THE IMPACT OF PARTIAL REPLACEMENT OF COARSE AGGREGATE WITH ELECTRONIC WASTE (E-WASTE) ON THE STRENGTH OF CONCRETE

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PLAGIARISM

This work **THE IMPACT OF PARTIAL REPLACEMENT OF COARSE AGGREGATE WITH ELECTRONIC WASTE (E-WASTE) ON THE STRENGTH OF CONCRETE** by MOMOH, Ernest Jesuofumi, with Mat. Number ENG2002108, of The Department of Civil Engineering, Faculty of Engineering, University of Benin, Benin City, Edo State, Nigeria, has PASSED the PLAGIARISM TEST.

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DEDICATION

This work is dedicated to the master of the universe, Almighty God, who by his grace and mercy saw me through the years of my studies in good health.

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ACRONYMS

EEE - - - Electrical and Electronics Equipment

E-Waste - - Electronics Waste

GGBFS - - Ground Granulated Blast Furnace Slag

HIPS - - - High-Impact Polystyrene

IT - - - Information Technology

OPC - - - Ordinary Portland Cement

ABSTRACT

Electronic waste is an emerging issue posing serious pollution problems to human and the environment. The specific objectives of this work are to determine the physical properties of crushed e-waste materials, granite and aggregates, to design a concrete mix incorporating e-waste and granite as the coarse aggregate, to investigate the strength development of e-waste concrete at 7, 14 and 28 days, under standard curing method, to determine the effect of e-waste replacement on the compressive and flexural strength of concrete, and to analyse the result and ascertain the benefits of e-waste in the production of concrete.

The research methodology will involve performing a comprehensive literature review and laboratory investigation of compressive strength and flexural test. Before that, several series of test would be carried out which includes specific gravity test, sieve analysis test, mix design, slump test, and casting of concrete test cubes.

The results showed that adding e-waste as a partial replacement for coarse aggregate increased workability but reduced strength. Slump values rose from 27 mm in the control mix to 61 mm at 20% replacement, indicating greater fluidity due to the smooth, non-absorbent surface of e-waste particles. In contrast, compressive strength dropped from 20.09 N/mm^2 to 10.43 N/mm^2, and flexural strength from 5.25 N/mm^2 to 0.38 N/mm^2 as e-waste content increased. The mix with 5% e-waste achieved 18.12 N/mm^2, close to the control, showing that small replacements maintain acceptable performance. Overall, e-waste improved workability but reduced strength, with 5% replacement identified as the optimum level for structural use. Using e-waste as a partial replacement for coarse aggregate is feasible up to 5%, giving the best compressive and flexural strength. Higher replacements (above 10%) reduce strength significantly. Further studies are recommended under real site conditions, for longer curing periods, and in combination with other waste materials to improve performance.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

In today's world, construction activities are nearly impossible to envision without concrete, as it is the most commonly used building material in the industry. Its widespread use is primarily due to its exceptional strength and long-lasting nature. However, with rapid global advancements and environmental changes, there is a growing emphasis on protecting the environment, conserving natural resources, and recycling waste materials. One of the new waste materials used in the concrete industry is E-waste. For adopting more sustainable approach for disposing the e-waste is partially filling the aggregates with e-waste in concrete. Use of these materials not only helps in getting them utilized in concrete and other construction materials, it helps in reducing the cost of concrete manufacturing, but also has several indirect benefits such as reduction in landfill cost, saving in energy, and protecting the environment from possible pollution effects. Electronic wastes include old computers, TVs, mobile phones, washing machines, refrigerators etc. that has reached its end of life. Tonnes of e-wastes are developing in this era. So the disposal is a big problem in recent years. Efforts have been made in the concrete industry to use non-biodegradable components of E-waste as a partial replacement of the coarse or fine aggregates. E-wastes will not disintegrate or degenerate. On one hand, the development of electronics products has made life easy for all but on the other hand, it has encouraged the "use and throw" mentality. (Muhsina *et al*., 2024)

These days, most people would rather purchase a new appliance than go through the hassle of repairing an old one. Such a trend not only leads to an increase in the volume of electrical and electronic waste but also poses a serious threat to public health and the environment. In developed countries, previously it was about 1% of total solid waste generation and currently it grows to 2% by 2010. In developing countries, it ranges 0.01% to 1% of the total municipal solid waste generation. E-waste is an emerging issue posing serious pollution problems to the human and the environment options need to be considered especially on recycling concepts. E-waste describes loosely discarded surplus, obsolete, broken, electrical or electronic devices. Rapid technology change, low initial cost has resulted in a fast growing surplus of electronic waste around the globe. Several tonnes of E-waste need to be disposed per year. E-waste contains numerous types of substances and chemicals creating serious human health and environment problems if not handled properly.

The development of infrastructures such as highways, power projects, industrial structures etc., is essential in a country to meet the requirements of globalization. In the construction of buildings and other structures, concrete plays a significant role and a large quantum of concrete is being utilized. Concrete is one of the most versatile, economical, and universally used construction material. Concrete is a mixture of water, cement or binder and aggregates. Properties of concrete applicable for construction purposes are compressive strength, tensile strength and flexural strength, elastic modulus, shrinkage, creep, durability, etc. of all the properties, compressive strength is its predominant property which gives the quality of hardened concrete. The strength of concrete depends on aggregate type, size and source (Abdullahi, 2012; Hassan, 2014: Aginam *et al* 2013; Jimoh and Awe, 2007). Aggregates amount to at least three-quarter of the volume of normal weight of concrete and they are cheaper than cement and also confers a considerable better durability in concrete than ordinary cement paste. The aggregates are divided into two major divisions by size fine and coarse. The fine aggregates are sizes of at least 5mm (Neville 2011). There has been concern about the best aggregate sizes to be adopted in the manufacturing of concrete in Nigeria construction industry. Compressive strength of concrete is the value of test strength below which not more than a percentage of the test results should fall (Kong and Evan 1987). It is found to depend on the water to cement ratio, degree of compaction, ratio of cement to aggregate, bond between mortar and aggregate, and grading, shape, strength and size of the aggregate (Rocco and Elices, 2009; Elices and Rocco, 2008). E-waste is a term used to cover almost all types of electrical and electronic equipment (EEE) that has or could enter the waste stream. Although e-waste is a general term, it can be considered to be covering TVs, computers, mobile phones etc.

