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USE OF CATHODE RAY TUBE (CRT) COMPOSITE WASTE GLASS FOR NUCLEAR SHIELD TILES

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ABSTRACT
This research is aimed at producing radiation shield tiles from cathode ray tube waste glass, borosilicate waste glass and soda lime silicate waste glass. The waste glasses were sourced for and crushed to powder. The powder was sieved through a 0.25 mm sieved with mesh number 60 and analysed using XRF spectrometer to ascertain their chemical constituents. Twenty-one samples were generated using a 21-point triaxial blend of the three waste glasses. The various samples were poured into moulds, fired in an electric furnace at 1000^{o}C and soaked for an hour. Radiation shielding test using a radioactive source (cobalt 60) was carried out. The radiation shielding tests shows that sample 1 which comprises of 100% CRT had the highest radiation shielding ability with 0.178 cm^{-1} linear attenuation coefficient and sample 21 which is made up of 100% soda lime silicate glass had the least radiation shielding ability with 0.109 cm^{-1} linear attenuation coefficient.According to the 49th NCRP report, conventional tiles HVL for 60-Co gamma is 6.2 cm; whereas HVL for the RST in this work ranges between 3.8-6.3 cm which shows that the RST is within the range of offering a good radiation protection. The results obtained in this study showed that the radiation shielding tiles developed can be used as wall tiles in nuclear power facilities and medical X-ray systems.

Keywords: Cathode ray tube (CRT), composite waste glass, radiation shielding tiles (RST), linear attenuation, radiation, shielding

INTRODUCTION
Cathode ray tubes (CRTs) are the video display components of Televisions (TV) and computer monitors, it is composed of four major parts (Fig. 1); the glass panel (or faceplate), a shadow mask, a glass funnel, and an electron gun. The glass panel is the front of the CRT that is seen when viewing a TV or monitor, the shadow mask is a thin metal sheet with apertures which is positioned immediately behind the glass panel, and the glass funnel is shaped like a funnel and is attached to the back of the glass panel (Ann, 2005; Robert, 2011; Yao *et al.*, 2018). The glass panel and glass funnel are connected using a glass frit solder which serve as support for the electron gun as well as forms the back end (neck) of the CRT. The electron gun produces the electrons that strike the glass panel and produce images that are seen on the TVs or monitors (Inner City Fund (ICF), 1999; Kaliyavaradhan *et al.*, 2022).
One of the benefits of CRT glass-to-glass recycling is the keeping of lead out of the municipal waste stream, this has a significant benefit to the environment considering the high content of lead present in CRT glass as such, in handling this type of glass, it is important to use specialised skills in handling this hazardous material for a green and healthy environment (Cho *et al.*, 2011) and (Maschio *et al.*, 2017). The typical CRT device is made up of between 15 and 90 pounds of glass, this serve as protection to the users from the radiation produced by the electron gun and electron beam deflector (Méar *et al.*, 2006; Zhang & Xu, 2016; Sun *et al.*, 2017). This protective glass can be found in four different components namely panel glass, funnel glass, solder glass and neck glass; the panel glass in the CRT glass which serve as it protective glass accounts for two-thirds of the CRTs weight and contains significant amount of barium oxide, thefunnel glass houses most of the lead in a CRT, the Neck glass surrounds the electron gun and contains lead. Solder glass seals the CRT and is 85 percent lead. While CRT display may be a dead technology, they are by no means gone (Sims Recycling Solution (SRS), 2011; Zeng *et al.*, 2017).

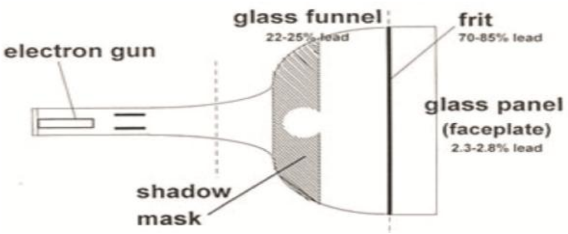

Figure 1: CRT components

Studies have shown that when CRTs are disposed of in landfill sites, lead leach from the CRT glass and contaminate ground water. This is a major driver for CRT recycling as such it is important to reclaim the other materials, such as ferrous and non-ferrous metals and plastics, which are associated with CRTs (Industrial Council for Electronic Equipment Recycling (ICEER), 2004).
CRT glass composition can be categorised based on application which is lead containing and non-lead containing glass. The one used for the funnel, neck

sections and solder glass is characterized by high levels of lead oxide while the other category use for the screen is typically a non-leaded glass that contains high levels of barium oxide for shielding (Jóźwiak-Niedźwiedzka, & Lessing, 2019; Bawab *et al*., 2021). There is considerable variation in the composition of glass, especially panel glass, made by different manufacturers, in addition to this variation, other materials are included in the CRT glass which, including ferrous and nonferrous metals, and coatings to the screen and funnel sections and plastic casing which house the CRTs (Ann, 2005).

