Potential of implementing cathode-ray tube (CRT) glass concrete piles in press-in engineering

Y. S. Kho
Master student, Department of Civil and Construction Engineering, Curtin University, Malaysia, CDT 250, 98009 Miri, Sarawak, Malaysia
K. S. Wong
Associate Professor, Department of Civil and Construction Engineering, Curtin University, Malaysia, CDT 250, 98009 Miri, Sarawak, Malaysia
N. N. M. Pauzi
Senior Lecturer, Department of Civil Engineering, College of Engineering, University Teknologi Mara, Shah Alam Selangor, 40450 Malaysia
M. S. Joo
Senior Lecturer, Department of Civil and Construction Engineering, Curtin University, Malaysia, CDT 250, 98009 Miri, Sarawak, Malaysia
T. Hadibarata
Associate Professor, Department of Civil and Construction Engineering, Curtin University, Malaysia, CDT 250, 98009 Miri, Sarawak, Malaysia

ABSTRACT

Concrete is the most implemented building material in the construction industry and the second most abundantly consumed product in the world after water as concrete has outstanding properties and low cost. Considering sustainability, e-wastes such as cathode-ray tube (CRT) are potentially being used to replace cement or aggregates in concrete, whereas the cement and aggregates are normally obtained from natural resources. CRT is defined as a vital element and technology implemented for displays in computer monitors and televisions while CRT glass occupies approximately 85% of CRT. Over the years, liquid crystal displays (LCDs), plasma display panels (PDPs), and light-emitting diode (LED) panels have been introduced to replace CRTs, and hence a large quantity of CRT waste is generated. In this paper, we aim to evaluate the existing knowledge about the usage of cathode-ray tube (CRT) glass replacing coarse aggregates in concrete. We also aim to explore the potential of using CRT glass in concrete piles which are commonly used in press-in engineering.

Keywords: *Cathode-ray tube glass, concrete piles, press-in engineering*

1. Concrete

1.1 Definition of concrete

Concrete is defined as a composite material that is produced by mixing aggregates (such as gravel, sand, stone), binding material (such as cement or lime), water and admixtures, in particular ratios. In general, concrete is a combination of fine and coarse aggregates, binding material, water, and admixture (optional) and the concrete quality and strength rely on the mixing ratios (Bharti et al., 2023; Lahmann et al., 2023; Likhit & Alex, 2023; Reda & Chidiac, 2023; Zhang et al., 2020).

1.2 Consumption of concrete

Concrete is the most implemented building material in the construction industry and the second most abundantly consumed product in the world after water as concrete has outstanding properties such as high compressive strength and adaptability, and is low cost (Bandyopadhyay et al., 2023; Bawab et al., 2021; Hilton et al., 2019; Kim et al., 2018; Luhar & Luhar, 2019; Seifan et al., 2016; Song et al., 2019; Yeo et al., n.d.). Over the years, the consumption of concrete keeps increasing due to the growing population in the world and increasing urbanization in developing countries. Therefore, concrete production has consumed many natural resources, especially aggregates because aggregates have a higher composition which estimated 70 to 80 percent in concrete, by volume, with approximately 25 to 35 percent of total aggregates produced in the world being implemented in concrete (Achal et al., 2013; Akshay et al., 2023; Chuo et al., 2020). The excessive implementation of natural resources in the production of concrete which raises environmental issues for having negative impacts on biodiversity and landscapes has become a major concern (Li et al., 2018; Meng et al., 2018).

1.3 Replacement of aggregates with waste in concrete

Since the natural resources of aggregates are limited and will be used up in the future, thus alternative materials need to be discovered to replace the natural aggregates in the production of concrete to attain a sustainable construction industry (Kim et al., 2018; Luhar & Luhar, 2019; Song et al., 2019). On the other hand, due to the speedy evolution of industry around the world, the amount of industrial waste disposed in the field keeps increasing to a worrying level and hence an effective recycling way needs to be proposed to treat the industrial waste properly to decrease the need for precious landfill space (Rashad, 2015). Furthermore, without an appropriate waste recycling framework, the large number of waste materials established will be either landfilled or burnt which will lead to critical contamination of the environment (Meng et al., 2018). Concrete has a high potential to reuse large quantities of waste materials to replace natural resources which is considered a win-win situation to reduce the implementation of natural resources and simultaneously recycle the waste materials in an effective way (Olofinnade et al., 2017). In summary, the implementation of recycled waste materials in concrete to replace natural aggregates can be a feasible solution to prevent the exhaustion of natural resources and enhance sustainability globally through the production of green concrete (Yeo et al., n.d.).

