E-Waste Glass in Radionuclide Immobilization

Tatjana Miljojčić, Ivana Jelić, Marija Šljivić-Ivanović and Slavko Dimović

Abstract — **Comprehensive needs for environmental protection are imposed by the prerogative of preserving natural resources, i.e. efficient usage of materials and energy. Therefore, there is an urgent need for different waste materials recycling or reusing. However, advances in new technologies in the electronics industry are leading to the problem of disposing of different types of E-waste, often discarded even before its usual time. This research represents an overview of E-waste glass utilization, like cathode ray tubes (CRT) from old computer monitors and TV screens, in mortar matrices for radionuclide immobilization. Due to its properties, mortar is used for liquid radioactive waste (LRW) solidification. Large quantities of cement, aggregates, and water are used annually for mortar and concrete manufacture. Also, cement production requires the consumption of large amounts of energy, i.e. the use of non-renewable fossil fuels. Nevertheless, mixing waste materials with mortar effectively reduces the amount of cement consumption. Aspects of this paper relate to a review of recent developments regarding the use of E-waste in cementitious materials. Emphasis was placed on their physico-mechanical properties to evaluate the possibility of CRT usage in mortar matrix for LRW immobilization.**

***Index Terms* — cathode-ray tubes; liquid radioactive waste; solidification**.

I. Introduction

Modernization and advancement of technology contribute to the rapid change that applies in big part to electrical devices [1]. This reflects upon the need for innovative technologies, which are more aesthetically pleasing, easier to handle, and especially devices that consume less energy [2]. Improvement in the electronic industry led to a massive problem with different types of E-waste which is often disposed of before their usual time.

In addition to the need for energy efficiency, that the technological leap brings, there is also the need for environmental preservation, especially the development of a "circular economy", which implies the efficient use of materials. As technology advances, the amount of waste increases significantly, and the depletion of natural resources becomes irreplaceable [3]. There is a pressing need for recycling or reuse of various waste materials, and the development of sustainable alternative methods to manage hazardous waste. Collected data last few years from the waste electrical and electronic equipment (WEEE) collection and pretreatment market states that roughly 50,000-150,000 million tons/year of cathode-ray tube glass (CRTs) are collected in Europe only, and this quantity is not expected to decrease in coming years. The widespread use of liquid crystal displays (LCDs), light-emitting diode (LED), and plasma display panels that replaced CRTs are dramatically progressing, producing a million units of waste (Fig. 1).

Fig. 1. E-waste

The environmental problems concerning disposing of CRTs arise because of the high lead (Pb) content stored in the glass, panel section, and funnel. This landfilling non-eco-friendly aspect triggered the call for a solution since the presence of lead in CRT glass means that common disposal methods are not the option. [4].

On the other hand, concrete is the second most widely used material worldwide, right after water. To produce mortar and concrete, large quantities of aggregates are used annually, including cement, water, and other resources. Mixing recycled and waste materials with concrete can reduce the amounts of spent natural raw materials, i.e. these materials could be used as a replacement for cement or aggregates [5]. Combinations

Tatjana Miljojčić is with the Vinca Institute of Nuclear Sciences, University of Belgrade, P.O. Box 522 11000 Belgrade Serbia (email: tatjana.miljojcic@vinca.bg.ac.rs).

Ivana Jelić is with the Vinca Institute of Nuclear Sciences, University of Belgrade, P.O. Box 522 11000 Belgrade Serbia (email: ivana.jelic@vinca.bg.ac.rs).

Marija Šljivić-Ivanović is with the Vinca Institute of Nuclear Sciences, University of Belgrade, P.O. Box 522 11000 Belgrade Serbia (email: marijasljivic@vinca.bg.ac.rs).

Slavko Dimović is with the Vinca Institute of Nuclear Sciences, University of Belgrade, P.O. Box 522 11000 Belgrade Serbia (email: sdimovic@vinca.bg.ac.rs).