Considering other research carried out on the utilization of CRT waste in road pavement, glass ceramics wares, wall cladding, high strength mortars and reinforced concrete beams, little or none used CRT, borosilicate glass and soda lime silicate glass for radiation shielding tiles. Though, several factors such as particle size distribution and differences in composition are to be considered to ensure quality of radiation shielding tiles manufactured from waste glasses. The present study concentrates on the preparation of radiation shielding tiles using CRT, borosilicate and soda lime silicate glasses. The developed radiation shielding tiles were subjected to physical and chemical tests. X-ray fluorescence spectrometer was used to analyze the mineral constituent of the waste glasses and the radiation shielding test was carried out to ascertain their radiation shielding ability. The result gotten would determine the potential application of the tiles.

MATERIALS AND METHODS

Materials and equipment

The materials used for this work were: clay, sand, kaolin, POP, soda lime silicate glass, borosilicate glass, CRT waste glass and groundnut oil. The equipment includes: electric furnace, XRF spectrometer, sieve, mould wooden guide with dimension 10cm x 10cm x 3cm, model wooden guide with dimension 5cm x 5cm x 1cm, metal mortar and pestle, weighing scale, plastic container, spatula, radiation detector, wooden table, cobalt-60 gamma radiation source and lead blocks.

Methods

The recycling steps of CRT glass into material for developing Radiation shielding Tiles (RST) was done in accordance with the study of Azeez *et al.* (2013) and Baalamurugan *et al.* (2021). The steps include the following; Dismantling of waste CRT from a Television (TV) sets,blending of borosilicate and soda lime glass into fine granules,fabrication of tile model, development of mould from model, blending of CRT glass into samples, Sample analysis, firing and property test of the samples.

Modelling

The design of the RST was sketched using coral draw application software (X7). The models were made by compacting clay in a lubricated wooden guide having dimension of 5cmx5cmx1cm for the breath, width and height respectively (Plate I). The models were removed from the wooden guides, and kept away from the sun. Hence, enabling it retain its plastic nature which eases the separation of the model from the mould.

Plate I: Development of RST model

Plate II: Separating the models from the moulds

Moulding

The moulds were made from Sand, Kaolin and Plaster of Paris (POP) in ratio 2:3:5 respectively (Plate II). The moulding materials were mixed thoroughly using a manual table mixer until it became homogenized. The homogenous composite of sand, Kaolin and POP was mixed with water in a ratio of 3:2 respectively; the mixed mould composite materials were gradually poured into the measured water in the bucket. Hence, the mixing of the moulding materials and water were done by hand, until the mixture became homogenized. The models were lubricated using oil and fenced with a wooden guide before the pouring of the moulding materials into it. The oil makes the separation of the model from the mould easy. The mixed moulding materials were poured unto the fenced and lubricated models and left for about 15 minutes for it to set and take the shape and size of the models. Hence, the models were carefully removed from the moulds with a spatula as shown in Plate 2 and were left to dry at room temperature.

Preparation of samples

The CRT waste glass (Plate III), soda lime silicate glass (Plate IV) and borosilicate glass (Plate V) were sourced from refuse dumps and were upgraded by washing using water for the purpose of removing dirts, stains, paint, or any matter from the CRT waste glass. The

CRT, Borosilicate and Soda lime Silicate Glasses were pulverised into discrete sizes using a crushing machine. The pulverised waste glasses were sieved through a 0.25 mm sieved with mesh number 60 (British standard) and analysed using XRF spectrometer to ascertain their chemical constituents. Twenty-onesamples were generated using a 21-point tri-axial blend (Figure 2), the waste glasses were coded at the different corners as specimen A, B and C with CRT coded as specimen A, Borosilicate Glass as specimen B, and Soda-lime Silicate Glass as specimen C while the flow along the vertices is then 80/20, 60/40, 40/60 and 20/80, respectively. Hence, 40 grams of waste glass was used at each corner. Thereby, 100% equals 40 grams, 80% of 40 grams was 32 grams, 60% was 24 grams, 40% was 16 grams and 20% was 8 grams. Each sample was poured into different moulds (Plate VI).

