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# 11th International Conference on Renewable Electrical Power Sources

# PROCEEDINGS

Editor Dr Milica Vlahović

Belgrade, November 02-03, 2023

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## 11th International Conference on Renewable Electrical Power Sources

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# OTPADNO STAKLO KATODNIH CEVI U PRIPREMI BETONA – POVEĆAVANJE ODRŽIVOSTI

# CATHODE RAY TUBE WASTE GLASS IN CONCRETE PREPARATION – INCREASING SUSTAINABILITY

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*Apstrakt. Građevinski sektor je odgovoran za približno 39% potrošnje energije i emisija ugljen-dioksida vezanih za date procese. Mešanje otpadnih materijala u beton, kao zamena za cement i/ili agregat, povećava energetsku efikasnost i održivost uopšteno. Pored toga, smanjuje se i pritisak na životnu sredinu smanjenjem eksploatacije prirodnih sirovina. S druge strane, brzi napredak elektronske industrije doveo je do stvaranja velike količine električnog otpada pre isteka njegovog životnog veka. Odlaganje starih monitora i TV ekrana, odnosno njihovih katodnih cevi (CRT), predstavlja veliki problem za životnu sredinu pošto je otpad od CRT-a klasifikovan kao opasan usled visokog sadržaja olova. Ovaj rad se bavi pregledom istraživanja o korišćenju CRT otpada u cementnim materijalima u cilju povećanja održivosti i podsticanja cirkularne ekonomije u građevinskom sektoru.*

***Ključne reči:*** *cement; sirovine; energetska efikasnost; životna sredina*

*Abstract. The construction sector is responsible for approximately 39% of energy use and process-related carbon dioxide emissions. Mixing waste materials into concrete, as a substitute for cement and/or aggregate, increases energy efficiency and sustainability in general. Additionally, pressure on the environment is decreasing by reducing the amount of exploitation of natural raw materials. On the other hand, the rapid progress of the electronic industry has led to the generation of a large* *amount of electrical waste before the end of its useful life. Disposal of old monitors and TV screens, i.e. their cathode-ray tubes (CRT), represents a major problem for the environment because CRT waste is classified as hazardous due to its high lead content. This paper deals with an overview of investigations on CRT waste utilization in cement materials in order to increase sustainability and encourage a circular economy in the construction sector.*

***Key words:*** *cement; raw materials; energy efficiency; environment*

## 1 Introduction

Construction, as an economic branch with a significant impact on the environment, is changing, under the trends that guide sustainable development. Based on statistical research, the overall industry accounts for 33-35% of energy consumption [1], where transportation, residential, and commercial sectors complement this amount. Still, the buildings and construction sector alone are responsible for approximately 36% of final energy use [2]. Additionally, up to 39% of energy and process-related carbon dioxide emissions also take place in the buildings and construction sector, 11% of which results from manufacturing building materials and products such as steel, cement, and glass [2]. Nevertheless, there is also a lower bound estimation of 24% greenhouse gas emissions by the industry sector, calculated for the 2020 year [3]. Therefore, it is quite realistic to estimate that the most prominent themes that would aid the circular economy, improve the building industry sector, and enable better effect on the environment, are the following: switching to renewable energy sources and energy-efficient approaches, improving building design, use of nature-based and traditional solutions, and improvement in materials in terms of their environmental impact. Likewise, the use of recyclable and recycled materials is a very important segment in this approach. Following the Sofia Declaration [4] on the Green Agenda for Western Balkan 2021–2030 which endorses the European Union (EU) Green Deal strategy and the New Circular Economy, the legislation is being taken from EU on waste management (National Assembly of the Republic of Serbia, 2018) and landfill disposal (Government of the Republic of Serbia, 2010), waste categories, (Government of the Republic of Serbia Ministry of Environmental Protection, 2021) and waste statistics.