 ISBN 978-86-7466-930-3

and mixtures used as aggregates contain about 70 to 80 % of concrete by volume, with around 25 to 35 % of total aggregates produced globally being used in concrete. Therefore, the demand for adequate materials is considerably increasing. Global consumption of aggregates exceeds 40 billion tons annually [6]. The result is disrupted biodiversity and the ecosystem, soil erosion, and depletion of natural resources. The most widely used is sand, which extraction rate is higher than the rate of its replenishment [7]. Reduction of natural raw materials utilization is possible if waste or already recycled materials are used. There is a large selection of waste materials that can serve as a replacement for most aggregates in concrete, one of which is glass waste [8]. This material has a wide application and is convenient for processing, and on the other hand, there is a lot of this waste kind.

Aggregate partial replacement with CRT glass has many advantages [9]. Numerous studies have confirmed that this waste glass also behaves like a pozzolanic material. It has positive effects on the mechanical properties, and it is stated that it can replace cement-mortar in some cases, due to inefficiency in cement production with high energy demands, and great consumption of natural, non-renewable materials.

There are many investigations that dealt with the recycling of waste glass, including CRT waste, in construction materials. Consequently, the need for new information and research in this area has increased in order to incorporate good practices, develop environmental awareness and find new solutions [10]. On the other hand, the same procedure of mixing E-waste glass and construction materials could be applied in the immobilization of liquid radioactive waste (LRW), which can be a good step toward finding more environmentally friendly solutions. Mortar-matrix is able to trap harmful substances and is known as an excellent matrix for radionuclide immobilization.

The aim of this research paper was to look at the possibility of using CRT glass to see the potential benefits that may arise from it, including the immobilization of LRW. This paper is related to the systematic research of literature and works dating back to a few years ago, and deals with the research of the properties of cement mortar and concrete mixed with waste-based CRT glass. The emphasis is on their phisico-mechanical properties and durability, as well as compression, density, consistency, alkali-silica reaction, and the possibility of LWR immobilization.

II. Immobilization of Liquid Radioactive Waste in Mortar Matrix

There is a great need for proper disposal and immobilization of radioactive waste since this type of waste cannot be destroyed. On an annual basis, a lot of nuclear waste is generated from nuclear power plants, as well as other waste raw materials that are contaminated, such as technological or medical waste. This waste can be found in liquid, solid, and gas forms. Material that is considered a radioactive waste implies the one containing (or contaminated with) radionuclides in such concentrations that the level of radioactivity is higher than the values specified by the competent authorities, without having a use-value. Conditioning of radioactive waste materials implies transformation into forms suitable for later manipulation. These are technological operations of immobilizing these materials into stable, insoluble forms using matrix materials (cement, bitumen, plastic, and glass).

Many years of experimenting proved that this kind of waste is best immobilized by solidification. Theoretical and experimental tests showed that the leaching rate of radionuclides from the solidified matrix was satisfactory. This approach gives a great variety of methods and interpretations of results. However, there have not been investigations dealing with the utilization of CRT waste in mortar matrix for radionuclides immobilization. Hence, there were many comprehensive types of research on the immobilization of heavy metals and radionuclides in mortar matrices [11].

Binder construction materials and demolition debris have proven to be very successful in various studies where it has been investigated how these materials would behave as immobilizers of hazardous, radioactive, and toxic waste. Global economic urbanization contributed to finding more effective technologies that could efficiently manage and solve the environmental issues regarding radioactive waste.

Due to the properties of mortar as a material, which is appreciated for capturing various types of waste materials because of its structure, numerous studies indicate the benefits of mixing cementitious materials and LRW in order to immobilize radionuclides. There is a rising demand for more energy-efficient methods and materials which, in this case, would completely or partially replace the natural raw materials used for its production.

Recently, extensive studies have been carried out on the use of waste products and mortar mixtures. However, there are not many of them dealing with the utilization of CRT glass as a possible replacement for the mortar itself as the solidifier of LRW. It is assumed that the aim of future investigations will be a determination of whether the CRT glass mortar-based matrices satisfy the physical and mechanical properties, instead of the classic mortar. Furthermore, immobilization, storage, and disposal of LWR are expensive, so there is a rising demand for the development of low-cost sorbents [12].