2. E-waste

2.1 Definition of e-waste

E-waste is defined as the solid waste material produced from useless and discarded electrical and electronic appliances and devices that are toxic and non-biodegradable (aini Osman & Aini Osman ab, 2016; Danish et al., 2023).

2.2 Implementation of e-waste in concrete

Over the years, the continuous development and glory technology in all the countries around the world causes a critical e-waste issue globally as the huge number of hazardous and non-biodegradable components generated from e-waste cannot be treated and managed appropriately (Hui et al., 2013; Yao et al., 2018). Since the disposal of e-waste in the field will endanger human health and lead to environmental pollution, recycled e-waste products can be reused to reduce the amount of e-waste at landfill (Danish et al., 2023). Therefore, a novel and viable solution is suggested by replacing the natural aggregates with e-waste in concrete to solve the e-waste disposal crisis, conserve the limited natural resources and avoid the negative consequences on human health and the environment (Luhar et al., 2022).

3. Cathode-ray tube (CRT) glass

3.1. Definition of CRT

Cathode-ray tube (CRT) is defined as a vital element and technology implemented for displays in computer monitors and televisions during the last decades (Choi & Lee, 2021; Iniaghe & Adie, 2015; Liu et al., 2020). CRT occupies two thirds of the overall weight of the computer monitors and televisions while CRT glass occupies approximately 85% of CRT (Liu et al., 2019; Wang et al., 2019; Zhao & Poon, 2017, 2021). The major raw material in CRT glass is silica while the other distinct metallic oxides, for example, lead oxide and barium oxide are also included in CRT glass as defenders for detrimental radiation (Iniaghe & Adie, 2015; Yao et al., 2018).

3.2. Components of CRT glass

As shown in **Fig. 1**, CRT glass is divided into three main components which are panel, funnel, and neck with a mass ratio of 65%, 30%, and 5% correspondingly (Gao et al., 2022; Grdić et al., 2022). The CRT panel glass contains a high concentration of barium oxide (12 percent by weight) and strontium oxide (12 percent by weight) and a low concentration of lead oxide (0-3 percent by weight). On the other hand, the CRT funnel and neck glass has a high concentration of lead oxide which are 22-25 percent by weight and 30 percent by weight respectively (Gao et al., 2022; Grdić et al., 2022).

3.3. CRT glass waste

In recent times, plasma display panels (PDPs), liquid crystal displays (LCDs), and light-emitting diode (LED) panels are invented to displace cathode ray tubes (CRTs) in computer monitors and televisions (Bawab et al., 2021; Pauzi et al., 2019b; Zhao et al., 2013). Therefore, the abandoned CRT version of computer monitors and televisions keeps increasing and thus establishing a huge amount of CRT waste (Lee et al., 2016; Pauzi et al., 2019a; Wei et al., 2020). Although the production of CRT computer monitors and televisions is suspended with the enhancement of technology, the disposal of CRT waste in landfills is still rising from time to time as the old computer monitors and televisions are still exist and implemented in households (Grdić et al., 2023).

4. CRT glass concrete

Nowadays, the implementation of waste materials in the manufacture of concrete is prevalent worldwide to attain the green development goal (Grdić et al., 2021; Pauzi et al., 2022). Therefore, the construction industry can be one of the potential tracks to dispose CRT glass waste (Grdić et al., 2023). The production of concrete, cement mortar, and paste from CRT glass waste can reduce the amount of e-waste in landfill and simultaneously protect natural resources, save cost, and enhance sustainability in the construction sector (Song et al., 2019). CRT glass waste is a suitable replacement for fine aggregates and cement in concrete as CRT glass is pozzolanic in nature, contains a high content of silica, performs sufficient intrinsic strength, and has low water absorption (Pauzi et al., 2019b). However, the process of manufacturing the CRT glass powder to substitute cement in concrete instigates serious dust contamination. Hence, implementing CRT glass waste as coarse aggregates in concrete is a more practical and secure disposal approach by only undergoing crushing (Gao et al., 2022).