Owing to the scarcity of coarse aggregate for the preparation of concrete, partial replacement of E-waste with coarse will be attempted. The work will be conducted on M20 grade mix. In this work, the percentage of various replacement levels of coarse aggregate with E-waste in the range of 0%, 10%, 15%, and 20%. Finally the mechanical properties of the concrete mix specimens to be obtained from the addition of these materials will be compared with that to be obtained by using control concrete mix.

The materials to be used for this project work include Portland cement, granite chippings, fine aggregate (sharp sand), and water. The fine aggregate will be sharp river sand, Dangote Portland cement (a popular Nigerian brand of cement) will be used, and the coarse aggregate to be used will be granite and E-waste.

1.2 Statement of the Problem

In today’s world, disposing of electronic products without harming the environment poses a significant challenge. To address the growing issue of e-waste, recycling it in the concrete industry has emerged as a practical solution. With the high demand for concrete, natural resources are depleting, leaving industries struggling to meet requirements. Incorporating e-waste into concrete not only promotes its reuse but also lowers construction costs, making it an economically and environmentally beneficial approach.

1.3 Aim and Objectives of Study

The aim of this study is to evaluate the impact of partial replacement of coarse aggregate with Electronic waste (E-waste) on the strength of concrete.

The specific objectives of this work are to:

1. Determine the physical properties of crushed e-waste materials, granite and aggregates.
2. Design a concrete mix incorporating e-waste and granite as the coarse aggregate.
3. Investigate the strength development of e-waste concrete at 7, 14 and 28 days, under standard curing method.
4. Determine the effect of e-waste replacement on the compressive and flexural strength of concrete.
5. Analyse the result and ascertain the benefits of e-waste in the production of concrete.

1.4 Scope of Study

The scope of this study focuses on evaluating the feasibility of partially replacing conventional coarse aggregates (granite) with crushed electronic waste (e-waste) in concrete production. A standard concrete mix was designed with varying e-waste replacement levels (e.g., 5%, 10%, 15%, 20%), followed by an investigation into the strength development of the e-waste concrete at 7, 14, and 28 days under standard curing conditions. The study assessed the impact of e-waste on compressive and flexural strength, comparing results with control specimens (0% e-waste) to determine optimal replacement percentages. The findings was statistically evaluated to determine the significance of e-waste incorporation, along with an assessment of its environmental benefits in promoting sustainable construction practices. The study is limited to non-metallic e-waste components, standard curing conditions, and mechanical strength properties. This research aims to contribute to waste recycling in construction while conserving natural resources.

1.5 Justification of study

This study was done due to the fact that electronic waste has caused serious health and pollution problems, the fact that electronic equipment contain serious contaminants such as lead, cadmium, beryllium etc. these contaminant are capable of affecting the environment (i.e. water, soil and air). To ameliorate these affect, hence the use as partial replacement of coarse aggregate.

Also, this work was carried out in order to reduce the cost of concrete production thereby reducing the cost of construction.

CHAPTER TWO

LITERATURE REVIEW

2.1 Concrete

Concrete is the predominant construction material globally, primarily due to its exceptional strength and long-lasting nature. As the world rapidly evolves and environmental conditions shift, there is a growing emphasis on sustainability, conservation of natural resources, and the recycling of waste materials. Among the innovative waste materials being incorporated into concrete production is electronic waste (E-waste). Reuse of E-waste in concrete is seen as a practical solution to manage its increasing disposal challenges. (Suchithra and Indu, 2015)

For years, researchers have explored the use of industrial by-products to enhance concrete's properties. Recent studies have focused on integrating materials like fly ash, silica fume, ground granulated blast furnace slag (GGBS), and crushed glass into construction projects. These by-products can serve as partial replacements for either aggregates or cement, depending on their chemical makeup and particle size. Their inclusion in concrete not only improves performance but also addresses environmental concerns related to waste disposal.

Electronic waste (e-waste) is emerging as a novel material in the concrete industry, offering a sustainable solution to its growing disposal challenges. Incorporating e-waste into concrete production is regarded as a practical approach to managing large volumes of discarded electronics. One effective method involves using processed e-waste as a partial or complete substitute for conventional coarse aggregates in concrete mixtures. Studies suggest that this not only reduces the environmental burden of e-waste but can also enhance concrete properties, such as strength and thermal insulation.

The applications of industry by products in concrete are to be partial aggregate replacement or partial cementitous materials depending on their chemical composition and gain size. Recent studies have shown that reuse of electronic waste has economical and technical advantage for solving the disposal of large amount of e-waste.

E-waste source in the form of loosely discarded, surplus, obsolete, broken, electrical or electronic devices from commercial informal recyclers have been collected which were crushed and ground to small size. Table 2.1 represents some physical properties of E-waste particle and coarse aggregate.

Table 2.1: Physical properties of e-waste particles and coarse aggregate

Properties	E-waste particles	Coarse aggregate (granite)
Specific gravity	1.9	2.74
Absorption	0.2	0.05
Crushing value	<2%	26.8%
Shape	Angular	Angular
Impact value	<2	24.9

Source: (Suchithra and Indu, 2015)

2.2 Electronics Waste (E-Waste)

Electronic waste, commonly known as e-waste or waste electrical and electronic equipment (WEEE), refers to discarded electronic or electrical devices that have reached the end of their useful life.(Kahhat, *et al*, 2008) This includes everything from computers and smart phones to household appliances and medical equipment, whether they are still functional or not. Even devices that are meant to be refurbished, reused, resold, or recycled are still considered e-waste if they are not properly managed. The improper handling of e-waste, particularly in developing countries where informal recycling practices are common, poses serious risks to both human health and the environment. (W.H.O., 2014) The rapid growth of e-waste is fueled by the Digital Revolution and constant technological advancements, such as crypto-currency mining, which drive frequent upgrades and shorter product lifecycles. Consumers often discard electronics prematurely due to the release of new models, low recycling rates, and decreasing lifespans of devices like computers.(Perkins, *et al*, 2014).