Cement-based materials and other concrete binders require a significant amount of energy and raw materials for their production, and they result in a notable amount of greenhouse gasses and CO_2 emissions into the atmosphere. On behalf of that, many studies have turned to find an adequate replacement for conventional aggregates that are used and suitable binders, for the purpose of radioactive waste solidification.

III. Recycling of CRT, Materials Used, Methodology of Work, and Test Methods

CRT glass should be recycled properly to maximize

 ISBN 978-86-7466-930-3

environmental safety [13]. When it comes to recycling CRT glass there are two options: closed-loop recycling and open-loop recycling (Fig. 2).

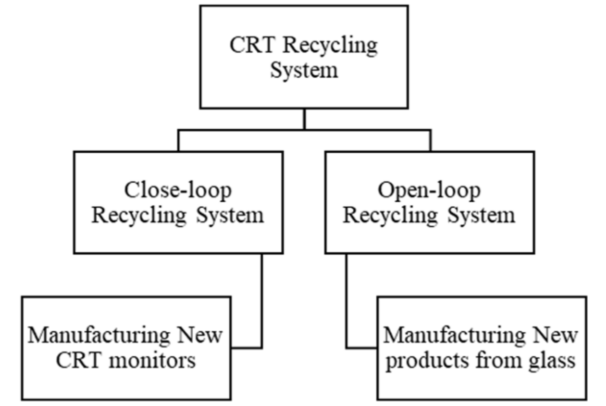

Fig. 2 Recycling system of CRT, redrawn from [3].

The first type of recycling refers to the recycling of old CRT screens in order to obtain new screens, but this method is outdated, new technologies have replaced the need for such screens. The second type of recycling is quite applicable, but the production process is more demanding. It consists of the use of these waste glasses in the form of obtaining new finished products. These species are far more cost-effective, and also have environmental value. Such products include construction materials, which are characterized by low water absorption properties and high silica content, making them an adequate substitute for sand and pozzolan in concrete [14].

CRT monitor consists of three main parts: front panel glass, funnel glass, and the electron gun. There are monochrome CRT (black and white) and color CRT screens (Fig. 3.).

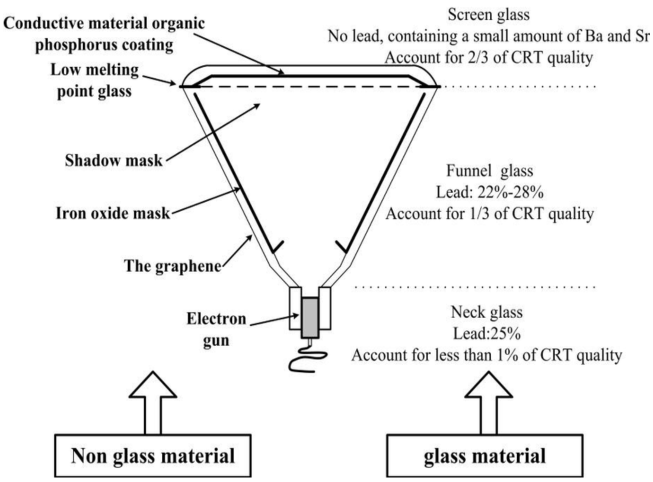

Fig. 3 Composition of a CRT monitor

Consequently, all kinds of chemical compositions are found in CRT glass, hence the main component of CRT is silica. When it comes to recycling and separation of CRTs, the external parts, plastic casing, and metallic parts are removed from TV sets and monitors. The panel and funnel glass are separated by laser cutting. In the recycling procedure of the panel, glass involves the removal of fluorescent powder and using a mechanical crusher to break it into smaller particle sizes.

A. Test methods (workability, durability, consistency, compression, ASR reaction)

There are a lot of investigations where it was estimated the share of ground CRT glass as a fine aggregate in various percentages. For instance, one study focused on using CRT glass 100% instead of sand [5]. Treated and non-treated CRTs were used. Authors reported that the mixture of mortar and non-treated CRT glass produced a higher slump flow than the mixture of mortar and river sand (over 165%), but if treated CRT was used, it decreased slump flow.