Sustainable development of the construction industry has become a growing concern. It is estimated that the worldwide annual production of concrete, as the most prominent construction material, is approximately 20 billion tones [5]. Concrete is the most used construction material after water, requiring large quantities of cement. However, cement production is an energy-intensive process that consumes large quantities of thermal energy. The production process requires heating to high-temperature levels, e.g. up to 1500°C in the kiln, and therefore requires thermal energy from fossil fuels combustion enhancing the greenhouse effect. Consequently, cement production accounts for about 7% of the total $CO_2$ emissions worldwide, and this industry is considered one of the main problems of environmental degradation and the cause of climate change and global warming [6]. The total volume of cement production in the world in 2022 was about 4.1 billion tons, and it was estimated that it would exceed 6 billion tones by 2025 [6]. For comparison, the total world cement production was only 1.4 billion tons in 1995 [7].

Mixing recycled and waste materials into concrete, as a substitute for cement and/or aggregate, increases energy efficiency and sustainability in general [8]. Additionally, pressure on the environment is decreasing by reducing the amount of exploitation of natural raw materials.

The rapid advancement of technology has led to the generation of a large amount of electrical waste (e-waste) and its disposal before the end of the product's life, making it a special waste stream with the fastest growing rate globally [9]. A large part of this waste can be recycled; however some types of it, such as TV screens and computer monitors with cathode ray tubes (CRT), are hazardous waste due to the content of toxic components, primarily lead. By developing new types of screens, e.g. displays with liquid crystals (Liquid-Crystal Display, LCD), displays with light-emitting diodes (Light-Emitting Diode, LED), and plasma displays, the demand for new CRT devices does not exist, and landfills worldwide are facing the problem of accumulating outdated devices (Figure 1) [10].

*Figure 2. Collected CRT waste [10]*

Considering that new CRT devices are no longer produced, the so-called Closed-loop recycling, which includes the production of new devices from old ones, is no longer possible. As a result, Open-loop recycling remained the only possible way of recycling when planning the reuse of old CRT glass. Data from the last few years from the e-waste collection and pretreatment market indicate that approximately 50,000 to 150,000 million tons of CRT glass are collected annually in the European Union (EU), and are not expected to decrease in the coming years [11]. It is believed that the amount of waste CRT glass will continue to grow until the mid-thirties of this century [12].

Waste CRT glass has a high potential for further reuse in sustainable concrete production due to its chemical composition, availability, and cost-effectiveness. Partial substitution of cement or sand with finely ground or crushed CRT glass reduces the amount of their consumption, increasing the sustainability level through the production of sustainable cement-based materials. The leaching results show that lead concentrations leached into the environment are often below the permissible limits depending on the proportion of CRT glass due to the encapsulation in the mortar matrix. Also, numerous studies have confirmed that this waste behaves like a pozzolanic material and has a positive effect on the mechanical properties of mortar and concrete. This paper deals with an overview of investigations on CRT waste utilization in cement materials. Accordingly, the overall future project is adopted to preserve the environment and sustainability through increasing energy efficiency, waste reduction, raw materials preservation, climate change, and global warming prevention, as well as directing the e-waste stream to circular principles.

## 2 CRT Glass

The first CRT was designed by the German physicist Ferdinand Braun in 1897, and serial production of TV devices began in Germany in 1934. In the middle of the 20th century, color CRTs appeared, and at the end of the 1970s, the production of computer monitors with CRTs began [13].

CRT is a vacuum tube consisting of non-glass and glass parts (Figure 2). In a CRT, electrons are focused and fall on a fluorescent screen, producing a visible spot on it [13]. The cathode heats up and emits electrons, which are accelerated to the anode.

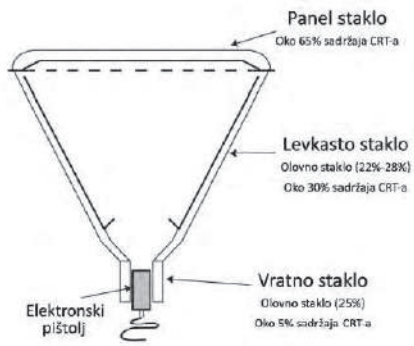


*Figure 2. CRT scheme [12]*

In monochromatic (e.g. black and white) CRTs, there is one system for accelerating electrons, called an electron gun. In color CRTs, there are three electron guns, each for a specific color (red, green, and blue). Electrons accelerated in this way are passed through the so-called deflection plates, where they turn left-right or upside-down. The screen is covered with a phosphorus material that glows when is stricken by an electron [14]. By moving the focus point on the screen surface, it is possible to produce an image made up of individual dots, or pixels. In this way, the image on the screen is obtained.