Many electronic components, including CPUs and circuit boards, contain hazardous materials like lead, cadmium, beryllium, and brominated flame retardants, which can be harmful if not disposed of properly. The recycling and disposal processes, especially in informal settings, expose workers and nearby communities to significant health risks. (Sakar, 2016) In places like Bengaluru, India, e-waste is often collected, disassembled, and processed without proper safety measures, leading to environmental contamination and health problems. When electronic products are thrown away after use, they contribute to the growing global e-waste crisis, which is exacerbated by consumer culture and rapid technological advancements. The sheer volume of e-waste generated highlights the urgent need for better recycling systems, stricter regulations, and more sustainable consumption habits to mitigate its harmful effects on people and the planet.

Examples of electronic waste include, but not limited to:

i. TVs, computer monitors, printers, scanners, keyboards, mice, cables, circuit boards, lamps, clocks, flashlight, calculators, phones, answering machines, digital/video cameras, radios, VCRs, DVD players, MP3 and CD players

ii. Kitchen equipment (toasters, coffee makers, microwave ovens)

iii. Laboratory equipment(hot plates, microscopes, calorimeters)

iv. Broken computer monitors, television tubes (CRTs)

2.3 E-Waste and the Nigeria Situation

Nigeria's urban centers grapple with substantial waste management difficulties, the scale of which is often proportional to a city's population and financial resources. A critical environmental concern in these expanding urban zones is the ineffective handling of municipal and industrial refuse, from its collection to its final disposal. In both cities and rural areas, accumulating heaps of uncontrolled solid waste mar the landscape, diminish real estate worth, and exacerbate air and water contamination, creating significant public health dangers. Furthermore, the widespread method of disposing of unsorted waste in open areas often results in unregulated burning and the emission of toxic substances.

The absence of a domestic Information Technology industry in Nigeria means the sector is heavily reliant on imports. Consequently, in addition to the e-waste generated locally, a significant portion originates from the importation of used Electrical and Electronic Equipment (EEE), which may be either intentional or unintentional (Schmidt, 2006). The growing environmental threat from informal recycling and disposal practices has recently drawn media attention (Puckett, 2005). However, this issue has yet to receive substantial consideration from both policy makers and electronics manufacturers. Research conducted under the E-waste Africa project indicates a consistent rise in the volume of EEE within Africa, particularly Nigeria (Wasswa, 2008; Magashi, 2011; Finlay, 2008). This trend inevitably forecasts a corresponding increase in future e-waste generation (Schluep *et al.*, 2009).

2.4 E-Waste Concrete

Concrete is a composite material composed of a binder—Portland cement—mixed with water to form a paste that binds aggregates such as fine river sand, granite, and, in this case, e-waste. This mixture hardens over time to form e-waste concrete.

The utilization of industrial by-products in concrete, whether as a partial aggregate replacement or a supplementary cementitious material, is determined by their chemical properties and particle size. Research indicates that incorporating finely ground e-waste into concrete offers both economic and technical benefits, presenting a viable solution for managing large volumes of this waste stream (Muhsina *et al.*, 2024). Consequently, based on its specific composition and size, e-waste can be repurposed within the construction industry as a coarse aggregate, fine aggregate, or a fine filler.

Concrete is comparatively weak in tension. Generally the flexural tensile strength of cement concrete is about one eighth to one tenth of its compressive strength. It is difficult to measure direct tensile strength and hence flexure tensile strength is commonly measured.

The flexural tensile strength of concrete typically exceeds its direct tensile strength. This difference arises because, in a direct tension test, the stress is uniformly distributed, and a crack propagates immediately once the local tensile capacity is exceeded. In contrast, during a flexural test, the stress distribution is non-uniform, and adjacent, less-stressed material can help restrain crack propagation. Since concrete's strength is governed by its weakest point, its flexural strength (also known as the modulus of rupture) is defined as its resistance to cracking under bending loads. Furthermore, empirical relationships have been established between this modulus of rupture and the tensile stress at failure in direct compression specimens.

The flexural tensile strength of concrete is significantly influenced by the physical characteristics of its aggregates. Research indicates that concrete made with angular, crushed aggregates (such as the processed e-waste used in this study) demonstrates higher flexural strength than concrete with smooth, rounded gravel. This enhancement is attributed to the superior mechanical interlock provided by the rougher texture and sharper edges of the crushed particles (Hariharan and Punitha, 2024).

Furthermore, the ratio of a concrete's tensile strength to its compressive strength is not fixed; it tends to decrease as the concrete ages and as its overall strength grade increases.

2.5 Utilization of E-Waste in Construction

The civil construction industry has a long history of endeavoring to incorporate industrial by-products like fly ash, silica fume, blast furnace slag, and recycled glass or plastics. Repurposing such waste materials offers a viable strategy for mitigating environmental and ecological challenges. This practice provides dual benefits: it facilitates the productive consumption of waste in cement, concrete, and other building materials, thereby lowering production costs, and it yields significant indirect advantages. These include reduced landfill demand, conservation of energy, and the prevention of potential pollution.

Aditya *et al*. (2016) worked on the Utilization of E Waste in Concrete as Coarse aggregates and fine aggregates. Strength tests and durability tests were carried out on M20 grade conventional concrete and concrete with e-waste as coarse aggregates and e- waste as fine aggregates. The results were same as the conventional concrete up to 10% replacement for both coarse and fine aggregate replacements. E- Waste as Fine aggregates showed good usability than as coarse aggregates due to the bonding problem of e-coarse aggregates and segregation of concrete. It showed good workability improvements in e- fine aggregates than river sand due to the water absorption problems of river sand.

