IMMOBILIZATION OF HIGH-LEADED CATHODE RAY TUBE GLASS IN FIRED CLAY BRICKS BY RECYCLING

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ABSTRACT

End-of-life cathode ray tubes (CRTs) have become global concern in the pool of electrical and electronics waste owing to higher concentration of lead (Pb), and this needs urgent management in an eco-friendly 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 particle 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 moulded using dry compression technique, dried and fired in furnace at 800°C. 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. The total recoverable lead (Pb) from optimum test composition was 96mg/L or 96,000 mg/kg that exceeded the permissible 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, Immobilization, Clay Bricks.

1. INTRODUCTION

Waste Electronics and Electrical Equipment otherwise called e-waste is a ubiquitous challenge of global concern. E-waste encompasses wide range of products containing both precious and hazardous substances such as gold, silver, palladium, platinum, plastics, lead-containing CRT glass, mercury, cadmium, batteries, flame retardants, printed circuit boards (PCBs) among others with economic viability and deleterious environmental impact EC (2003), Tsydenova and Bengtson (2011).

Cathode ray tubes (CRT) are the technology used in most televisions and computer display screen which are the viewing portions of these devices Nnorom et al. (2010b). Rapid improvement in this 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
A cathode ray tube (CRT) computer color monitor/TV is composed of a leaded-CRT, a deflection yoke, a Printed Wire Board, a plastic casing, connecting wires, and other metals. Cathode ray tube (CRT) displays consist of 85% glass, in which 65% is panel, 30% funnel and 5% neck glass. The panel glass which is the front part (screen) of the CRT is made primarily of barium strontium glass (up to 12% barium oxide and up to 12% strontium oxide) whose weight is about two thirds of the whole CRT while the funnel is a lead glass (containing ~ 25% lead oxide) whose weight is around one third of the whole CRT shield the viewers from radiation from electron gun. The neck of the CRT which envelopes the electron gun consists of a glass with very high lead content (up to 40% lead oxide) while the frit consists of a low melting lead glass (up to 85% lead). Lead is purposely used in the CRT production in the form of lead oxide used to provide the necessary shielding from radiation generated in form of X-rays within the operating CRT. 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, as an additive in ceramic industry for the production of high insulating foam glass, utilized as substitute for frit in transparent glazes for ceramic tiles with comparable mechanical properties with the standard ones, as a replacement for river sand in the high-density concrete, as a replacement for frit in transparent glazes for ceramic tiles with comparable mechanical properties with the standard ones, utilized as substitute for frit in transparent glazes for ceramic tiles with comparable mechanical properties with the standard ones, as a replacement for river sand in the high-density concrete, as a replacement for river sand in the high-density concrete, as a replacement for river sand in the high-density concrete, as a replacement for river sand in the high-density concrete, as a replacement for river sand in the high-density concrete, as a replacement for river sand in the high-density concrete, as a replacement for river sand in the high-density concrete, as a replacement for river sand in the high-density concrete, as a replacement for river sand in the high-density concrete, as a replacement for river sand in the high-density concrete, as a replacement for river sand in the high-density concrete, as a replacement for river sand in the high-density concrete. 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 glass 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 aim of immobilizing the Pb in the glass.

2. MATERIALS AND METHODS

2.1. SAMPLE COLLECTION

Samples of eight obsolete coloured television cathode ray tube glass (CRT) of different brands of product were obtained from scrap shops in Ibadan metropolis, Nigeria. 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 to 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 chemical composition of the raw materials.
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.

| %CRT Composition | Weight of Clay (Kg) | Weight of Glass (Kg) | 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 different 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/mm². 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 °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 °C. The temperature of the furnace rose from room
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:

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

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:

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

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 channelings 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:

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

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 micrometer 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:

\[
\text{Exterior volume} = \text{suspended mass after 5 hours boil} - \text{saturated mass after 5 hours boil}
\]

\[
\text{Bulk Density} = \frac{\text{Dry mass in air}}{\text{Exterior volume}}
\]
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 formula for calculating the compressive strength was:

