Assessing the Applicability of Ecological Materials Obtained with CRT Glass

Florina - Diana Dumitru¹, Mihaela - Andreea Moncea¹, Andreea – Georgiana Baraitaru¹², Petache - Ionț Gheorghe¹, Silviu Stanciu³, György Deák¹, Romisuhani Ahmad⁴

¹National Institute for Research and Development in Environmental Protection, Bucharest, Romania
²Material Science and Engineering, University Politehnica of Bucharest, Romania
³“Dunărea de Jos” University of Galati, Romania
⁴Centre of Excellence Geopolymer and Green Technology (CEGeoGTech), Universiti Malaysia Perlis (UniMAP), Perlis, Malaysia
E-mail: andreea.moncea@incdpm.ro

Abstract. Recovery and recycling of cathode ray tube (CRT) waste glasses has been the focus of research in the last decade, due to their environmental and economic issues (such as leaching of lead ions, high disposal costs). A sustainable method of valorizing this hazardous waste is to embed it in cement, as a substitute for the natural aggregate. Therefore, within the present study, ecological materials with cementitious matrix were synthesized by using glass waste recovered from cathode ray tube monitors (CRT glass), which replaced the aggregate in different proportions (varying from 10 to 30%), and by substituting 25% of cement with lime paste. The compression strength of the obtained specimens was determined after 1, 2, 7 and 28 days of hardening and highlighted that the samples with lower CRT glass substitution percentage performed relatively similar to the reference sample. This behavior can be explained by scanning electron microscopy (SEM) coupled with energy dispersive X-ray spectroscopy (EDS). The samples microstructure revealed the presence of ettringite, calcium hydroxides, hydrosilicates and hydroaluminates, calcite and some unreacted particles. The opportunity of using these materials in practical applications was assessed by developing masonry specimens - the obtained mortar paste was interposed between two brick slabs, which were mechanically tested after 7 days of hardening. Both splitting tensile strength and flexural strength varied with the increase of CRT glass in the composition.

1. Introduction

Cathode Ray Tube (CRT) glass is classified as a hazardous waste due to the high lead content and other dangerous chemical elements found in the three parts composing the tube (neck, panel and funnel) [1, 2, 3]. The inhomogeneous composition of CRT glass waste makes it difficult to be recycled, as it lacks consistency of the quality of developed products [4], and its disposal in landfill
sites is not an option, as it can contaminate the soil and ground water due to leaching of heavy metals [5]. Due to their toxicity and persistence, the presence of these hazardous substances in soils and water bodies represents a high environmental risk [6].

Traditionally, several methods were used for the recycling of CRT glass waste, namely its reuse in newer CRT glass manufacturing and as fluxing agent for different ceramic products (such as bricks), glass tiles, form glass and others) [7, 8]. However, due to the low demand for new CRT glass manufacturing after technological development and the high costs of the processing stages necessary for meeting the producers requirements, it is imperative to identify new suitable solutions for CRT glass waste reutilization [9].

In the past decade, the researchers have focused on embedding CRT glass waste in materials for the construction industry. Accordingly, alkali activated slags (AAS) and geopolymers binders were obtained by incorporating discarded cathode ray tube (CRT) with lead content. The results showed that the influence of Pb from the CRT glass waste on the performances of developed binders depends on the nature of the binder and on the Pb concentration present in the waste [10]. Due to its pozzolanic properties, another option of embedding CRT glass waste is in concrete, where it can be used as aggregate replacement [11]. Also, CRT funnel glass was used as fine aggregate in concrete paving blocks with good compressive strength (values higher than 45MPa), but with possible lead leaching at CRT glass replacement ratios higher than 25% [12].

Although there are various researches regarding the use of CRT glass waste for new construction materials, there are limited results concerning their applicability. Thus, the aim of the present study is to obtain plastering mortars containing mixed CRT glass waste (neck and panel) as fine aggregate in different ratios and to assess the opportunity of using the developed materials in practical applications.