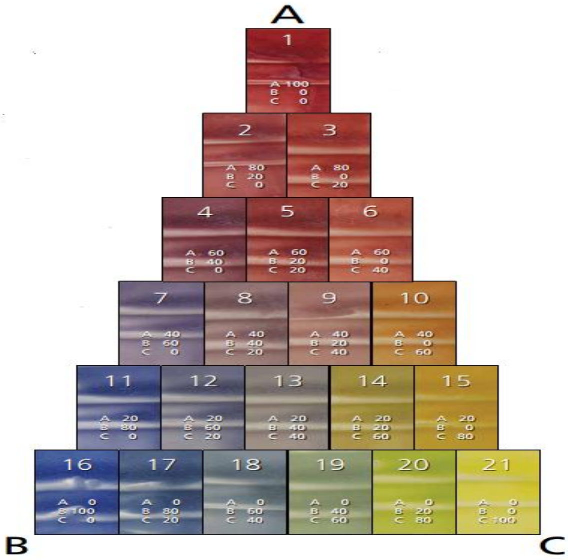

Figure 2: 21-points triaxial blend of three waste glasses

Plate III: Sourced CRT waste glass

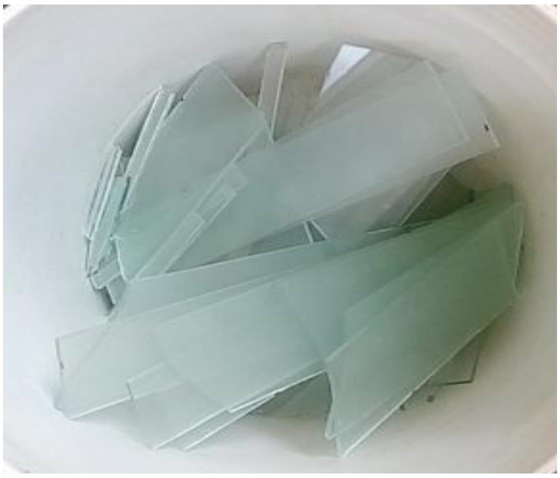

Plate IV: Sourced soda lime silicate waste glass

Plate V: Sourced borosilicate waste glass

Plate VI: Moulds and samples

Chemical analysis

The Soda-lime Silicate, Borosilicate and CRT glasses were analysed for their chemical composition by Mini Pal 4 X-ray fluorescence spectrometer. This was carried out at Center for Dry Land Agriculture Bayero University Kano, Kano State.

Firing

The samples charged into the different moulds were loaded into the Kiln for firing to a temperature of 1000°C for 50 minute, soaked for 1 hour and was allow to cool gradually at 20°C for 50 minutes. After the colling, spatula was used to remove the tiles from their various moulds. This was carried out at the Department of Glass and Silicate Technology, Ahmadu Bello University, Zaria.

Radiation shielding test

Radiation shielding test was carried out at Center for Energy Research and Training (CERT), Ahmadu Bello University, Zaria. A background reading was taken with a radiation detector to ensure that no radiation source is found around the surrounding which could affect accuracy of reading. A setup was established on a wooden table placing cobalt-60, a radiation source between two lead blocks. The radiation detector was placed at a distance of 8 inches from the radiation source to take the reading across the radiation source as shown in Plate VII. Another reading was taken on the tile placed across the cobalt-60 radiation source as shown in Plate VIII. Gamma-ray attenuation coefficients have been evaluated according to the exponential attenuation law and measured using experimental setup as shown in Plate VIII. Background radiation was subtracted from the initial intensity (I_0) and the Intensity (I) of the transmitted beam. From these measurements, the calculation of linear (μ) attenuation coefficient was computed by means of Equation (1).

$$I = Io e^{-\mu x} \quad (1)$$

Where;

μ = gamma-ray linear attenuation coefficient

I_0= intensity of the first measurement without specimen

I = intensity passing the specimen

X = thickness of the specimen sample.