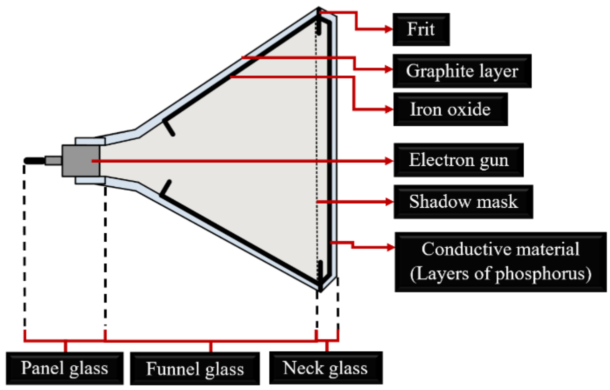

Fig. 1 Composition of a classic CRT monitor (modified from (Bawab et al., 2021))

5. Limitations of CRT glass concrete

5.1 Mechanical strength

One of the vital characteristics of concrete is mechanical strength, nevertheless, the compressive strength, tensile strength, and flexural strength of CRT glass concrete are lower than that of normal concrete due to the smooth surface of CRT glass aggregates which will weaken the bonds between the aggregates and mortar at the interfacial transition zone (ITZ) (Liu et al., 2018; Pauzi et al., 2021).

5.2 Lead leaching

Since CRT glass for the neck and funnel parts have a high concentration of lead oxide, thus the possibility of lead leaching is high in CRT glass concrete which leads to a major environmental concern in producing CRT glass concrete (Olofinnade et al., 2017). Therefore, mitigating the lead-leaching hazards from CRT glass waste in concrete by undergoing a proper treatment operation on CRT funnel glass to ensure that the leaching of lead does not surpass the control limit is considered a crucial recycling philosophy (Liu et al., 2020).

5.3 Alkali-silica reaction (ASR) expansion

According to **Fig. 2**, since CRT glass waste consists of a high content of silica, thus the utilization of CRT glass aggregates in concrete can cause serious alkali-silica reaction (ASR) expansion which is a main obstacle in implementing CRT glass concrete and thus raises durability concerns in the construction sector (Ling & Poon, 2014; Liu et al., 2018; Wang et al., 2019). ASR is defined as a chemical interaction between the alkaline concrete and the reactive aggregates or high silica content of aggregates, and ASR requires a long period of time to exhibit (Pauzi et al., 2021). ASR gel will be generated during the ASR and the exertion of internal pressure with the existence of moisture in the CRT glass concrete due to the swelling of ASR gel will cause expansion (Grdić et al., 2021). As a result, ASR is the main contributor to the cracking and damage of CRT concrete structures due to detrimental expansion which leads to high maintenance and reconstruction costs (Iniaghe & Adie, 2015).

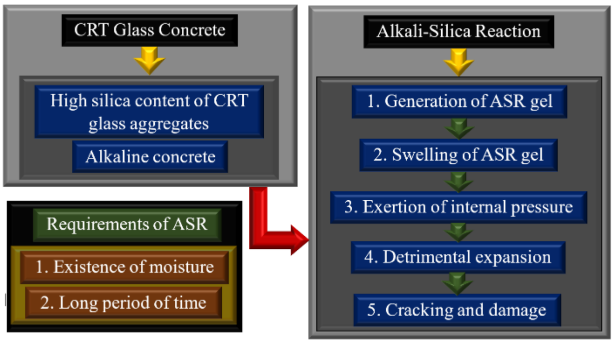

Fig. 2 Structure for ASR expansion of CRT glass concrete (modified from (Ling & Poon, 2014; Pauzi et al., 2019a))

6. Mitigations for the limitations of CRT glass concrete

Since CRT funnel glass comprises 30% of the CRT glass and contains a high concentration of lead oxide (PbO), thus CRT funnel glass waste needs to be recycled to produce crushed CRT funnel glass (GC) and spherical CRT funnel glass (GS) as shown in **Fig. 3** to mitigate the lead (Pb) leaching issue in CRT glass concrete (Liu et al., 2019; Pauzi et al., 2022). The CRT funnel glass waste needs to undergo a melting and annealing process, then cooled down to obtain GS. On the other hand, CRT funnel glass waste is required to undergo a smashing and grading process to produce GC (Danish et al., 2023).

