87	18.9	0.32	19	0.62	17.6	0.34	18.7	1.12
<1.0mm	18.2	1.89	20.4	0.92	18.8	0.95	19	0.65	17.4	0.6	17.4	0.44
<2.0mm	18.2	1.89	20	0.4	18.7	0.3	17.3	0.3	17.3	0.8	16.6	0.4

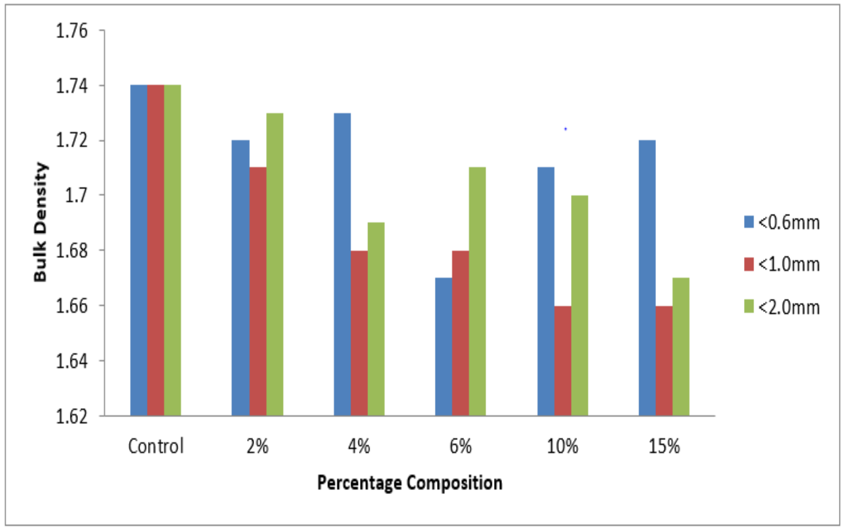

Figure 2 Bulk Density of the particle sizes

Water Absorption

Water absorption is a special property that deals with resistance to water sorption capacity and the durability of the clay brick materials. The amount of water to be absorbed by brick largely depends on the porosity of the structure and its density. Figure 3 presented the results of water absorption capacity in all the compositions and particle sizes obtained from 5-hour boil test. From the results, it can be noted that the 2, 6 and 10wt% compositions of less than 0.6mm had higher resistance to water compared to the reference clay brick (0% CRT) of 10.4±1.19 as shown in the figure. The two other compositions of the same particle size have higher water absorption value than the reference brick. Whilst the water absorption of 1.0mm and 2.0mm particle sizes in the 6-15wt% compositions were in the same or slightly less than the reference clay value. Increasing the waste CRT glass content in the bricks reduced the water absorption and the less porous structure obtained and this was in agreement with the studies of Abdeen and Shihada (2017), Hameed et al. (2018). This may be due to reduction in the amount of clay and higher proportion of CRT glass which imparted water permeability and more compaction in brick. On the contrary, the higher water absorption capacity had strong relation to the volume of the open porosity and lower densification of the clay brick indicating the high infiltration of water into the brick bodies. The result of higher water absorption for CRT glass incorporated in clay brick was supported by Loryuenyong et al. (2009) who attributed it to the increasing amount of open pores, influenced by some glass particles oozing out onto the brick surface. It was also reported that this will consequently lower the bulk density and apparent porosity as observed in some compositions in this research.

However, the effect of particle size variation brought decrease in water absorption of the fired bricks, although this did not follow a regular pattern, then the coarser the particle size with higher resistance to water sorption compare to finer particle size. This finding is analogous to the study of Ling and Poon (2012) that particle size of CRT glass has more pronounced effect on the water absorption capacity of concrete mortars. Variation in water absorption is mainly due to variable raw materials and manufacturing process of the bricks.