Rajiv *et al*. (2015) experimented in utilization of different combinations of e-wastes and recycled coarse aggregate together as a substitute for conventional aggregates.

The site-tested concrete specimens which would contain recycled aggregates were collected and were combined with the e-waste as complete replacement of coarse aggregates by altering the proportions of these wastes. M20 grade of concrete was made. The e-waste strips were also used as reinforcement in concrete to enhance the tensile properties. The results show that optimum mix of recycled aggregates and e-waste as coarse aggregates can be effectively used in the sub base preparation for the rigid pavements.

The results indicated 33.7% decrease in strength values for 15 percent replacement in coarse aggregates by e-waste and 16.86% decrease when coarse aggregates in the construction of low volume concrete pavements.

Krishna and Kante (2014) experimented the e-waste particles that were used as coarse aggregates in M30 mix grade of concrete. 0%, 5%, 10%, 15% and 20% proportions were used in the design as replacement of coarse aggregates. Also fly ash (10%) was used along with the e-waste for same proportions. Compressive strength and split tensile strength tests were carried for 7, 14 and 28 days cured samples are replaced by 20% e-waste plus fly ash (10%). The optimum strength was obtained at 15% replacement of coarse aggregates by e-waste.

Previous research on the use of e-waste in concrete has primarily focused on its application as a partial substitute for both coarse and fine aggregates. Further investigations have explored the inclusion of e-waste fibers to enhance the material's tensile properties. The collective findings from these studies indicate that e-waste possesses a superior impact and crushing value, typically less than 2%. This body of work has commonly involved concrete grades such as M20, M25, and M30, prepared with a standard water content.

This present research involves studying the strength of the E-waste utilized as partial replacement of coarse aggregates in the concrete for target strength of M20 with reduced water cement ratio.

2.6 Advantages and Limitations of E-Waste Concrete

2.6.1 Advantages

1. It has Good Compressive and Flexural Strength
2. It offers good performance to Chemical acid attacks
3. Better workability.
4. Water absorption in E-waste is lesser than 0.2% due to which, it doesn't affect the hydration of cement.
5. Easy manufacturing technique.
6. Use of E-waste in concrete, reduces its volume for disposal.
7. May solve the problem of adverse effects of e-waste disposal.
8. Provides economical and safe disposal of e-waste.

2.6.2 Limitations

1. The quantity of E-waste that can be used as partial replacement for coarse aggregate in concrete is limited.
2. Segregation occurs if it is used after a certain limit, due to which there could be rapid decrease in the strength value.
3. Problem in bonding.

2.7 Constituents of E-Waste Concrete

1. **Cement:** Portland cement is a fundamental binding agent in global construction, essential for producing concrete, mortar, stucco, and grout. Its manufacturing process involves calcining a blend of limestone and clay or shale at approximately 1450°C to produce clinker. This clinker is subsequently pulverized

with a small quantity of gypsum, which controls the setting time. The material derives its name from its visual similarity to the prestigious Portland stone, a durable English limestone, once it has cured. Patented by Joseph Aspdin in 1824, its enduring prevalence in modern construction is attributed to its strength, adaptability, and hydraulic properties—hardening through a chemical reaction with water known as hydration. This versatility renders it indispensable for a vast array of applications, from structural elements like foundations and bridges to pavements and architectural finishes.

2. **Water:** In the production of e-waste concrete, water is an essential component for combining the constituent materials into a workable mix. The quality of this water directly influences the final strength of the concrete, as impurities can interfere with the cement's hydration and setting processes. Consequently, it is a standard practice to use water that is potable, or fit for drinking, to ensure the integrity of the concrete (Neville, 2011).
3. **Aggregate:** Aggregates, which constitute approximately 60-75% of concrete's volume, are fundamental to its composition. These granular materials, which include sand, gravel, crushed stone, and various recycled substances, serve several critical functions. They provide structural bulk, improve the mixture's durability, reduce drying shrinkage, and decrease overall cost by limiting the amount of cement needed (Neville, 2011).
4. **Coarse Aggregate in Concrete:** Coarse aggregate is categorized as particulate material exceeding 4.75 mm (0.187 inches) in size, according to the ASTM C33 standard (ASTM International, 2023). It includes materials like gravel, crushed stone, and recycled concrete, which are vital for imparting strength and stability to the concrete matrix. A properly graded coarse aggregate minimizes voids

within the mixture, thereby enhancing its overall density and load-bearing capacity. The performance of the concrete is further affected by the aggregates' physical characteristics; angular, rough-textured particles create a stronger mechanical bond with the cement paste, while smoother, rounded aggregates offer greater workability at a potential cost to ultimate strength (Kosmatka *et al.*, 2008). It is also critical that these aggregates are durable, clean, and devoid of detrimental coatings or organic impurities, as such contaminants can compromise the long-term integrity of the concrete.

5. **Fine Aggregate in Concrete:** fine aggregate consists of smaller particles, typically less than 4.75 mm but larger than 75 microns (No. 200 sieve) (ACI 318, 2019). Natural river sand is the most commonly used fine aggregate, though alternatives like crushed stone dust and manufactured sand are also employed, especially in regions with sand shortages. Fine aggregates fill the gaps between coarse aggregates, ensuring a dense and cohesive mixture. They enhance workability, making the concrete easier to place and finish while contributing to the overall strength and durability of the hardened structure (Mehta & Monteiro, 2017). The quality of fine aggregate depends on factors such as particle size distribution, cleanliness, and shape—finer particles improve workability, while excessive silt or clay content can weaken the concrete.

2.8 Electronic Waste as an Alternate Course Aggregate

The conventional production of concrete depletes significant natural resources. To preserve these non-renewable assets for future generations, it is imperative to adopt sustainable engineering practices focused on conservation. In response, researchers have been developing innovative technologies to promote sustainability within the construction sector. A key strategy involves recycling substantial quantities of industrial, domestic, and agricultural waste to partially replace cement or aggregates in concrete, utilizing such by-products as alternative building materials (Senthil and Baskar, 2018).