Other than that, according to the literature, the smaller the particle size of CRT glass, the more severe the lead leaching in CRT glass concrete. Therefore, the size of GC used in CRT glass concrete is suggested to be controlled at the range of 4.75 mm to 19 mm to reduce the negative consequences of lead leaching (Song et al., 2019). Even though the mechanical strength of CRT concrete is decreased due to the smooth surface of GC and GS, the combination of 40% GC and 60% GS in concrete was discovered to have sufficient strength as the mix of GC and GS can produce coarse aggregates that comprising of distinct sizes and shapes which can thus create a more compacted CRT glass concrete (Pauzi et al., 2019a). Furthermore, adding silica fume in CRT glass concrete can also help to improve the mechanical performance of CRT glass concrete (Pauzi et al., 2022).

According to the literature, the implementation of spherical CRT funnel glass (GS) can reduce the detrimental ASR expansion and thus mitigate the formation of cracks in CRT glass concrete (Pauzi et al., 2021). Other than that, the addition of appropriate pozzolan, for example, silica fume, fly ash for a particular proportion to substitute cement partially in CRT glass concrete can inhibit the ASR expansion (Liu et al., 2018; Romero et al., 2013).

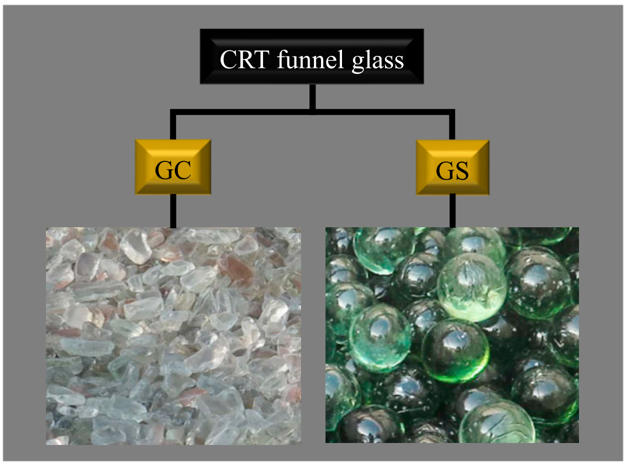

Fig. 3 Crushed (GC) and spherical (GS) CRT funnel glass (modified from (Pauzi et al., 2021))

7. Potential of implementing CRT glass in concrete piles for press-in engineering

Square reinforced concrete (RC) pile is commonly used in press-in engineering. The strength of concrete with CRT glass in the form of crushed and spherical is approximately 50 MPa, comparable to the strength of square RC pile, which is 45 MPa (Pauzi et al., 2019b). Therefore, in terms of strength, there is a potential to replace coarse aggregates in square RC piles with CRT glass. However, ASR expansion of CRT glass concrete used as RC pile needs to be considered and the crack width due to the expansion also needs to be controlled. Moreover, the potential of lead leaching needs to be evaluated to prevent contamination of groundwater.

Prestressed high-strength concrete piles such as spun piles with typical concrete strength of 80 MPa are also commonly used in press-in engineering. To date, the implementation of CRT glass in high-strength concrete is limited. The potential to replace the coarse aggregates in the piles with CRT glass needs to be further investigated.

8. Conclusion

In a nutshell, the CRT glass waste generated can be recycled to replace the coarse aggregates in concrete to enhance sustainability and reduce the e-waste at landfills. The CRT glass concrete has the potential to be used in producing reinforced concrete piles and then implemented in press-in engineering. However, the usage of CRT glass in prestressed high-strength concrete pipe piles needs further investigation.