The three basic glass elements of the CRT screen are: the neck, the funnel, and the panel, and their mass shares are different and amount to 1%, 33%, and 66%, respectively. The neck, although the least represented by mass in the monitor, contains about 25% lead, the most of all glass parts. The funnel is the largest part of the CRT and contains about 20% lead. The panel is the front, visible part of the CRT that contains almost no lead (0 – 3%) but is coated with layers of barium and strontium that have the role of protecting the user from the harmful effects of UV and X radiation generated by electron guns [14]. As can be concluded, all three types of glass are very different in chemical composition. However, although CRT glass has different chemical contents, its main component is silicon dioxide.

Due to the content of lead, barium, and strontium, CRT glass is hazardous waste according to the Waste Catalog and belongs to the following waste categories: 16 02 13*, 16 02 15*, and 16 03 03* [15]. The chemical composition of CRT glass makes its further recycling, that is, its application in the production of another product, very difficult. Its chemical composition is such that the recycling process must meet the special conditions that apply to waste labeled as "hazardous". Illegal disposal of old monitors and TV screens, i.e. their CRTs, represents a major problem for the environment due to the potential leaching of harmful metals. Glass with lead impurities, such as CRT glass, according to legislation, cannot be recycled before the lead is separated. In case there are no suitable smelters, it is exported, representing a financial burden for the operators.

## 3 An overview of recent research

Previous investigations indicate the possibility of CRT glass utilization in the production of various types of bricks, ceramic tiles, and special rooms for the disposal of nuclear waste. A review of investigations related to the use of glass CRT waste in cement-based concrete and mortar until 2021 [16] showed that recycling this type of waste, as a substitute for sand, improves some properties of mortar and concrete. CRT glass waste usage in such materials enhances their consistency due to smoother surfaces and particularly lower water absorption. In some cases, it improves both compressive and flexural strength. When used in mortar or concrete, CRT glass waste reduces drying shrinkage and water absorption. The addition of fly ash or metakaolin reduces the risk of alkali-silicate reaction (ASR) in concrete containing CRT glass. The authors concluded that lead leaching can be mitigated by various techniques, including acid treatment, but also by encapsulation using biopolymers, adding fly ash, or encapsulation in the mortar matrix itself, limiting the amount of CRT glass in the mixture. In general, the authors assessed that CRT glass waste can be a valid component in the production of sustainable cement-based materials [16].

Other authors examined the possibilities of combined application of recycled aggregate with CRT waste, with a reduced percentage of CRT glass in order to avoid the possibility of leaching harmful elements into the environment (Figure 3) [17]. The mechanical properties of the materials and the potential contamination were examined. The results showed that the addition of CRT glass, in an amount of 10%, reaches a satisfactory level of compressive strength of the pavement substructure. Also, all mixtures were classified as inert waste, and it was concluded that the mentioned materials could be used in civil engineering.