Aligned with this approach, the present study aims to investigate the properties of concrete where coarse aggregate is partially replaced by processed E-waste. Specifically, electronic circuit boards were crushed and sieved to sizes of 4.75mm, 10mm, and 20mm. These processed materials were then used to substitute conventional coarse aggregate by weight at replacement levels of 10%, 15%, and 20%.

2.8.1 Physical and Chemical Properties of E-Waste

Electronic waste (e-waste) represents one of the fastest-growing waste streams globally, consisting of discarded electrical and electronic equipment such as computers, mobile phones, and household appliances. The complex composition of e-waste, containing both valuable materials and hazardous substances, necessitates a thorough understanding of its physical and chemical properties for effective management and recycling. This paper examines these properties in detail, highlighting their implications for recycling processes and environmental protection. (Kaiqi, 2023).

Physical Properties of E-Waste

The physical properties of electronic waste are highly variable, reflecting its complex and non-uniform composition. A typical breakdown by material consists of 40-60% metals (including both base and precious types), 20-30% plastics, and 5-10% glass, alongside other elements such as ceramics and rubber (Jin and Dehuai, 2013). For recycling, the waste is commonly shredded into particles ranging from 1 to 20 mm. The significant disparity in density among these components (for instance, copper at 8.96 g/cm^3 compared to plastics at 1-1.5 g/cm^3) facilitates their separation.

Furthermore, thermal characteristics vary widely; plastics possess high calorific values (30-40 MJ/kg) yet degrade at relatively low temperatures (200-400°C), whereas metals like gold necessitate processing at extremes exceeding 1000°C.

Chemical Properties of E-Waste

The chemical composition of e-waste presents both opportunities and challenges. Hazardous substances include heavy metals like lead, cadmium, and mercury, along with halogenated compounds such as brominated flame retardants and polychlorinated biphenyls. These toxic components pose significant environmental and health risks through leaching and atmospheric release. Conversely, e-waste contains valuable materials, with circuit boards containing 80-350 g/ton of gold and up to 3,300 g/ton of silver - concentrations far exceeding typical ore grades. The chemical behavior under various conditions, particularly the leaching potential of heavy metals in acidic environments ($pH < 4$), requires careful consideration in disposal and processing. (Purchase *et al,* 2020)

2.8.2 Processing and Treatment Before Use in Concrete

The successful integration of electronic waste (e-waste) into concrete as an aggregate depends on a methodical processing protocol to guarantee material suitability and structural integrity. The initial phase consists of collection and manual dismantling, followed by automated separation techniques to isolate metallic components (Zhang & Xu, 2016; Cui & Forssberg, 2003). Subsequently, the sorted e-waste is mechanically crushed or shredded to produce particles within a 5–20 mm range, ensuring they align with established aggregate grading specifications (Poon & Chan, 2006). To improve the adhesion between the e-waste and the cement paste, surface treatments like acid etching or thermal modification are often employed (Kim *et al.*, 2017). Before being approved for use, the processed material must pass stringent quality checks, including assessments for density, water absorption, and leachate potential, to confirm compliance with safety and performance standards (Islam *et al.*, 2016).

These treatment procedures are designed to mitigate primary concerns such as potential contamination and poor bond strength at the interface. Research indicates that with appropriate processing, e-waste aggregate can achieve water absorption rates of less than 5% and demonstrate negligible leaching of heavy metals, confirming its feasibility for construction use. Nevertheless, ongoing research is crucial to optimize these methods for large-scale, consistent production. Ultimately, converting e-waste into a functional construction material through these processes supports sustainable waste management and resource efficiency, advancing the goals of a circular economy (Tam *et al.*, 2015).

2.8.3 Mix Design Consideration

The integration of e-waste aggregates into concrete necessitates specific modifications to standard mix designs to accommodate their distinct physical properties. Processed e-waste possesses a lower density (1.8-2.2 g/cm^3) than natural stone (2.6-2.8 g/cm^3), requiring careful mass-to-volume calculations during batching (Kou *et al.*, 2012). Furthermore, its elevated water absorption rate (3-8%) often calls for either pre-saturation of the aggregates or a higher water-to-cement ratio to maintain workability (Ling & Poon, 2013). The smooth surface of some e-waste components can also weaken the bond with the cement paste, a issue that can be mitigated by increasing the cement content or incorporating supplementary cementitious materials (Poon & Chan, 2006).

Successful mix design strategies for e-waste concrete often involve several key adjustments. The use of water-reducing admixtures (1-2% by cement weight) can effectively counteract the high absorption of the aggregates (Kim *et al.*, 2017). Replacing 20-30% of cement with fly ash or slag can enhance the quality of the interfacial transition zone. To combat increased brittleness, the inclusion of fibers at 0.5-1.5% by volume has proven effective (Zhang & Xu, 2016). With these optimizations, it is possible to produce structural-grade concrete with compressive strengths between 25-40 MPa (Cui & Forssberg, 2003).

With global e-waste generation surpassing 50 million metric tons per year, its repurposing in concrete represents a significant opportunity for sustainable construction (Forti *et al.*, 2020). Although mix design adjustments are essential, the resulting material can fulfill performance criteria for numerous applications. Continued research is vital to further improve the workability, strength, and durability of e-waste concrete, ensuring that its environmental advantages are realized without compromising the material's structural integrity and long-term service life.

