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Utilization Of Recycled Cathode Ray Tube Waste Glass In Cement Mortar Composites For Gamma Radiation Shielding Applications

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Abstract

The rapid obsolescence of Cathode Ray Tube (CRT) technology has created a large global stockpile of electronic waste, which poses serious environmental hazards due to its lead content. This study explores the use of recycled CRT glass as a substitute for fine aggregate in cement mortar for gamma radiation shielding. CRT glass obtained from discarded television sets was processed and used to replace natural sand at 0%, 25%, 50%, 75%, and 100% by weight. The resulting composites were tested for compressive strength, water absorption, density, and gamma radiation attenuation using a Cobalt60 source. The results showed that incorporating CRT glass increased mortar density; the 100% CRT composite reached 2620 kg/m³ compared to 2410 kg/m³ for the control mix. Compressive strength initially dropped at 25% replacement but rose significantly at higher levels, with the 100% CRT mix achieving 34.40 MPa. All CRT mixes exhibited lower water absorption (1.43–1.65%) than the control (2.09%). Gamma radiation shielding improved progressively as CRT content increased, with the highest attenuation observed at 100% replacement. The study concludes that recycled CRT glass is an effective, sustainable aggregate for producing highdensity cement mortar with improved mechanical properties and enhanced gamma radiation shielding capability.

Keywords: Cathode ray tube; cement mortar; radiation shielding; electronic waste; gamma attenuation

1. Introduction

The growing volume of electronic waste (ewaste) is one of the most critical environmental challenges today. Among the various types of ewaste, cathode ray tube (CRT) glass from old televisions and computer monitors is especially hazardous because of its high lead content. According to Connelly and Lopata (1991), CRT panel glass contains 0–3 wt% lead oxide (PbO), funnel glass contains 22–25 wt% PbO, and neck glass contains about 30 wt% PbO. While this lead was essential for radiation protection during the operational life of CRT devices, it becomes an environmental threat after disposal due to possible leaching into soil and groundwater (Connelly & Lopata, 1991).

At the same time, there is a continuous need for effective radiation shielding materials in medical centers, nuclear facilities, and research laboratories. Previous researchers have examined various additives to improve the shielding ability of mortar against neutrons and gamma rays (Gallala *et al.*, 2017; Gencel *et al.*, 2010; Kharita *et al.*, 2007). The present study proposes using recycled CRT glass as fine aggregate in cement mortar for gamma radiation shielding applications.

Earlier work has shown that CRT glass can be successfully incorporated into construction materials. For example, Maschio *et al.* (2013) used waste CRT glass in highstrength mortars, and Ling *et al.* (2012) reported an approximately 60% improvement in Xray shielding with CRT glass mortars. However, systematic characterization across the full range of replacement levels (0% to 100%) is still limited. This study therefore

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investigates CRT glass replacement at 0%, 25%, 50%, 75%, and 100% levels.

2. Materials and Methods

2.1 Materials

The cement used was ASTM Type I Ordinary Portland Cement (42.5R grade) obtained from Dangote Group, Nigeria. Its chemical composition is shown in Table 1. Natural fine aggregate (river sand) was collected from Ahmadu Bello University Dam, with physical properties given in Table 2.

Table 1: Chemical composition of Dangote Portland Cement

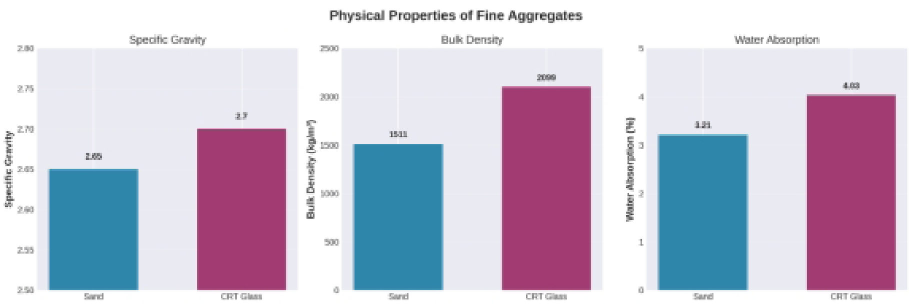
Oxide Composition	Percentage (%)	ASTM C150 Limits
SiO_2	21.45	-
Al_2O_3	5.09	6.0 max
CaO	63.51	-
Fe_2O_3	3.20	6.0 max
SO_3	2.55	3.0 max
MgO	1.51	6.0 max
K_2O	0.83	-