9. Acknowledgements

The authors acknowledge the research fund under the Fundamental Research Grant Scheme (FRGS/1/2022/TK01/CURTIN/03/1) provided by the Ministry of Higher Education (MOHE), Malaysia.

References

Achal, V. et al. 2013. Biogenic treatment improves the durability and remediates the cracks of concrete structures. *Construction and Building Materials*, *48*, 1–5. https://doi.org/10.1016/j.conbuildmat.2013.06.061

aini Osman, N., & Aini Osman ab, N. 2016. *Handling E-Waste in Malaysia: Management, Policies and Strategies Environmental Life Cycle Assessment (LCA) of CRT and LCD in E-waste View project English Proceedings of the Eleventh International Conference on Waste Management and Technology Peer-review under responsibility of Tsinghua University/ Basel Convention Regional Centre for Asia and the Handling E-Waste in Malaysia: Management, Policies and Strategies*. https://www.researchgate.net/publication/309642705

Akshay, J. P. et al. 2023. Experimental Study on Durability and Mechanical Properties of Lightweight Mortar with Encapsulated Spore Forming Bacteria. *Lecture Notes in Civil Engineering*, *284*, 1185–1197. https://doi.org/10.1007/978-3-031-12011-4_98

Bandyopadhyay, A. et al. 2023. Microbial repairing of concrete & its role in CO2 sequestration: a critical review. In *Beni-Suef University Journal of Basic and Applied Sciences* (Vol. 12, Issue 1). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1186/s43088-023-00344-1

Bawab, J. et al. 2021. Structural performance of reinforced concrete beams incorporating cathode-ray tube (Crt) glass waste. *Buildings*, *11*(2), 1–16. https://doi.org/10.3390/buildings11020067

Bharti, G. et al. 2023. Effect of Self-healing Concrete on Modular Structure. *Lecture Notes in Civil Engineering*, *281*, 323–331. https://doi.org/10.1007/978-981-19-4731-5_31

Choi, Y. S., & Lee, S. M. 2021. Fundamental properties and radioactivity shielding performance of concrete recycled cathode ray tube waste glasses and electric arc furnace slag as aggregates. *Progress in Nuclear Energy*, *133*. https://doi.org/10.1016/j.pnucene.2021.103649

Chuo, S. C. et al. 2020. Insights into the current trends in the utilization of bacteria for microbially induced calcium carbonate precipitation. In *Materials* (Vol. 13, Issue 21, pp. 1–28). MDPI AG. https://doi.org/10.3390/ma13214993

Danish, A. et al. 2023. A compendious review on the influence of e-waste aggregates on the properties of concrete. *Case Studies in Construction Materials*, *18*. https://doi.org/10.1016/j.cscm.2022.e01740

Gao, X. et al. 2022. Performance of fly ash-based geopolymer mortars with waste cathode ray tubes glass fine aggregate: A comparative study with cement mortars. *Construction and Building Materials*, *344*. https://doi.org/10.1016/j.conbuildmat.2022.128243

Grdić, D. et al. 2022. Potential for Use of Recycled Cathode Ray Tube Glass in Making Concrete

Blocks and Paving Flags. *Materials*, *15*(4). https://doi.org/10.3390/ma15041499

Grdić, D. Z. et al. 2021. Durability properties of concrete supplemented with recycled crt glass as cementitious material. *Materials*, *14*(16). https://doi.org/10.3390/ma14164421

Grdić, Z. et al. 2023. Concrete Resistance Achieved with Subtly Ground Tube Glass of Cathode Ray as Supplementary Cementitious Material to Sulphate Attack. *Periodica Polytechnica Civil Engineering*, *67*(1), 298–307. https://doi.org/10.3311/PPci.21086

Hilton, B. et al. 2019. The functional and environmental performance of mixed cathode ray tubes and recycled glass as partial replacement for cement in concrete. *Resources, Conservation and Recycling*, *151*. https://doi.org/10.1016/j.resconrec.2019.104451

Hui, Z. et al. 2013. Properties of mortar prepared with recycled cathode ray tube funnel glass sand at different mineral admixture. *Construction and Building Materials*, *40*, 951–960. https://doi.org/10.1016/j.conbuildmat.2012.11.102