2. Materials and methods

The plastering mortar specimens developed within this investigation were prepared by using Portland cement type CEM I 42.5, lime paste, CRT glass and sand. The lime paste substituted 25% of the cement, while the CRT glass replaced 10 – 30 % of the natural aggregate. The CRT glass waste, obtained from both neck and panel glass (1:1 ratio), was ground below 0.31 mm, so that it can be framed within 0.1 – 1 mm particle size range. The prepared binder compositions are presented in table 1.

| Specimen | Binder | Aggregate | Water/binder ratio | Binder / sand ratio |
|----------|--------|-----------|--------------------|---------------------|
|          | Portland cement (%) | Lime paste (%) | Sand (%) | CRT glass (%) |                  |                     |
| R        | 75     | 25        | 100     | -       | 0.50              | 1/2                |
| SL10     | 75     | 25        | 90      | 10      | 0.50              | 1/2                |
| SL20     | 75     | 25        | 80      | 20      | 0.50              | 1/2                |
| SL30     | 75     | 25        | 70      | 30      | 0.50              | 1/2                |

The obtained cubic mortar specimens with 25 mm side dimensions were cured for 1, 2, 7 and 28 days, on water, under normal conditions of temperature (T = 20 ± 2°C) and humidity (U.R. ≈ 90%)
and subsequently mechanically tested. The compression tests were performed on a Matest C071N Concrete Compression Machine. Three determinations were carried out for each condition to ensure the repeatability of the results, and the average value was used for further correlations.

The samples hardened for 7 days were characterized by using a Hitachi SU-70 scanning electron microscopy (SEM) coupled with energy dispersive spectroscopy (EDS) detector. To stop the hydration process and remove the water film from the sample surface, the analyzed specimens were washed with ethanol and dried at 55°C for 2 hours, and to enhance the sample conductivity, an AuPd conductive layer was applied by using the SC7620 Mini Sputter Coater/Glow Discharge System. Additionally, leaching tests have been carried out on the plastering mortars with / without CRT glass waste, following SR EN 12457 / 1-4: 2003 [13].

Subsequently, the practical applicability of the mortar paste obtained in the laboratory was investigated, as masonry specimens were realized in which the obtained mortar was the bonding layer with a height of 10 mm. The masonry specimens were cured for 7 days under normal temperature and humidity conditions, after which the splitting tensile tests and flexural tests were performed.

3. Results and discussion

3.1. Characterization of plastering mortars

The influence of the CRT glass waste on the compressive strengths of the plastering mortars can be observed in figure 1.

![Figure 1. Compressive strengths of plastering mortars with / without CRT glass waste.](image)

When water is added in the Potland cement-lime system, the equilibrium between C₃A, C₃S, C₃S and C₄AF constituents is disturbed. In the presence of supplementary CH (Ca(OH)₂) the delayed precipitation of Ca(OH)₂ from C₃S occurs. The initial low strengths for all mortar specimens result from conversion of hexagonal C₃A hydrate to the crystalline C₃AH₆ and also from the rapid hydration of C₄AF to C₃AH₆ and CFH. High initial strengths of SL20 and SL30 are obtained from the interaction between free Ca(OH)₂ and the siliceous CRT aggregates to which is added the calcium silicate hydrate (CSH) resulted from C₃S and C₃S hydration. After 7 and 28 days of hardening, the compressive
strength of SL10 specimen is comparable to that of the reference mortar, but the further increase of sand substitution degree with CRT glass waste causes a decrease in the compressive strength values. This behavior was observed by various researches, which showed that the compressive strengths decrease with the increase of CRT glass waste replacement ratio, due to the smooth surface and hydration delay caused by the lead concentration [14, 15]. These lower mechanical resistances can be explained by microstructural characterization. Thus, the obtained plastering mortars were analyzed after 7 days of hardening, as it can be seen in figure 2.