CRT glass was obtained from discarded television sets using the gravitational fall method described by Lee *et al.* (2004). The glass was cleaned, crushed, and sieved to achieve a particle size distribution similar to that of natural sand, in accordance with ASTM C33 (1993). Table 2 presents the physical properties of both fine aggregates.

Table 2: Physical properties of fine aggregates

Properties	Fine Sand	CRT Glass
Specific gravity	2.65	2.70
Bulk density (kg/m^3)	1511	2099
Absorption capacity (%)	3.21	4.03

Figure 1: Physical properties of fine aggregates comparison



2.2 Mix Design and Sample Preparation

Cement mortar mixes were prepared using a weight proportion of 1:3:0.42 (cement: aggregate: water). Five mix designs (C0–C4) were developed, representing 0%, 25%, 50%, 75%, and 100% replacement of natural sand with CRT glass. The mix proportions are given in Table 3.

Table 3: Mix proportions for mortar samples (kg)

Mix ID	Cement	Sand	CRT Glass	Water
C0 (0%)	0.75	2.25	-	0.50
C1 (25%)	0.75	1.69	0.56	0.50
C2 (50%)	0.75	1.13	1.13	0.50
C3 (75%)	0.75	0.56	1.69	0.50
C4 (100%)	0.75	-	2.25	0.50

Specimen casting followed IS 2250:1981 procedures. Forty cube specimens (50×50×50 mm) were prepared and cured in water at 23±3°C for 7, 14, and 28 days.

2.3 Testing Procedures

Compressive strength testing followed BS 1881-116:1983. Density and water absorption were determined per ASTM C642 (2006) and IS 3495 (1992). Gamma radiation shielding was evaluated using a Cobalt-60 source (1.25 MeV) at the Centre for Energy Research and Training, Zaria. Linear attenuation coefficients were calculated using the Beer–Lambert law (L'Annunziata, 2012).

3. Results and Discussion

3.1 Density of Hardened Mortar

CRT glass incorporation resulted in systematic density increases across all replacement levels. Results are presented in Table 4.

Table 4: Density of hardened mortar composites

Mix ID	CRT Content (%)	Density (kg/m^3)
C0	0	2410
C1	25	2520
C2	50	2553
C3	75	2581
C4	100	2620

The 100% CRT mix achieved an 8.7% density increase (2620 kg/m^3) relative to the control (2410 kg/m^3), representing an additional 210 kg/m^3. This linear correlation reflects the superior bulk density of CRT aggregate (2099 kg/m^3) compared to natural sand (1511 kg/m^3). These findings align with Ling and Poon (2012) and Gencel *et al.* (2010) and approach values for conventional heavyweight aggregates.