Iniaghe, P. O., & Adie, G. U. 2015. Management practices for end-of-life cathode ray tube glass: Review of advances in recycling and best available technologies. *Waste Management and Research*, *33*(11), 947–961. https://doi.org/10.1177/0734242X15604212

Kim, I. S. et al. 2018. Evaluation of durability of concrete substituted heavyweight waste glass as fine aggregate. *Construction and Building Materials*, *184*, 269–277. https://doi.org/10.1016/j.conbuildmat.2018.06.221

Lahmann, D. et al. 2023. Autogenous self-healing of concrete: Experimental design and test methods-A review. In *Engineering Reports* (Vol. 5, Issue 1). John Wiley and Sons Inc. https://doi.org/10.1002/eng2.12565

Lee, J. S. et al. 2016. Recycling of cathode ray tube panel glasses as aggregates of concrete blocks and clay bricks. *Journal of Material Cycles and Waste Management*, *18*(3), 552–562. https://doi.org/10.1007/s10163-015-0350-6

Li, W. et al. 2018. Recent Advances in Intrinsic Self-Healing Cementitious Materials. *Advanced Materials*, *30*(17). https://doi.org/10.1002/adma.201705679

Likhit, M. L., & Alex, J. 2023. A Potential Review on Self-healing Material – Bacterial Concrete Methods and Its Benefits. *Lecture Notes in Civil Engineering*, *284*, 1087–1110. https://doi.org/10.1007/978-3-031-12011-4_92

Ling, T. C., & Poon, C. S. 2014. Use of recycled CRT funnel glass as fine aggregate in dry-mixed concrete paving blocks. *Journal of Cleaner Production*, *68*, 209–215. https://doi.org/10.1016/j.jclepro.2013.12.084

Liu, C. et al. 2020. Self-healing of concrete cracks by immobilizing microorganisms in recycled aggregate. *Journal of Advanced Concrete Technology*, *18*(4), 168–178. https://doi.org/10.3151/jact.18.168

Liu, H. et al. 2019. An investigation on physical, mechanical, leaching and radiation shielding behaviors of barite concrete containing recycled cathode ray tube funnel glass aggregate. *Construction and Building Materials*, *201*, 818–827. https://doi.org/10.1016/j.conbuildmat.2018.12.221

Liu, T. et al. 2018. Experimental investigation on the durability performances of concrete using cathode ray tube glass as fine aggregate under chloride ion penetration or sulfate attack. *Construction and Building Materials*, *163*, 634–642. https://doi.org/10.1016/j.conbuildmat.2017.12.135

Luhar, S. et al. 2022. A Review on the Performance Evaluation of Autonomous Self-Healing Bacterial Concrete: Mechanisms, Strength, Durability, and Microstructural Properties. In *Journal of Composites Science* (Vol. 6, Issue 1). MDPI. https://doi.org/10.3390/jcs6010023

Luhar, S., & Luhar, I. 2019. Potential application of E-wastes in construction industry: A review. In *Construction and Building Materials* (Vol. 203, pp. 222–240). Elsevier Ltd. https://doi.org/10.1016/j.conbuildmat.2019.01.080

Meng, Y. et al. 2018. Recycling of wastes for value-added applications in concrete blocks: An overview. In *Resources, Conservation and Recycling* (Vol. 138, pp. 298–312). Elsevier B.V. https://doi.org/10.1016/j.resconrec.2018.07.029

Olofinnade, O. M. et al. 2017. Sustainable Green Environment through Utilization of Waste Soda-Lime Glass for Production of Concrete. *JMES*, *8*(4), 1139–1152. http://www.jmaterenvironsci.com/

Pauzi, N. N. M. et al. 2019a. Influence of spherical and crushed waste Cathode-Ray Tube (CRT) glass on lead (Pb) leaching and mechanical properties of concrete. *Journal of Building Engineering*, *21*, 421–428. https://doi.org/10.1016/j.jobe.2018.10.024