Determination of half-value layer and tenth-value layers of the samples

The effectiveness of gamma-ray shielding is described in terms of the half value layer (HVL) or the tenth value layer (TVL) of a material. The HVL is the thicknesses of an absorber that will reduce the gamma radiation to half, and the TVL is the thicknesses of an absorber that will reduce the gamma radiation to the tenth of its intensity. The HVL and TVL were determined using the linear attenuation coefficient (μ) of equations 2 and 3, respectively.

$$HVL= \frac{\ln 2}{\mu} \quad (2)$$

$$TVL= \frac{\ln 10}{\mu} \quad (3)$$

Plate VII: Taking reading across the radiation source

Plate VIII: Taking reading across the tile

RESULTS AND DISCUSSION

Compositional analysis of the test samples

The result of the XRF analysis of Soda-lime Silicate (Table 1), CRT (Table 2) andBorosilicate glasses (Table 3) revealed that the waste glasses have high Silica content. Soda lime silicate glass contains the highest SiO_2 with 92.40%, Borosilicate waste glass with 66.98% and Cathode Ray Tube waste glass has the least value of 43.18%. Also, CRT waste glass contain the highest PbO with 25.59%, the high lead content in CRT makes it useful in the production of RST which could adequately shield against radiation (Song *et al.*, 2019). The chemical oxides obtained by XRF of waste glasses were similar to the work reported by Adawara *et al.* (2017) Jaha *et al.* (2022).

Table 1: Composition of Soda-lime silicate glass used in the research

Oxides	Composition (%)
SiO_2	92.40
Al_2O_3	3.36
K_2O	1.50
CaO	0.37
SO_3	0.53
P_2O_5	0.80
ClO_2	0.41
TiO_2	0.15
Fe_2O_3	0.13
ZrO_2	0.10
PbO	0.03
La_2O_3	0.07

Table 2: Composition of cathode ray tube (CRT) waste glass used in the research

Oxides	Composition (%)
SiO_2	43.18
P_2O_5	0.88
K_2O	8.60
CaO	5.69
Na_2O	6.20
Al_2O_3	3.48
MgO	1.90
PbO	25.59
Fe_2O_3	1.01
La_2O_3	0.50
BaO	0.45
As_2O_3	0.39
Ga_2O_3	0.28
ZrO_2	0.28
ClO_2	0.18
MnO	0.16
SrO	0.14
TiO_2	0.13
Sb_2O_3	0.12
V_2O_5	0.10
SeO_2	0.10
GeO_2	0.08
Bi_2O_3	0.08
Rb_2O	0.08
ZnO	0.06

Table 3: Composition of Borosilicate glass used in the research

Oxides	Composition (%)
SiO_2	66.98
Na_2O	8.6
Al_2O_3	1.79
MgO	3.7
K_2O	0.46
CaO	16.17
SO_3	0.71
P_2O_5	0.41
ClO_2	0.24
TiO_2	0.28
Fe_2O_3	0.31
ZrO_2	0.11
SrO	0.05
La_2O_3	0.06

Development of radiation shielding tests

Based on the result presented in Plate IX, the study showed that trail-axial batched design of Sodalime Silicate glass, CRT glass and Borosilicate glass at an elevated temperature and controlled cooling was able to produce glass tiles with radiation shielding ability. The result revealed that the reduction of percentages of CRT glasses in the batch affect colouration of the RST in a directly proportionalmanner as we move from samples 1 to 21. Also a uniformity in melting and forming is excellent with batches that has more percentage of CRT glass in them as the PbO present in the batch act as fluxing agent which lowers melting temperature, gives ample room for forming and finning without formation of stones which is due to incomplete batch melting and pours which as a result of trapped bubbles.

Plate IX: Developed radiation shielding tiles

Radiation shielding tests

From the result of the radiation shielding test obtained from 21-point triaxial blending of three waste glasses as represented in Table 4 and Figure 3. The result showed that sample 1 which comprises of 100% CRT had the highest radiation shielding ability with 0.178 cm^{-1} linear attenuation coefficient and sample 21 which is made up of 100% soda lime silicate glass had the least radiation shielding ability with 0.109 cm^{-1} linear attenuation coefficient, the exceptional higher percentage of radiation shielding in sample 1 which was made up of 100% CRT was due to the high percentage of lead in the sample and is in agreement with the studies of Restrepo *et al.* (2016) and Song *et al.* (2019) which opined that the presence of Lead in CRT glass is responsible for radiation shielding and protection. This is clearly seen in the behaviours of the RST where the radiation shielding ability of the tiles increased with increase in CRT waste glass composition and decreased with decrease in CRT waste glass composition due to the presence of lead which helps to shield against radiation. The radiation shielding ability of the tiles decreased in order of sample 1 with 0.178 cm^{-1}, sample 2 with 0.171 cm^{-1}, sample 3 with 0.171 cm^{-1}, sample 4 with 0.168 cm^{-1}, sample 5 with 0.162 cm^{-1}, sample 6 with 0.160 cm^{-1}, sample 7 with 0.154 cm^{-1}, sample 8 with 0.150 cm^{-1}, sample 9 with 0.150 cm^{-1}, sample 10 with 0.146 cm^{-1}, sample 11 with 0.142 cm^{-1}, sample 12 with 0.140 cm^{-1}, sample 13 with 0.139 cm^{-1}, sample 14 with 0.139 cm^{-1}, sample 15 with 0.138 cm^{-1}, sample 16 with 0.137 cm^{-1}, sample 17 with 0.134 cm^{-1}, sample 18 with 0.131 cm^{-1}, sample 19 with 0.124 cm^{-1}, sample 20 with 0.118 cm^{-1} and sample 21 with 0.109 cm^{-1} due to difference in composition.