2.9 Effect of Temperature on E-Waste Concrete

Research conducted by Senthil and Baskar (2018) revealed that heat exposure considerably affects the performance of concrete incorporating High-Impact Polystyrene (HIPS) from e-waste. Their findings showed that while temperatures of 100°C caused no observable harm, surface discoloration became evident at 200°C, signaling the onset of thermal breakdown. The situation progressed at 300°C, with hairline fracturing emerging as a result of HIPS decomposition on the surface, alongside a noticeable smell of burning polymer. The practice of rapid water cooling intensified micro-fissuring, especially in batches with 30–50% HIPS content, a consequence of the mismatched thermal expansion between the plastic aggregates and the surrounding cement paste. Conversely, the HIPS-enhanced concrete displayed improved thermal insulation characteristics, taking longer to stabilize its internal temperature compared to standard concrete, which points to possible energy-saving uses in construction. This investigation underscores both the challenges and the prospective advantages of employing e-waste concrete in non-load-bearing applications where thermal performance is a key consideration.

2.10 Curing of E-Waste Concrete

Proper curing is an essential procedure for e-waste concrete, vital for achieving complete hydration, optimal strength gain, and long-term durability, particularly as the inclusion of electronic aggregates can influence its overall performance. Water curing, maintained for 7 to 28 days, is generally the most effective technique. It helps counteract the minimal water absorption characteristic of plastic-based e-waste, though their water-repellent nature can sometimes necessitate a longer curing duration. Other viable techniques involve applying a membrane-forming compound for vertical elements, using steam curing to accelerate strength in precast units, and employing internal curing methods with water-retaining polymers. The efficacy of the curing process is governed by several factors, including the inherently low absorptivity of e-plastics, their thermal characteristics, chemical makeup, and the proportion used—with a 10–15% replacement rate being ideal. Inadequate curing in mixes with elevated e-waste content can lead to a strength reduction of 13–23%.

2.10.1 Purposes of Curing

i. The curing protects the concrete surfaces from sun and wind.

ii. The presence of water is essential to cause the chemical action which accompanies the setting of concrete. Normally, there is an adequate quantity of water at the time of mixing to cause hardening of concrete. But it is necessary to retain water until the concrete has fully hardened.

iii. The strength of e-waste concrete gradually increases with age if curing is efficient. This increase in strength is sudden and rapid in early stages and it continues slowly for an indefinite period.

2.11 Mechnical Properties of E-Waste Concrete

2.11.1 Compressive Strength

Compressive strength defines concrete's capacity to withstand axial loads that cause it to fracture or collapse (CCAA, 2004). This characteristic is among the most critical and widely utilized properties of concrete, as it is primarily designed to bear compressive forces in the vast majority of structural applications. Consequently, compressive strength is often employed as a key indicator of overall concrete quality and performance. Previous research by Gopala *et al.* (2016) has evaluated this property in E-waste concrete by benchmarking it against conventional concrete at the 28-day mark. Their findings indicate that a 15% replacement of coarse aggregate with processed E-waste can result in a compressive strength up to 27% higher than that of standard concrete.

2.11.2 Flexural Strength

Flexural strength, or modulus of rupture, quantifies a material's resistance to failure when subjected to bending forces. For concrete, this property indicates the highest tensile stress reached at the outermost fiber of a beam or slab just as cracking initiates under a flexural load. This parameter is especially critical for concrete, which has low inherent tensile resistance, in structural members like beams, pavements, and slabs that must withstand bending moments. Flexural strength values are generally greater than those from direct tension tests because the non-uniform stress distribution in a bending member allows less-stressed material to help restrain crack propagation. Key variables influencing this property include the aggregate characteristics—where angular materials such as crushed e-waste enhance mechanical interlock and strength—along with curing methods, concrete maturity, and mix design. Standardized testing procedures, including the three-point and four-point bending tests (ASTM C78 or IS 516-1959), are employed to measure this essential characteristic, which is fundamental for guaranteeing the safety and performance of structures exposed to dominant bending stresses.

2.11.3 Durability Properties of Concrete

Durability in concrete refers to its capacity to endure environmental weathering, chemical deterioration, and surface wear while retaining its intended structural characteristics. The required level of durability varies significantly with the concrete's exposure conditions and its functional purpose. For instance, the specifications for concrete subjected to tidal marine environments differ substantially from those for an interior slab. The long-term durability and service life of concrete are influenced by the quality of its constituents, their proportional mix, the chemical interactions between them, the methods of placement and curing, and the conditions it encounters in service.

Within the construction sector, the 28-day compressive strength test is frequently used as the primary, and sometimes only, measure for accepting a concrete mix. This practice stems from the widespread belief that higher compressive strength inherently translates to superior durability, implying a direct correlation between the two properties. While the desired performance attributes of E-waste concrete are often associated with its strength, this focus stems principally from the fundamental role that compressive strength plays in all structural concrete applications.

2.12 Review of Previous Studies

Numerous investigations have examined the incorporation of electronic waste (e-waste) as a partial substitute for coarse aggregate in concrete, with a primary focus on its effects on strength and durability characteristics. Findings reveal that e-waste aggregates, including crushed printed circuit boards (PCBs), possess distinct physical properties; they generally demonstrate a lower specific gravity (1.9–2.2) and reduced water absorption (0.2–0.5%) compared to natural granite aggregates (specific gravity 2.6–2.7). A potential drawback, however, is the smooth surface of e-waste particles, which can compromise the bond integrity with the cement matrix and subsequently impact concrete strength.

In terms of mix proportioning, previous research has commonly utilized concrete grades from M20 to M30, with e-waste replacing 0–30% of the coarse aggregate by volume or weight. The consensus indicates that a substitution rate of 10–20% preserves adequate strength for structural purposes, whereas levels exceeding 20% frequently result in considerable strength loss. Parallel studies involving granite waste as a fine aggregate have observed potential enhancements in density and thermal resistance, though this often necessitates modifications to the water-cement ratio to offset higher absorption.

The strength progression of e-waste concrete under standard curing conditions is well-documented. Specimens containing 10–15% e-waste typically attain 70–80% of their ultimate 28-day compressive strength within the first 7 days. At 28 days, the comprehensive compressive strength can diminish by 9–52% relative to conventional concrete, contingent on the replacement percentage, though mixes with 10–15% e-waste often remain within structural limits (e.g., 25–35 MPa for M25 grade). Flexural strength, while following a comparable declining pattern, is generally less impacted, with some research noting improved ductility and crack resistance attributed to the inherent flexibility of certain e-waste constituents.