Figure 2: Effect of CRT glass content on mortar density

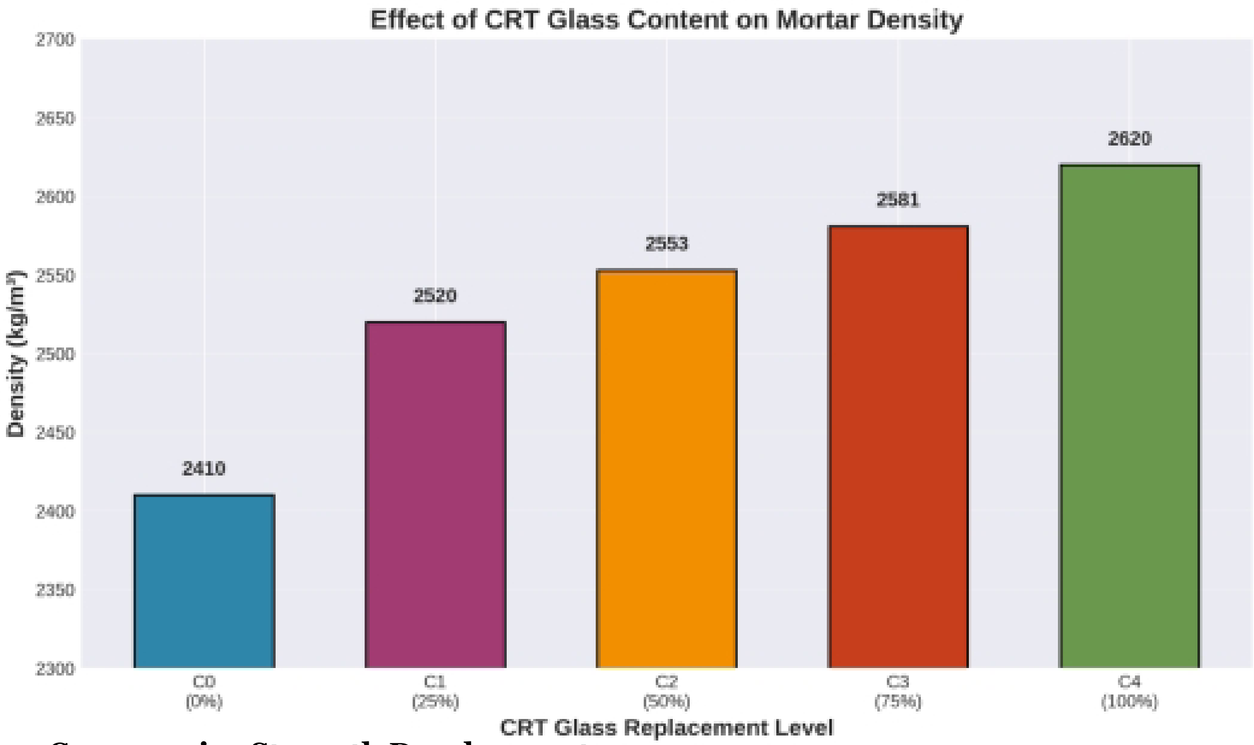


Table 5: Compressive strength of mortar composites at 28 days

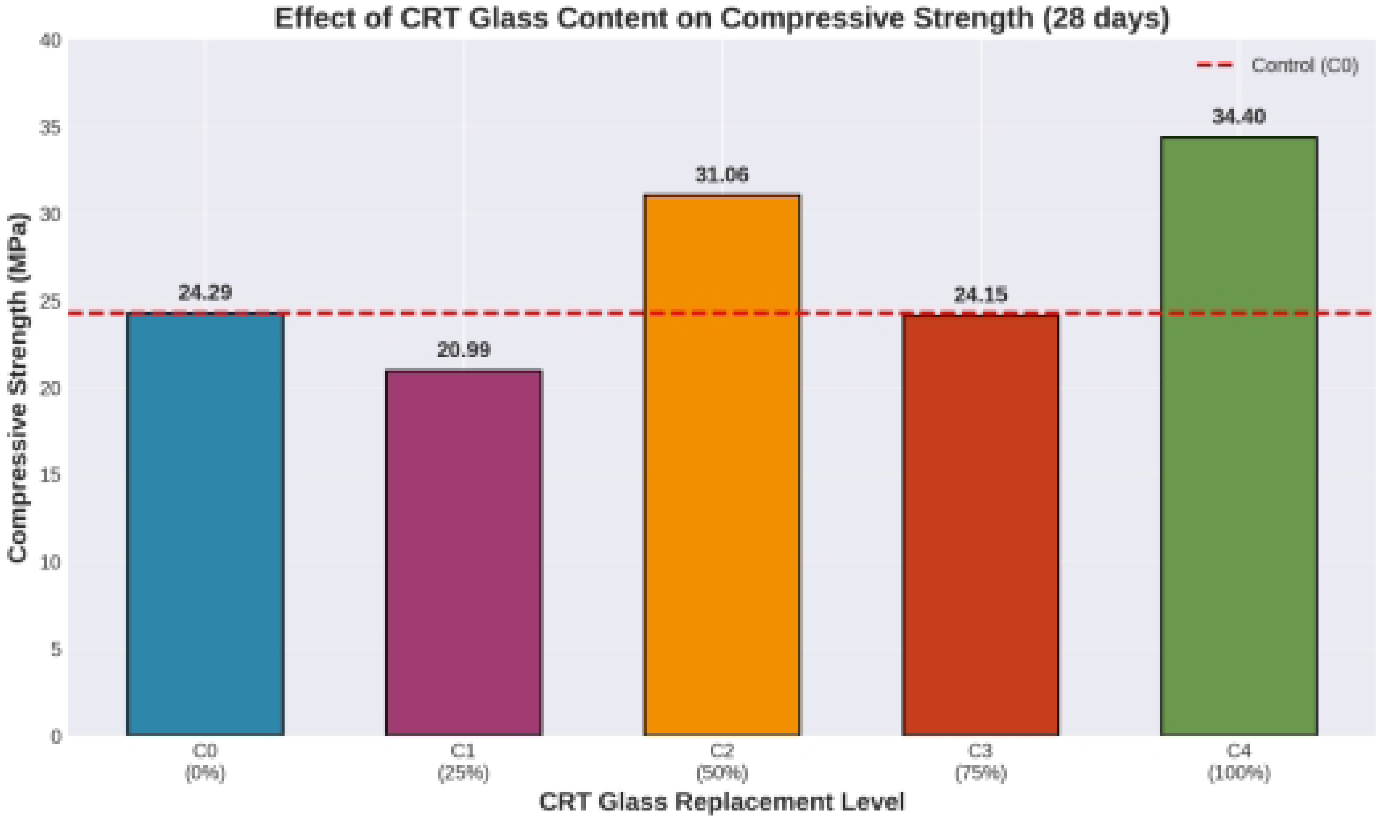
Mix ID	CRT Content (%)	Compressive Strength (MPa)
C0	0	24.29
C1	25	20.99
C2	50	31.06
C3	75	24.15
C4	100	34.40

At 25% replacement, the compressive strength dropped to 20.99 MPa. This reduction can be attributed to the smooth surface of CRT glass particles, which reduces mechanical interlocking between the aggregate and the cement paste, a finding that agrees with Ali and AlTersawy (2012). At higher replacement levels, however, strength increased substantially. The 50% CRT mix reached 31.06 MPa, and the 100% CRT mix attained 34.40 MPa, representing a 41.6% improvement over the control. The better performance of mixes with 50%, 75%, and especially 100% CRT can be explained by earlier work (Ling & Poon, 2012; Lee *et al.*, 2013), which suggests that at high replacement levels, fine CRT particles improve particle packing and may undergo pozzolanic reactions over time, thereby refining the microstructure and enhancing strength.

3.2 Compressive Strength Development

The compressive strength results at 28 days are presented in Table 5, showing a nonlinear relationship with CRT content.