Other research [10] found that if used different replacement levels of CRT (0%, 25%, 50%, and 75%) would get different flow speeds and consistency. CRT glass has a smooth surface and is impermeable in nature. Other studies [11,12], as well, showed that the consistency of these mixes is decreased if there is less percentage of CRT. What is evident is that if a higher percentage of CRT glass is used, a more homogeneous mixture is obtained, with less segregation (Fig. 4.).

Fig. 4. Particles of CRT glass

However, it was proven that an increase of CRT in mortar or cement decreases workability and has an important impact on a slump. Consequential is the method of crushing glass, as well as the size of particles and textures, which later has a great influence on mixing with building materials [13].

One research [14] found when CRT glass quantity was increased by replacement of 0 to 75% that caused an increase in the wet density of mortar and cement from 2176 to 2408 kg/m^3. Nevertheless, this was expected, hence density of river sand is lower (2620 kg/m^3) than the density of CRT glass (3042 kg/m^3). Same researchers reported similar results in another study [15], where it was found that the wet density of concrete increased from 2914 to 2992 kg/m^3 after replacing 75% of sand with CRT. Other scientists [16,17] also reported an increase in the wet density of concrete when replacing limestone sand with CRT. In one study [18] sand in the mortar was replaced with treated CRT and non-treated CRT glass at levels of 0%, 25%, 50%, and 75% also. With the increase in substitution level, wet density also increased. The only difference was that non-treated CRT glass in mortar had a higher density, while treated CRT had a lower density. The incorporation of CRT glass into mortar and concrete has led to an increase in density, because of the higher density of CRT glass itself compared to river sand. Higher density in this case is desirable and can be used specifically for concrete used in radiation protection, but not so much for structural concrete.

Researchers came to the conclusion [5] that mortar with non-treated and treated CRT glass has a higher compressive strength compared to a mortar with river sand. The compressive strength of mortar that was mixed with non-treated CRT glass was 41% higher than mortar that was mixed with river sand only. This examination was concluded on the 28th day of the experiment, due to the high probability of improvement in the particle packing. In the same research, they found that mixtures of mortar and CRT glass have higher grades of flexural strength, especially if non-treated CRT glass was used. [19]

Some studies [11] found that while increasing levels of CRT in mortar, there has been a decrease in flexural and compressive strength both, but only in early curing stages. It was speculated that it was probably because of the weaker bond in the cement paste, while during the later curing stages there was a chemical reaction between calcium hydroxide and CRT glass, as a pozzolanic material, and there was a smaller decrease in strength.

When it comes to combining CRT glass with concrete, there has been one investigation [11] that indicated that compressive strength and splitting tensile strength are reduced during the early curing time. In that experiment, they replaced river sand with 100% of non-treated CRT glass. Another study figured that lead, which is located in CRT, is responsible for cement dehydration, and after a longer period of curing, compressive and splitting tensile strengths are increasing. Furthermore, a recent study [20] investigated that strength reduction is also responsible less effective bonding area between cement and CRT glass, because of the smooth surface of the glass.

Regarding water absorption tests, some studies [21,22] found that when sand was replaced with 100% of treated CRT glass in concrete, it was found that usage of this waste material was responsible for the water absorption decrease. This was somewhat expected since CRT glass has lower absorption than sand. Another study [22] found that there was a reduction of permeability when adding CRT glass to concrete, which was more obvious when adding a higher water binding ratio. It was observed that 15% reduction in absorption when aggregate was replaced with 100% of CRT glass. Other authors [23,24] also reported that an increase in the quantity of CRT glass led to a further absorption decrease in cement mortar and concrete, the smaller particle size led to a further decrease in water absorption, also.

Many studies reported that utilization of CRT glass as a fine aggregate increased expansion in cement and mortar mixture, due to the alkali-silica reaction (ASR). During mortar mixtures testing without CRT glass as a fine aggregate, researchers reported an insignificant increase in expansion after 14 days, while mortar mixtures that did contain CRT glass continued to expand. Authors mentioned that utilization of fly ash led to a decrease in expansion, due to the pozzolanic reaction which reduced alkali content [25]. Also, when combining results with treated and non-treated glass, there was noticed that treated glass also led to expansion due to ASR. Other researchers reported that surface treatment of CRT glass can reduce ASR, with or without other fine aggregates. Scientists found that treating the CRT glass with nitrilotriacetic acid effectively reduced the expansion caused by ASR, unlike mortars that contained non-treated CRTs [26].