Analysis of mechanical properties confirms a decline in compressive strength with increasing e-waste content, largely ascribed to the inferior bond at the aggregate-cement interface and the lower inherent stiffness of the e-waste material. Reductions in flexural strength are comparatively less pronounced (5–39% at elevated replacement levels), implying possible advantages in scenarios demanding toughness. Techniques to mitigate strength loss, such as confinement with Carbon Fiber Reinforced Polymer (CFRP), have been explored and shown to restore up to 20% of the diminished strength in high-replacement mixes.

Beyond structural performance, the utilization of e-waste in concrete presents notable environmental and economic incentives. It diverts material from landfills, conserves natural aggregate sources, and can reduce overall material costs due to its lower density. Furthermore, at optimal replacement levels (10–15%), e-waste concrete can demonstrate superior performance in resisting water absorption, abrasion, and thermal expansion. These characteristics make it a viable candidate for non-structural applications, including lightweight partition walls, paving units, and thermal insulation boards.

Notwithstanding these insights, research gaps persist, particularly concerning the long-term durability of e-waste concrete against chloride penetration and sulfate attack. Subsequent work, including the present study, could productively investigate hybrid mixtures that combine granite and e-waste to optimize the balance between mechanical performance and sustainability. Examining varied curing regimes and reinforcement strategies, such as fiber incorporation, may also lead to further performance enhancements. Addressing these areas can yield valuable contributions towards the practical implementation of e-waste in sustainable construction practices.

2.13 Summary of Literature Review

Concrete continues to be the predominant construction material globally, prized for its strength and longevity. Nonetheless, increasing environmental concerns and the need to preserve natural resources have prompted investigations into alternative materials, such as electronic waste (E-waste), for use in concrete mixes. E-waste, which comprises discarded electronic equipment, is among the most rapidly increasing waste categories worldwide; it reached an estimated 53.6 million metric tons in 2019 and is expected to grow to 74.7 million tons by 2030. Using processed E-waste in concrete provides a dual advantage: it helps address the environmental issue of E-waste accumulation and lessens the dependence on limited natural aggregates. Research demonstrates that, contingent on its makeup and particle size, E-waste can function as a partial substitute for coarse or fine aggregates, or even as fibrous reinforcement. This strategy is consistent with circular economy ideals, turning waste into a useful building resource while possibly improving specific attributes of concrete, including its thermal insulation and resistance to chemicals.

The distinct physical and chemical nature of E-waste means it must undergo careful preparation before being included in concrete. Its physical structure includes 40-60% metals, 20-30% plastics, and other constituents such as glass and ceramics, yielding a density between 1.8-2.2 g/cm^3, which is lower than the 2.6-2.8 g/cm^3 of natural aggregates. Chemically, while it contains valuable elements like gold and silver, it also includes dangerous materials like lead, cadmium, and brominated flame retardants that require appropriate processing. The preparation sequence consists of gathering, sorting, and crushing the material to sizes usually between 5-20mm, followed by surface treatments such as acid etching to strengthen the bond with the cement paste. Quality assurance procedures verify that the resulting aggregates satisfy criteria for water absorption, typically under 5%, and show only minimal leaching of heavy metals. The final E-waste aggregate demonstrates outstanding impact and crushing values, below 2%, confirming its structural potential irrespective of its lower density.

The mechanical performance of concrete incorporating E-waste presents a balanced profile of advantages and constraints. Investigations reveal that substituting up to 15-20% of conventional coarse aggregates with processed E-waste can preserve or even improve compressive strength, with certain studies documenting a 27% enhancement at 15% replacement. Beyond this threshold, however, replacement ratios of 20-50% generally result in diminished performance, showing compressive strength reductions of 9-52%, flexural strength decreases of 10-39%, and split tensile strength declines of 7-47%. Formulating these mixtures demands specific adjustments to accommodate E-waste's elevated water absorption capacity (3-8%) and less textured surface morphology, frequently through the addition of water-reducing agents (1-2% of cement weight) and cementitious supplements such as fly ash or silica fume (20-30% cement replacement). These adaptations preserve workability while strengthening the bonding interface between aggregate particles and cement paste. Furthermore, angular E-waste fragments contribute to improved flexural performance by establishing superior mechanical interlocking compared to naturally rounded aggregates.

In terms of durability, E-waste enhanced concrete displays several beneficial properties that compensate for certain mechanical compromises. The composite demonstrates enhanced performance against water penetration, capillary absorption, and surface wear compared to standard concrete, rendering it especially appropriate for marine environments. Additionally, it exhibits notable resilience to chemical degradation, including sulfuric acid exposure, owing to its reduced permeability when correctly formulated. Thermal characteristics reveal a dual nature: while the material delivers improved insulation capacity (demonstrating slower heat transfer), it simultaneously displays vulnerability to elevated temperatures. Research documents visible surface changes at 200°C, fine cracking at 300°C, and aggravated micro-fracturing due to thermal stress, particularly at replacement levels of 30-50%. Appropriate curing practices are essential, with water immersion for 7-28 days being standard, though the water-repellent nature of certain E-waste constituents may necessitate prolonged curing durations or alternative approaches such as membrane protection or steam curing.

Practical implementation of E-waste concrete spans both structural and non-structural domains, determined primarily by replacement proportions. Structural applications generally maintain E-waste content below 20% of coarse aggregates, while mixtures containing 20-50% replacement suit non-load-bearing elements. The benefits encompass reduced waste volumes, decreased exploitation of natural resources, enhanced chemical stability, minimal water absorption (<0.2%), and superior thermal insulation. From an economic perspective, it provides savings in both waste processing and material procurement. Nevertheless, challenges persist, including inadequate bonding at the aggregate-cement interface, particle separation at elevated replacement rates, and probable strength deterioration beyond optimal percentages. Existing knowledge gaps comprise the absence of uniform evaluation standards, insufficient long-term durability data, and incomplete environmental impact quantification via Life Cycle Assessment. Overcoming these obstacles through sustained investigation and technological refinement could establish E-waste concrete as a conventional sustainable building material, substantially advancing global waste minimization and resource preservation initiatives.