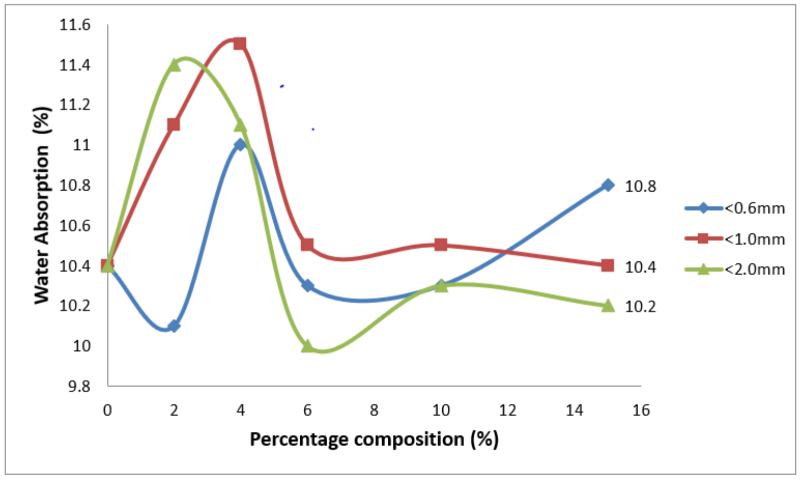

Figure 3 Water absorption capacity of the three particle sizes

Compressive Strength

The compressive strength is the most common test conducted because most of the desirable characteristics of brick and the structural design purpose are related to compressive strength. Figure 4 depicted the compressive strength results of the CRT immobilized fired clay products. Carefully looking into the detail, addition of CRT glass appreciably improves the workability and durability of the clay bricks with increasing strength. It is obvious that the compressive strength of the percentage compositions in the three particle sizes were above the reference clay brick (5.08±1.14MPa) with exception of 2wt% and 15wt% CRT in less than 0.6mm and 1.0mm with a lower average strength of 4.57±1.35MPa and 3.79±1.63MPa respectively. The highest compressive strength was found among the 0.6mm particle size with 4wt% CRT composition (8.35±1.64MPa). The significant increase in compressive strength can be as a result of better particle size distribution that enhances more sealed pores within the fired clay bricks. Particle size and glass composition did not show any significant influence in the compressive strength of the clay bricks as shown in Figure 4. The trend shown by compressive strength demonstrated that glass addition imparted largely on the strength of the fired bricks and other mechanical properties of the test probes. Generally, the clay bricks produced by this work on addition of CRT glass showed compressive strength values slightly lower than the Class 3 Grade bricks minimum requirement set out according to the American Standard ASTM C62 (2006). The three most fundamental and unique characteristics according to Adie and Osibanjo (2013) that determine the grade and durability of fired brick products used for building purposes were water absorption (WA), total linear shrinkage (TLS) and compressive strength of the products. It was noted that effect of CRT glass replacement in clay bricks on those three mechanical parameters were most positive in the 4wt% (CRT) composition of less than 0.6mm particle size and was selected as the optimum composition. This composition had shown a maximum average compressive strength of 8.35±1.64Mpa, lower shrinkage of 3.87±1.58% and insignificant resistance to water absorption. The reason may be adduced to better particle size distribution, good manufacturing process and firing position in the furnace. When comparing the optimum composition with American Standard, it was observed that the optimum possesses the attributes of Class grade 1 in relation to water absorption and saturation coefficient, Class 2 grade for total linear shrinkage. The compressive strength of the optimum brick was in consonance with Class 3 grade (Table 5) which makes the brick suitable and acceptable as constructional material for some purposes in less severe and negligible environmental conditions.