Combining the fly ash with a mixture of CRT glass is also an adequate method. Either way, cement mortar has exceptional potential to encapsulate hazardous waste in its matrix. The authors also suggested the utilization of additional pozzolanic materials (metakaolin, fly ash, etc.) which are responsible for the denser microstructure of the material, hence it reduces expansion due to ASR [27].

IV. Conclusion

The aim of this paper was the review the investigations related to CRT waste management and its utilization in mortar matrices.

Improvement in the electronic industry led to a massive problem with different types of E-waste which is often disposed of before their usual time. Collected data last few years from the waste electrical and electronic equipment (WEEE) collection and pretreatment market states that roughly 50,000-150,000 million tons/year of cathode-ray tube glass (CRTs) are collected in Europe only, and this quantity is not expected to decrease in coming years. The widespread use of liquid crystal displays (LCDs), light-emitting diode (LED), and plasma display panels that replaced CRTs) are dramatically progressing, producing a million units of waste.

In order to produce mortar and concrete, large quantities of aggregates are used annually, including cement, water, and other resources. Mixing recycled and waste materials with concrete can reduce the amounts of spent natural and raw materials, i.e. these materials could be used as a replacement for cement or other aggregates. There are many investigations that dealt with the recycling of waste glass, including CRT waste, in construction materials.

Many studies reported that the utilization of CRT glass in the mortar was beneficiary to its physico-mechanical properties such as density, water absorption, workability, permeability, compressive, flexural, and splitting tensile strength.

The final result would be that CRT waste glass could partially replace cement-mortar as a suitable waste immobilizer, but more investigations are needed.

Acknowledgment

The research presented in this paper was done with the financial support of the Ministry of Education, Science and Technological Development of the Republic of Serbia, within the funding of scientific research work at the University of Belgrade, Vinca Institute of Nuclear Sciences (Contract No. 451-03-68/2022-14/200017).

References

[1] N. Singh, J. Wang, J. Li, "Waste cathode rays tube: An assessment of global demand for processing", *Procedia Environ. Sci*., 31, 465–474, 2016.

[2] Z. Yao, T. Ling, P.K. Sarker, W. Su, J. Liu, W. Wu, "Recycling difficult-to-treat e-waste cathode-ray-tube glass as construction and building materials: A critical review" *Renew. Sustain. Energy Rev*., 81, 595–604, 2018.

[3] N. Singh, J. Li, X. Zeng, "Global responses for recycling waste CRTs in e-waste." *WASTE Manag*., 57, 187–197, 2016.

[4] N.N.M. Pauzi, M. Jamil, R. Hamid, A.Z. Abdin, M.F.M. Zain, "Influence of spherical and crushed waste Cathode-Ray Tube (CRT) glass on lead (Pb) leaching and mechanical properties of concrete", *J. Build. Eng.*, 21, 421–428, 2019.

[5] Z. Hui, W. Sun, "Study of properties of mortar containing cathode ray tubes (CRT) glass as replacement for river sand fine aggregate", *Constr. Build. Mater*., 25, 4059–4064, 2011.

[6] J. Khatib, A. Jahami, O. Baalbaki, A. Elkordi, H. Abdelgader, "Behavior of reinforced concrete beams containing lightweight aggregate in the tensile zone", *BAU J. Sci. Technol.*, 1, 3, 2020.

[7] S.K. Kirthika, S.K. Singh, A. Chourasia, "Alternative fine aggregates in production of sustainable concrete-A review", *J. Clean. Prod*., 268, 122089, 2020.

[8] Y. Qi, X. Xiao, Y. Lu, J. Shu, J. Wang, M. Chen, "Cathode ray tubes glass recycling: A review", *Sci. Total Environ*., 650, 2842–2849, 2019.