Figure 3: Effect of CRT glass content on compressive strength



3.3 Water Absorption and Durability

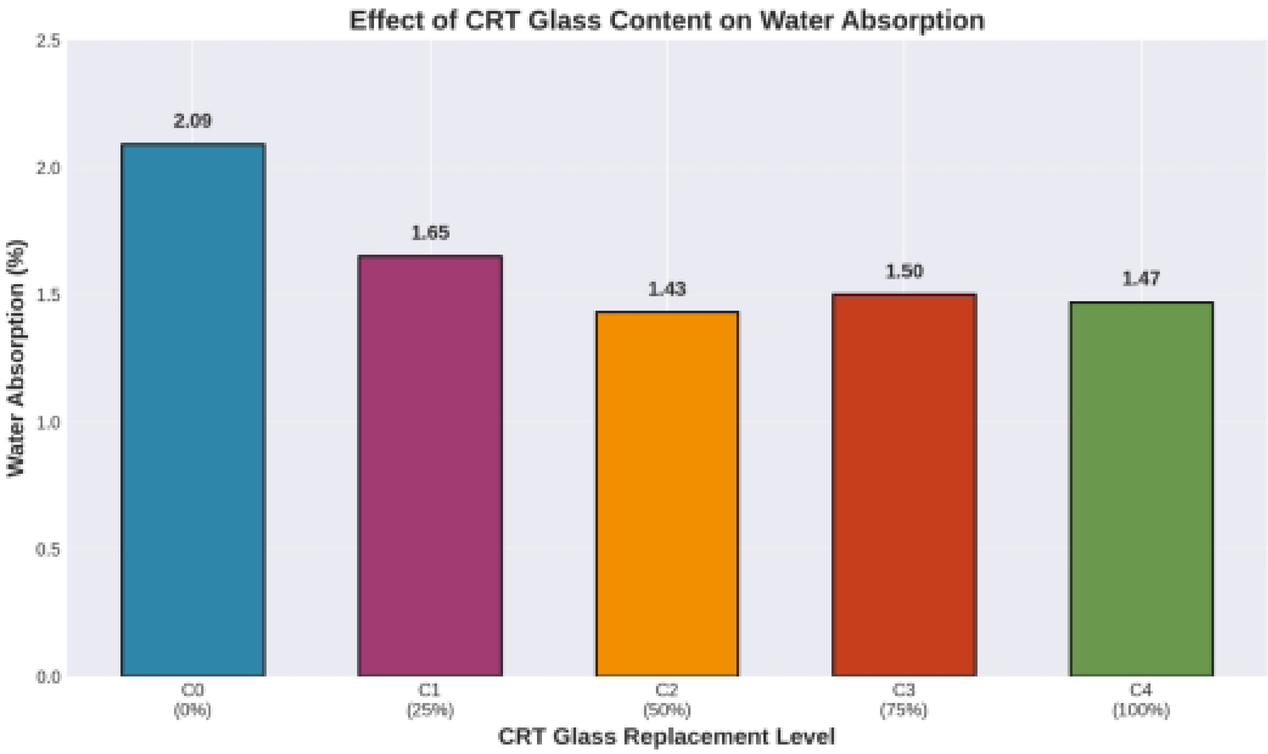
Water absorption testing revealed consistent improvements with CRT incorporation, as shown in Table 6.

Table 6: Water absorption of mortar composites

Mix ID	CRT Content(%)	Water Absorption (%)
C0	0	2.09
C1	25	1.65
C2	50	1.43
C3	75	1.50
C4	100	1.47

All CRT mixes exhibited lower water absorption (1.43–1.65%) than the control (2.09%), with the 100% CRT mix showing a 29.7% reduction. This finding differs from some previous studies (Lee *et al.*, 2013; Penacho *et al.*, 2014) but can be explained by the superior particle packing achieved because 14.75% of the fine CRT particles pass the 0.15 mm sieve. Lower permeability improves durability, which is particularly important for longterm radiation shielding applications.