SEM image of the reference mortar with lime content (figure 2a) revealed a porous microstructure with pores that can exceed 10 µm, in which mostly calcium hydroxide crystallizes to a greater extent due to the substitution of cement with 25% lime paste. There was also observed an abundant presence of cubic shaped C₃AH₆. Poorly crystallized calcium hydroxides form interconnected agglomerated structures with other hydrocompounds, such as ettringite, in the pores and microcracks of the binder matrix. Also, unreacted cement particles were identified, typical for the 7 days hydration period. The microstructure of the SL10 plastering mortar, with lime paste content and 10% sand substitution with CRT glass waste, displayed an interconnected hydrosilicate gel network and crystalline structures in the form of rods that can be attributed to ettringite. Additionally, areas with abundant crystallization of calcium hydroxide have been observed in the hydrosilicate matrix.

![SEM images of the obtained plastering mortars: a) R, b) SL10, c) SL20 and d) SL30 (along with EDS elemental maps).](image)

Figure 2. SEM images of the obtained plastering mortars: a) R, b) SL10, c) SL20 and d) SL30 (along with EDS elemental maps).

Similar to the microstructure of SL10 plastering mortar, the SL20 specimen has a poorly structured microstructure in which interconnected hydrosilicates gels, calcium hydroxide, ettringite, calcium carbonate are observed. For the SL30 mortar a porous structure is observed inside which CSH, CH and ettringite crystallize. Also, the elemental maps obtained by X-ray spectroscopy with dispersive energy (EDS) showed besides the elements specific to the chemical composition of the cement, elements such as Pb, Na, K, found in excess in the area of the glass granule (figure 2d).

Leaching tests performed to determine the lead embedding efficiency in the cementitious matrix of the plastering mortars and to establish the safety degree of the developed materials for the environment and human health have showed values below the detection limit for Pb, Zn, Ni,
highlighting the opportunity of their practical use, as they can be considered safe and non-toxic.

3.2. Applicability assessment for masonry specimens

The practical applicability of the plastering mortars prepared in the laboratory was assessed. Thus, masonry specimens cured for 7 days were mechanically tested. The splitting tensile strength and flexural strength of the masonry specimens were determined (figure 3). During the splitting tensile tests, the crack did not occur on the plastering mortars prepared in the laboratory, the brick being the one that yielded to pressure, highlighting that the developed plastering mortars adhered to the brick surface, and that the weakest zone in the masonry specimens was the brick surface [16].

It can be noticed that for the developed specimens, the best results for both splitting tensile strength (6,395 MPa) and flexural strength (6,030 MPa) were obtained for the samples where CRT glass replaced 10% of the aggregate. These results are similar to those obtained for the reference sample.

![Figure 3](image)

**Figure 3.** a) Splitting tensile strength and b) flexural strength of the masonry specimens.

4. Conclusions

Plastering mortars were developed by substituting 25% of cement with lime paste and the natural aggregate with different percentages of CRT glass waste (10%, 20% and 30%). The complex characterization showed that:

- the mechanical resistance decreases with the increase of CRT glass waste replacement, the SL10 plastering mortar having a behavior similar to that of the reference, as the compressive strength obtained after 28 days is 99% of the etalon value. For higher CRT glass waste replacement percentages (20% and 30%), the compressive strengths are 80% and 72% of the etalon value for SL20 and SL30, respectively.
- the microstructure revealed the formation of CSH, C₃AH₆, ettringite and abundant CH in the binder matrix. Also the EDS analysis revealed the presence of Pb, Na, K, found in excess in the area corresponding to the glass granule.
- the leaching tests showed that the obtained plastering mortars can be used in practical applications, as Pb, Zn and Ni were below the detection limit, being thus safe and non-toxic.

The masonry specimens obtained using the plastering mortars highlighted good results for splitting tensile strength and flexural strength for the SL10 specimen, emphasizing the applicability of this material. Based on these results, further research will be carried out to optimize the percentage of lime paste and CRT glass waste substitution in order to develop new construction materials.
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