[9] Z. Hui, W. Sun, "Study of properties of mortar containing cathode ray tubes (CRT) glass as a replacement for river sand fine aggregate", *Constr. Build. Mater.*, 25, 4059–4064, 2011.

[10] T.C. Ling, C.S. Poon, "Utilization of recycled glass derived from cathode ray tube glass as fine aggregate in cement mortar", *J. Hazard. Mater*., 192, 451–456, 2011.

[11] F. Fu, Q. Wang, "Removal of heavy metal ions from wastewaters: A review", *J. Environ. Manag.*, 92, 407-418, 2011.

[12] S.-H. Hong1; C.-G. Lee; S.-J. Park. "Removal of Cd^{2}+, Cu^{2}+, Pb^{2}+, and Ni^{2}+ by sludge produced from liquid crystal display glass substrate", *Int J. Environ. Sci. Technol. (Tehran)*, 2021

[13] S.T. Yildirim, „Research on strength, alkali-silica reaction and abrasion resistance of concrete with cathode ray tube glass sand", In *Sustainable Buildings—Interaction between a Holistic Conceptual Act and Materials Properties*, IntechOpen: London, UK, 2018; pp. 131–149.

[14] T.C Ling, C.S. Poona, "Development of a method for recycling of CRT funnel glass", *Environ. Technol*., 33, 2531–2537, 2012.

[15] T.C. Ling, C.S. Poon, "Effects of particle size of treated CRT funnel glass on properties of cement mortar", *Mater. Struct. Constr*., 46, 25–34, 2013.

[16] P.O. Iniaghe, G. Adie, "Incorporation of finely ground waste cathode ray tube glass in concrete", *J. Solid Waste Technol. Manag,* 43, 207-215, 2017.

[17] H. Zhao, C.S. Poon, T.C. Ling, "Properties of mortar prepared with recycled cathode ray tube funnel glass sand at different mineral admixture", *Constr. Build. Mater*., 40, 951–960, 2013.

[18] H. Zhao, C.S. Poon, T.C. Ling, "Utilizing recycled cathode ray tube funnel glass sand as river sand replacement in the high-density concrete", *J. Clean. Prod*., 51, 184–190, 2013.

[19] D. Romero, J. James, R. Mora, C.D. Hays, "Study on the mechanical and environmental properties of concrete containing cathode ray tube glass aggregate", *Waste Manag.*, 33, 1659–1666, 2013.

[20] J. Bawab, J. Khatib, S. Kenai, M. Sonebi, "A Review on cementitious materials including municipal solid waste incineration bottom ash(MSWI-BA) as aggregates", *Buildings*, 11, 179, 2021.

[21] H. Zhao, C.S. Poon, "A comparative study on the properties of the mortar with the cathode ray tube funnel glass sand at different treatment methods", *Constr. Build. Mater*., 148, 900–909, 2017.

[22] L.A.P Oliveira, J.P. Castro-Gomes, P. Santos, "Mechanical and durability properties of concrete with ground waste glass sand", *DBMC*, Istanbul, Turkey, 1, 11–14, 2008.

[23] J. Wang, S. Guo, Q. Dai, R. Si, Y. Ma, "Evaluation of cathode ray tube (CRT) glass concrete with/without surface treatment", *J. Clean. Prod*., 226, 85–95, 2019.

[24] T.C. Ling, T.S. Poon, "Use of CRT funnel glass in concrete blocks prepared with different aggregate-to-cement ratios", *Green Mater*., 2, 43–51, 2014.

[25] I.S. Kim, S.Y. Choi, E.I. Yang, "Evaluation of durability of concrete substituted heavyweight waste glass as fine aggregate", *Constr. Build. Mater*., 184, 269–277, 2018.

[26] I.B. Topçu, A.R. Boğa, T. Bilir, "Alkali–silica reactions of mortars produced by using waste glass as fine aggregate and admixtures such as fly ash and Li2CO3", *Waste Manag*., 28, 878–884, 2008.

[27] D. Kim, I.G. Petrisor, T.F. Yen, "Evaluation of biopolymer-modified concrete systems for disposal of cathode ray tube glass", *J. Air Waste Manage. Assoc.*, 55, 961–969, 2005.