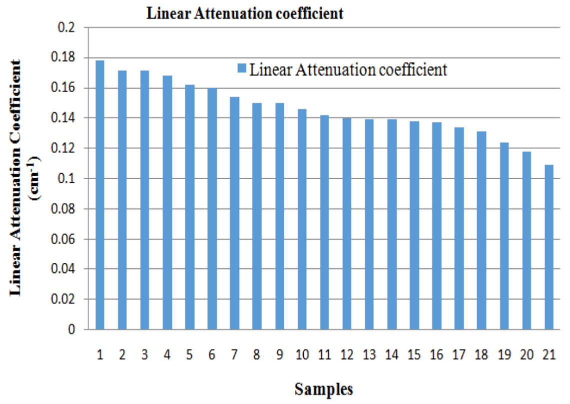

Figure 3: Radiation shield test

Table 4: Results of radiation shielding of the samples

Sample	Waste Glass Composition %			Linear attenuation coefficient (cm^{-1})	Half-value layer (cm)	Tenth value layer (cm)
	CRT glass	Bor. glass	Soda lime glass			
1	100	0	0	0.178	3.893	12.938
2	80	20	0	0.171	4.053	13.468
3	80	0	20	0.171	4.053	13.468
4	60	40	0	0.168	4.125	13.708
5	60	20	20	0.162	4.278	14.216
6	60	0	40	0.160	4.331	14.394
7	40	60	0	0.154	4.500	14.955
8	40	40	20	0.150	4.620	15.353
9	40	20	40	0.150	4.620	15.353
10	40	0	60	0.146	4.747	15.774
11	20	80	0	0.142	4.880	16.218
12	20	60	20	0.140	4.950	16.450
13	20	40	40	0.139	4.986	16.568
14	20	20	60	0.139	4.986	16.568
15	20	0	80	0.138	5.022	16.688
16	0	100	0	0.137	5.058	16.810
17	0	80	20	0.134	5.172	17.187
18	0	60	40	0.131	5.290	17.580
19	0	40	60	0.124	5.589	18.573
20	0	20	80	0.118	5.873	19.517
21	0	0	100	0.109	6.358	21.128

Bor. glass = Borosilicate glass

According to the 49th NCRP report, conventional tiles HVL for 60-Co gamma is 6.2 cm; whereas HVL for the RST in this work ranges between 3.8 and 6.3 cm and the TVL ranges from 12.938-21.128 which shows that the RST is within the range of offering a good radiation protection. Hence, an increase and decrease in the radiation shielding ability of the tiles was found to be highly affected and dependent on the composition of the samples, as results showed that radiation shielding ability of the tiles increased with an increase in amount of CRT waste glass and decreased as the amount of CRT waste glass decrease due to the present of lead which is an outstanding shielding material (Adawara *et al.*, 2017; Aliyah *et al.*, 2023; El-Khatib *et al.*, 2023).

CONCLUSION AND RECOMMENDATIONS

Conclusion

Considering the result obtained from the study, the study concludes that waste glasses obtained from different sources and composition has the ability to be transformed into tiles which has radiation shielding abilities as presented in plate IX and in the analysis of Figure 3 and Table 4, respectively. Also base on the values of the HLV and TLV, the developed tile is able to find application in areas as shielding material in area prone to radiation discharges.

Recommendations

In other to improve the quality of the RST, the study recommends that the developed tile be subjected to other property test such as mechanical, optical chemical to mention but a few so as to ascertain their specific areas of application.

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