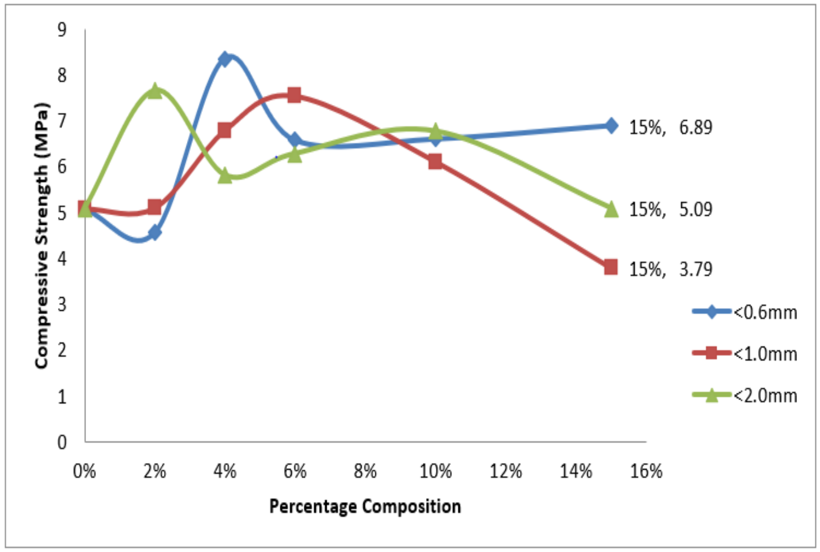

Figure 4 Compressive Strength of the three particle sizes

3.3. LEACHING TESTS

Leaching tests were conducted to evaluate the inertization of lead (Pb) in the fired clay bricks incorporated in highly leaded cathode ray tube glass and to verify the safety and environmental fitness of the brick products. The result performed on the leachate solutions of the Clay-CRT-glass to determine the total recoverable lead in the fired test bricks immobilized with CRT for the three particle sizes were presented in Table 5 using Toxicity characteristics leaching procedure, synthetic precipitation leaching procedure and acid digestion method 3050B. The amount of leachable lead using TCLP solution for 0.6mm particle size was below detection limit of 0.01mg/L of AAS used and the highest concentration of 0.06 mg/L was shown by 15wt% CRT composition. Undoubtedly, the concentration of lead (Pb) leached for all the compositions were all within the safe permissible limit of 5mg/L by USEPA. It was indicated that the total recoverable lead in the CRT glass leached with TCLP solution varied with particle size in the order 69.6, 50.9 and 45.7mg/L in increasing size order (0.6: 1.0: 2.0 mm) and these were extremely far beyond regulatory permissible limit. This implies incorporation of leaded-CRT in fired bricks is a veritable and sustainable method of immobilising Pb in the the CRT glass. The fired products were seen not to pose any threat when disposed in a municipal landfill. Similarly, the result of synthetic precipitation leaching procedure for the CRT glass and fired products were below safe regulatory limit by USEPA and the compositions between 2-6wt% were below detection limit. These results established that the optimum and other compositions could therefore be classified as safe and non-hazardous construction materials which cannot pose any environmental and health risk.

Table 5 Comparison of Optimum (4%) composition with ASTM Standards

Parameters	Class 1	Class 2	Class 3	Optimum
Water Absorption (%)	≤ 20	≤ 22	No limit	11.0 ± 0.39
Total Linear Shrinkage (%)	≤ 3.125	No limit	No limit	3.87 ± 1.58

Compressive Strength (MPa)	≥ 20.7	≥ 15.5	≥ 10.3	8.35 ± 1.64
Saturation Coefficient	≤ 0.75	≤ 0.88	No limit	0.81 ± 0.01

4. CONCLUSION

This study compares the quality of fired clay brick products arising from incorporation of three particles sizes (0.6, 1.0 and 2.0 mm) of highly-lead CRT glass of three different particle sizes The chemical and technological properties indicated replacement of 4 wt. % CRT of 0.6 mm particle size as the optimum. All compositions were within the EPA limit of 5 mg/L for both TCLP and SPLP tests Furthermore, lower particle sizes enhanced the workability, durability, and long-term mechanical performances of clay bricks incorporated with CRT glass while higher particle size showed high water resistance. The results also presented that with proper firing at elevated temperatures, waste CRT glass addition of up to 15% could immobilise Pb with leaching within set limits by regulatory agencies. The optimum composition was noted to meet the minimum requirements for load-bearing application for construction.

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