Figure 4: Effect of CRT glass content on water absorption



3.4 Gamma Radiation Shielding Performance

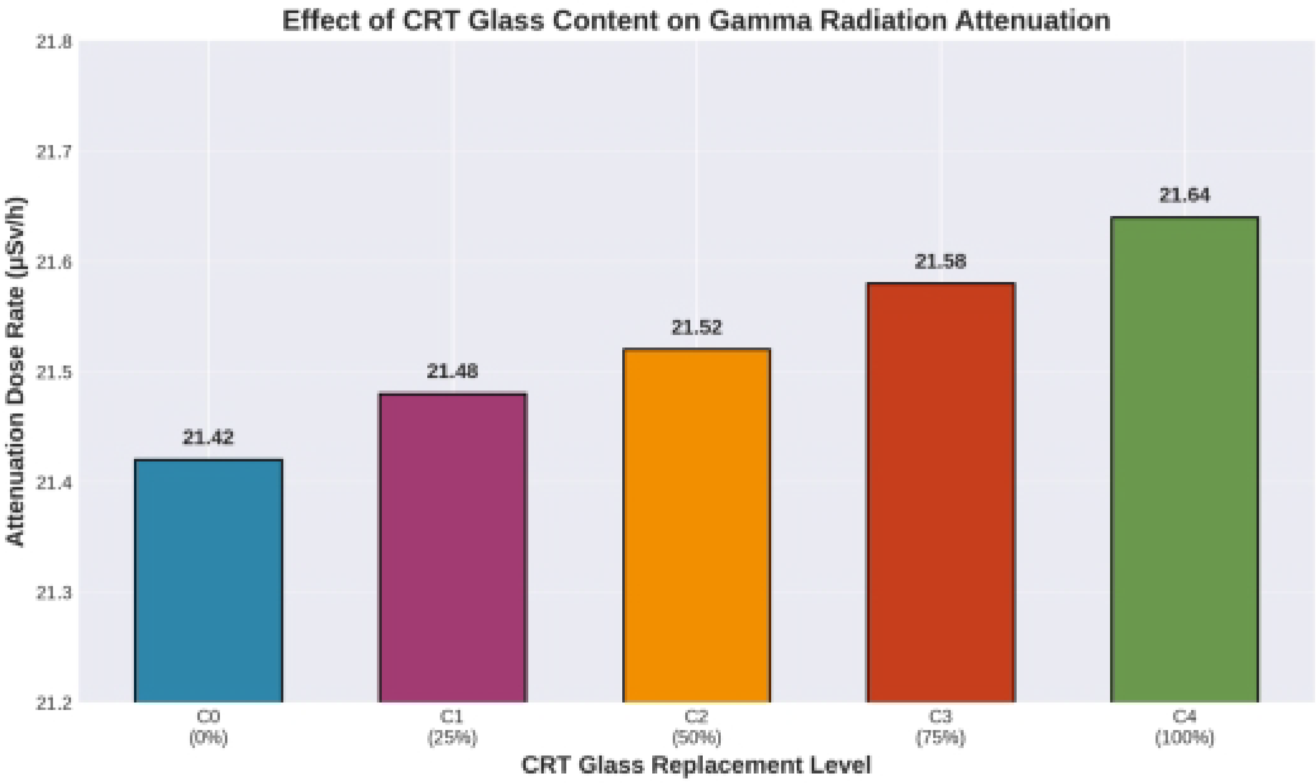
Gamma radiation attenuation using a Cobalt-60 source (1.25 MeV) demonstrated progressive shielding enhancement with increasing CRT content. Results are presented in Table 7.

Table 7: Gamma radiation attenuation performance

Mix ID	CRT Content (%)	Attenuation (μSv/h)
C0	0	21.42
C1	25	21.48
C2	50	21.52
C3	75	21.58
C4	100	21.64

Enhanced shielding results from three mechanisms: photoelectric effect, Compton scattering, and pair production (Kontani *et al.*, 2011). At 1.25 MeV, Compton scattering dominates. The 8.7% density increase translates to proportionally higher interaction probability. Barium (13.10% BaO, Z = 56) and lead enhance attenuation through high atomic numbers. Results align with Ling *et al.* (2012), who reported 60% X-ray shielding enhancement, and Kim *et al.* (2005) regarding the potential of leaded glass.

Figure 5: Effect of CRT glass content on gamma radiation attenuation



4. Conclusion

This study has demonstrated that recycled cathode ray tube waste glass can be effectively used as a fine aggregate in cement mortar composites for gamma radiation shielding. The main conclusions are:

(i) CRT waste glass possesses suitable properties for use as fine aggregate, with superior specific gravity (2.70) and bulk density (2099 kg/m^3) compared to natural sand.

(ii) Complete replacement (100%) yielded optimal results: highest density (2620 kg/m^3), superior compressive strength (34.40 MPa; 41.6% improvement), lowest water absorption (1.47%), and best gamma shielding.

(iii) Improved water absorption at all CRT levels indicates enhanced durability, which is critical for long-term shielding applications.

(iv) Systematic gamma attenuation improvement with increasing CRT content confirms the radiation shielding hypothesis, attributed to high-atomic-number elements (barium and lead) and enhanced density.

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