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

2.5. **ACID DIGESTION METHOD 3050B**

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 1g of the weighed sample and added into a polypropylene digestion tube and 10mL of 1:1 HNO₃ (70.5% Analar grade) was added to make the slurry, covered and transferred to heating device and was heated to about 95±5°C and refluxed for 15 minutes without boiling. This sample was allowed to cool, then 5mL concentrated nitric acid was added, heated for 30 minutes and later allowed to cool. More of 5mL concentrated nitric acids were added at a time until no more brown fumes were generated. Afterwards, the sample was allowed to cool and 10mL aliquot of 30% hydrogen peroxide was added, and this was heated for 2 hours without boiling. Again, 5mL 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 Whatmann No 1 filter paper and the filtrate was collected in a 100mL standard flask and made up to the mark with distilled water. The sample filtrate was analyzed 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**

This 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 landfill condition. Twenty grams (20g) of the crushed particles were taken into the polypropylene extraction vials and leached with 400mL of the extraction fluid which comprises acetic acid and sodium hydroxide solution at pH 4.92 of the desired pH range and corked with the cover. The mixtures were agitated for 18 hours on a locally fabricated rotary shaker at 28rpm. 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 extraction fluid composed of two acids mixture prepared by mixing sulphuric (H₂SO₄) acid and nitric acid (HNO₃) in the ratio of 6:4 (w/w) to mimic rainwater in case the fired products were exposed to it according to EPA 1312 EPA (1996) method. This was carried out by accurately weighing 6g of sulphuric acid and 4g of nitric into a 1L beaker. This solution was used to adjust the pH of distilled
water to pH 5.0 and this formed the SPLP extraction fluid. Twenty grams each of the
fired products were weighed after crushing into polypropylene extraction vessels
and 400mL (indicating a 1:20 ratio) of the SPLP extraction fluid were added and
corked. Agitation was done as for TCLP for 18 hours at 28rpm and the leachate were
filtered and analysed as for TCLP. Quality assurance was ensured by adding blind
samples throughout all the method prior to analysis.

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,
glasswares and grinders used were thoroughly washed, rinsed in distilled water and
soaked in 5% 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 of the 3 PS, leaching extracts for instrumental analysis and
properly labeled. All chemicals used were of Analytical grade: HNO₃ (70.5%), HCl
(35.4%), H₂O₂ (30%), H₂SO₄ (98.0%), glacial acetic acid (99.85%) and reagents were
prepared using distilled water. Reagent blank determinations were carried out to
correct the analyte signal from bias resulting from impurities in reagents or distilled
water. Instruments were calibrated before analysis using various dilutions of
standard solutions of Lead (II) nitrate, Pb(NO₃)₂, readings were taken for the
standards and calibration graph was plotted. Check standard was run after every
ten samples injections and blind samples included in the samples being analyzed.

3. RESULTS AND DISCUSSION
3.1. CHEMICAL CHARACTERIZATION OF RAW MATERIALS

| 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  | 116  |

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 consists 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 qualities 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 frying at temperature of 800 °C for the three particle sizes of less than 0.6mm, 1.0mm and 2.0mm were 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 shrink 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 study of 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 |
|-----------------------------------------------------|
| Compositional (%) | 0 | 2 | 4 | 6 | 10 | 15 |
|--------------------|---|---|---|---|----|----|
| <0.6mm             | 8.05 | 1.3 | 4.57 | 1.1 | 3.87 | 1.5 | 7.07 | 1.1 | 5.92 | 0.0 | 4.58 | 1.8 |
| <1.0mm             | 8.05 | 1.3 | 3.53 | 1.4 | 5.39 | 3.8 | 6.55 | 0.1 | 5.88 | 0.1 | 7.43 | 1.4 |
| <2.0mm             | 8.05 | 1.3 | 6.03 | 0.2 | 6.99 | 5.3 | 5.99 | 0.1 | 6.03 | 0.2 | 6.15 | 0.1 |