Pauzi, N. N. M. et al. 2019b. The effects of using cathode ray tube (CRT) glass as coarse aggregates in high-strength concrete subjected to high temperature. *Journal of Material Cycles and Waste Management*, *21*(6), 1414–1425. https://doi.org/10.1007/s10163-019-00893-7

Pauzi, N. N. M. et al. 2021. The effect of melted-spherical and crushed CRT funnel glass waste as coarse aggregates on concrete performance. *Journal of Building Engineering*, *35*. https://doi.org/10.1016/j.jobe.2020.102035

Pauzi, N. N. M. et al. 2022. Potential use of spherical glass sourced from cathode ray tube funnel glass for the application as coarse aggregate in concrete. *Journal of Applied Science and Engineering (Taiwan)*, *25*(3), 437–445. https://doi.org/10.6180/jase.202206_25(3).0010

Rashad, A. M. 2015. Recycled cathode ray tube and liquid crystal display glass as fine aggregate replacement in cementitious materials. In *Construction and Building Materials* (Vol. 93, pp. 1236–1248). Elsevier Ltd. https://doi.org/10.1016/j.conbuildmat.2015.05.004

Reda, M. A., & Chidiac, S. E. 2023. Properties and Performance Metrics of Healing Agents in Self-healing Concrete. *Lecture Notes in Civil Engineering*, *248*, 403–414. https://doi.org/10.1007/978-981-19-1004-3_34

Romero, D. et al. 2013. Study on the mechanical and environmental properties of concrete containing cathode ray tube glass aggregate. *Waste Management*, *33*(7), 1659–1666. https://doi.org/10.1016/j.wasman.2013.03.018

Seifan, M. et al. 2016. Bioconcrete: next generation of self-healing concrete. In *Applied Microbiology and Biotechnology* (Vol. 100, Issue 6, pp. 2591–2602). Springer Verlag. https://doi.org/10.1007/s00253-016-7316-z

Song, W. et al. 2019. Effects of recycled CRT glass fine aggregate size and content on mechanical and damping properties of concrete. *Construction and Building Materials*, *202*, 332–340. https://doi.org/10.1016/j.conbuildmat.2019.01.033

Wang, J. et al. 2019. Evaluation of cathode ray tube (CRT) glass concrete with/without surface treatment. *Journal of Cleaner Production*, *226*, 85–95. https://doi.org/10.1016/j.jclepro.2019.03.300

Wei, H. et al. 2020. Dynamic and environmental performance of eco-friendly ultra-high performance concrete containing waste cathode ray tube glass as a substitution of river sand. *Resources, Conservation and Recycling*, *162*. https://doi.org/10.1016/j.resconrec.2020.105021

Yao, Z. et al. 2018. Recycling difficult-to-treat e-waste cathode-ray-tube glass as construction and building materials: A critical review. In *Renewable and Sustainable Energy Reviews* (Vol. 81, pp. 595–604). Elsevier Ltd. https://doi.org/10.1016/j.rser.2017.08.027

Yeo, J. S. et al. n.d. *An overview on the properties of eco-friendly concrete paving blocks incorporating selected waste materials as aggregate*. https://doi.org/10.1007/s11356-021-13836-3/Published

Zhang, W. et al. 2020. Self-healing cement concrete composites for resilient infrastructures: A review. In *Composites Part B: Engineering* (Vol. 189). Elsevier Ltd. https://doi.org/10.1016/j.compositesb.2020.107892

Zhao, H. et al. 2013. Utilizing recycled cathode ray tube funnel glass sand as river sand replacement in the high-density concrete. *Journal of Cleaner Production*, *51*, 184–190. https://doi.org/10.1016/j.jclepro.2013.01.025

Zhao, H., & Poon, C. S. 2017. A comparative study on the properties of the mortar with the cathode ray tube funnel glass sand at different treatment methods. *Construction and Building Materials*, *148*, 900–909. https://doi.org/10.1016/j.conbuildmat.2017.05.019

Zhao, H., & Poon, C. S. 2021. Recycle of large amount cathode ray tube funnel glass sand to mortar with supplementary cementitious materials. *Construction and Building Materials*, *308*. https://doi.org/10.1016/j.conbuildmat.2021.124953