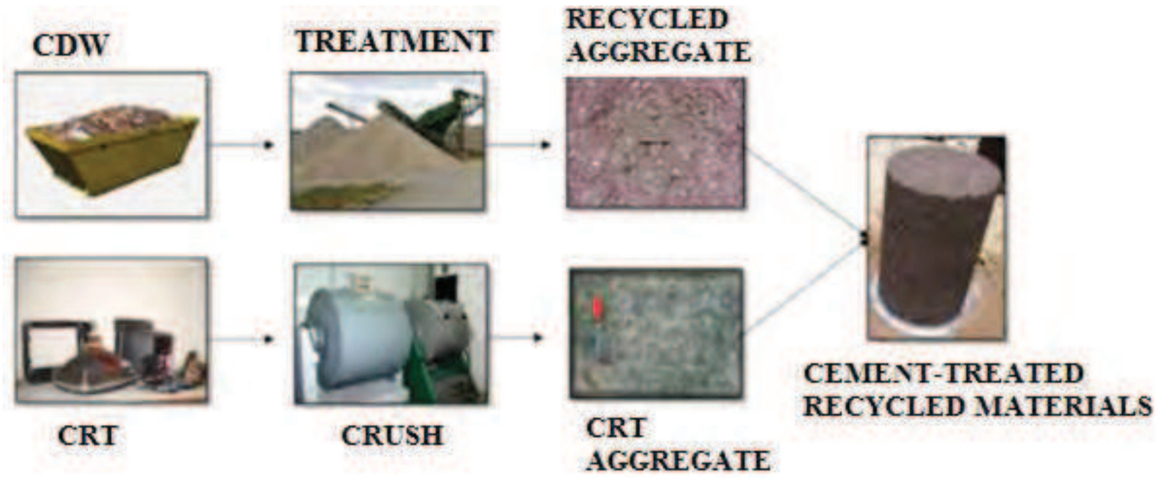


*Figure 3. Use of Cathode Ray Tube Glass (CRT) and Recycled Aggregates for Road Sub-Bases [17]*

In another study [18] the reference sample was made of quartz sand, while the other product was a mixture of quartz sand and CRT glass (50%). The glass was ground to a fraction corresponding to the fineness of the quartz sand. Water absorption, freeze-thaw resistance, and flexural strength were tested. It was concluded that the addition of CRT glass does not increase water absorption or reduce the flexural strength below the values prescribed by standards EN 1338 and EN 1339 for paving blocks. In another study, the same authors [18] investigated the potential for using finely ground CRT glass as an additional cementitious material while investigating the resistance of such concretes to sulfate action. The percentage of replacement of cement with CRT glass was 5%, 10%, 15%, 20% and 35%. The assessment of the durability of concrete to the effect of sulfate was done by visual examination of concrete, as well as the examination of variations in compressive strength of concrete samples aged 3, 6, 12, and 36 months. After immersing the samples in a 5% $Na_2SO_4$ solution for 36 months, concrete samples with 15% and 20% cement replacement with finely ground CRT glass showed satisfactory compressive strength and sulfate resistance at the same time, and it was concluded that this range of cement replacement with finely ground CRT glass can recommend for practical use.

In addition, a group of authors [19] studied CRT glass utilization as a fine aggregate in a geopolymer composite based on fly ash and slag. They examined the compressive strength, ASR, and leaching of lead from geopolymer mortars, and the results showed that the hardening mechanism of such geopolymers involves not only physical encapsulation but also chemical binding of lead. As the silica modulus increases, the compressive strength and ASR first increase and then decrease, while the leached lead concentration decreases significantly. The increased modulus of silica has been shown to improve the chemical binding of lead ions by forming lead silicate. Additionally, increasing the silica modulus significantly improves overall porosity, resulting in better physical performance of Pb ion encapsulation.

## 4 Conclusion

This paper deals with an overview of investigations on sustainable CRT waste utilization in cement materials. Considering construction is an activity that is harmful to the environment in multiple ways, there is plenty of room for implementing the principles of sustainable development. The buildings and construction sector alone are responsible for approximately 36% of final energy usage. Additionally, up to 39% of energy and process-related carbon dioxide emissions also take place in the buildings and construction sector, 11% of which results from manufacturing building materials and products such as steel, cement, and glass. The most prominent themes that would aid the circular economy, improve the building industry sector, and enable better effect on the environment, are the following: switching to renewable energy sources and energy-efficient approaches, improving building design, use of nature-based and traditional solutions, and improving in materials in terms of their environmental impact. Mixing recycled and waste materials into concrete, as a substitute for cement and/or aggregate, increases energy efficiency and sustainability in general.

CRT represents three types of glass that are very different in chemical composition. Due to the content of lead, barium, and strontium, CRT glass is hazardous waste. This chemical composition of cathode glass makes its further recycling, that is, its application in the production of another product, very difficult. However, numerous studies have confirmed that CRT glass behaves like a pozzolanic material and that it has a positive effect on the mechanical properties of mortar and concrete. Partial substitution of cement or sand with finely ground or finely crushed CRT glass reduces the amount of their consumption, increases energy efficiency, and enhances the level of sustainability of the process. By reviewing the literature, it is concluded that the use of CRT glass improves the specific properties of concrete depending on the proportion of waste raw materials. The results of leaching show that the concentrations of lead leached into the environment could be in some cases below the permissible limits depending on the proportion of CRT glass and, often, thanks to the encapsulation in the mortar matrix.

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