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 of Beal et al. (2019), but decreased down the trend as more waste CRT glass were added. From the result in the Table 4, the average apparent porosity of 2wt% CRT-clay composition of the particle sizes was in the order of $17.1\pm0.87 < 20.4\pm0.92 < 20.4\pm0.40$ in comparison with $18.2\pm0.18$ 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 give 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 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 (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).

| Particle Size | 0 | 2 | 4 | 6 | 10 | 15 |
|--------------|---|---|---|---|----|----|
| %            | 18.2 | 18.9 | 18.9 | 18.9 | 18.7 | 18.7 |
| SD           | 1.8 | 0.8 | 0.3 | 0.6 | 0.3 | 1.1 |
| %            | 18.2 | 20.4 | 18.8 | 19.0 | 17.4 | 17.4 |
| SD           | 1.8 | 0.9 | 0.9 | 0.6 | 0.6 | 0.4 |
| %            | 18.2 | 20 | 18.7 | 17.3 | 17.3 | 16.6 |
| SD           | 1.8 | 0.4 | 0.3 | 0.3 | 0.8 | 0.4 |
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 is largely depends on the porosity of the structure and its density. Figure 3 presented the results of water absorption capacity in the 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 impermeability 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 number 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 course the particle size with higher resistance to water sorption compared 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.
Compressive Strength

The most common test conducted to evaluate the desirable characteristics of brick and the structural design purposes 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 do not really 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 C62-899). The three most fundamental and unique characteristics Adie and Osibanjo (2013) that determine the grade and durability of fired brick products used for building purposes were compressive strength (CS), water absorption (WA) and total linear shrinkage (TLS) of the products. It was noted that effect of CRT glass replacement in clay bricks on those three mechanical parameters were more positive and drastic 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 total recoverable lead concentration in the optimum test composition was 96mg/L or 96,000mg/kg which is above toxicity threshold limit concentration of 1000mg/kg. The amount of leachable lead in the TCLP of the compositions for 0.6mm particle size were below detection limit of 0.01mg/L of AAS except 15wt% CRT composition having TCLP value of 0.06mg/L in the leachable solution up to 98.8% lead (Pb) immobilized in the brick. Meanwhile, the TCLP results of 1.0mm and 2.0mm particle sizes of 2-6wt% compositions were also below detection limit but 10-15wt% showed an insignificant concentration of lead (Pb) ranging from 0.03-0.43mg/L. Undoubtedly, the concentration of lead (Pb) leached for all the compositions were far below the safe permissible limit of 5mg/L by USEPA. It was indicated that the total recoverable lead in the CRT glass varied with particle size in the order 69.6, 50.9 and 45.7mg/L in increasing size order and these were extremely far beyond regulatory permissible limit. This implies that the leaded-CRT incorporated fired bricks pose no 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     |

Total recoverable Lead (Pb) from optimum composition was 96mg/L or 96,000mg/kg

4. CONCLUSION

In this research, the work demonstrated the comparative feasibility of immobilization of highly rich lead (CRT) glass of three different particle sizes (<0.6mm, <1.0mm, <2.0mm) in clay bricks ranging from 2-15% CRT compositions as a better approach to manage the CRT glass. The chemical, technological properties and leaching tests of the compositions were measured and assessed in the three particle sizes for comparison. From the experimental study, the 4wt% CRT glass composition in the less than 0.6mm particle size were selected as the optimal composition which gives good quality, durability and workability with high compressive strength and lower linear shrinkage. Findings revealed that lower particle size enhances the workability, durability and long-term mechanical performances of clay bricks and higher particle size showed high water resistance. The results also presented that with proper firing at elevated temperature at 800 °C, waste CRT glass addition up to 15% did not cause any significant deleterious effect to the properties of the clay bricks and these met the minimum requirements for load-bearing application for construction as set by American Standard. Lead (Pb) concentration in the products for both leaching tests was far below the expected regulatory and safe permissible limit of 5.0mg/L by EPA. The clay incorporated CRT glass fired bricks were non-toxic and non-hazardous in the environment. Therefore, the optimum (4wt%, <0.6mm) composition can be recommended and encouraged as better recycling technique of CRT glass and for construction purposes.

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