CHAPTER THREE

METHODOLOGY

3.1 Procedure

The tests/procedures involved in this investigation include:

i. Procurement of materials and preparation of apparatus needed.

ii. Sieve analysis test

iii. Mix design

iv. Slump test

v. Casting of concrete test cubes

vi. Compressive strength test

vii. Flexural test

3.2 Materials

All materials (coarse aggregate, fine aggregate, water and cement) used for the production of the concrete was obtained locally.

The electronic waste (E-waste) used in this study was sourced from a repair shop located on Eweka Street, off Siluko Road in Egor, Benin City. The granite (coarse aggregate) and sharp sand (fine aggregate) were procured from the structural laboratory within the Civil Engineering Department at the University of Benin, Benin City. For the production of all concrete samples, Ordinary Portland cement compliant with the BS12 standard was utilized.

The materials were air dried in the laboratory. The coarse aggregate (granite and E-waste) was passed through a set of standard sieves. The portion retained on sieve 20mm to 4.75mm was used.

3.2.1 Coarse Aggregate

The coarse aggregate used were crushed of igneous origin (granite) and crushed electronic waste of size 20mm and below

3.2.2 Fine Aggregate

The sharp sand used were dry, clean, and free from dirt and organic matter and was passed through 5mm sieve.

3.2.3 Portland Cement

Ordinary Portland cement (OPC), Dangote brand type with properties conforming to those specified in the BS 12 was used. The cement supplied in 50kg bags was well protected from dampness to avoid lumps.

3.2.4 Water

The water utilized in this experiment, sourced from the Civil Engineering Laboratory at the University of Benin, conformed to the BS 3148 (1980) standard. The chemical reaction between water and cement, known as hydration, is critical as it produces the compounds responsible for the concrete's binding and strength-gaining properties. To ensure this process was not compromised, it was essential to use water free from pollutants or impurities that could interfere with the reaction. Consequently, potable tap water was employed for all mixes in this study.

3.3 Laboratory Equipment

The equipment’s used are those available in the Structural Laboratory of Civil Engineering Department, University of Benin.

3.3.1 Weighing Machine

Weighing machine of 25kg capacity was used to weigh the individual materials that make up each mix and the cubes after curing. Along with the weighing machine are standard weights (ranging from 100g to 5kg).

3.3.2 Compression Testing Machine

This hydraulically operated machine applies a compressive force to a test cube positioned between two steel platens: a fixed lower platen and a movable upper one. The apparatus, calibrated in kiloNewtons (kN), is equipped with both digital and analog gauges for recording the load. Prior to each test, these gauges were reset to zero. During testing, the upper platen descends until the concrete specimen fails. Upon failure, the needle on the analog dial reverses towards zero, while a maximum-value indicator remains in place to record the ultimate compressive strength.

3.3.3 Moulds

The moulds used in this project work were 100×100×100mm dimension. Along with the moulds are bolts, nuts and spanners for demoulding.

3.4 Sieve Analysis of Coarse Aggregate

Apparatus

1. Set of sieves
2. Sieve shaker
3. Cleaning brush
4. Weighing balance

Procedure

1) Firstly the sample was air dried.
2) The sieves was arranged according to specification in a decreasing order of size from top to bottom with a receiving pan at the bottom.
3) The sample was then poured into the sieves and placed on a mechanical shaking device and then started for some minutes.
4) After shaking, the amount of aggregate retained on each sieve was weighed and recorded. At the end of the experiment, the total weight of coarse samples

retained and passing through each sieve was calculated and then expressed as a percentage of the total weight of the soil sample.

$$\% \text{ Retained} = \frac{\text{weight of sample retained}}{\text{Total weight}} \times 100$$

3.5 Mix Design

The concrete was designed using a standard mix design for grade 20 which is 1:2:4 and water/cement ratio was 0.55 for all mixes. Mixing was done in revolving drum mixer in accordance with ASTM C 192. The aggregate replacements was selected at 0%, 5%, 10%, 15% and 20% of the weight of coarse aggregate.

3.5.1 Slump Test

The slump test was conducted in accordance with the ASTM C 143 standard to assess the consistency of the concrete. This method measures the reduction in height of a compacted concrete cone to determine its workability. The resulting slump value serves as an indicator of the mixture's stiffness, which is directly related to its water content.

Apparatus

1) Slump cone
2) Scale for measurement
3) Tamping rod (steel)
4) Base plate.

Procedure

This test involves the use of a cone mould of height 300mm with base 200mm in diameter with a smaller opening at the top.

1) The base of the cone was placed on a smooth plate and the mould was then filled with concrete in three layers, tamping each layer 25 times with a steel rod to ensure full compaction.

2) After filling, the mould was then leveled and then the cone is slowly and carefully removed vertically, an unsupported concrete slumped.

3) The slump was then measured by placing the cone just beside the slump concrete and the tamping rod was placed over the cone in a way that it also came over the area of slumped concrete. The decrease in height of concrete to that of the mould was then measured using metre rule.

3.6 Experimental Preparation of Concrete Cube

Nine test cubes was tested for each mix proportion (three each for 7, 14 and 28 days) and the average strength for the 7th, 14th and 28 days was obtained. A total of 45 test cubes was casted.

3.6.1 Mixing

A concrete mixer was employed to achieve a homogeneous blend of the constituent materials: cement, fine aggregate, coarse aggregate, and water.

3.6.2 Casting of Cubes

Apparatus

i) Standard cube moulds (100×100×100mm)

ii) Trowel

3.6.3 Method

The assembled moulds were coated with a release agent to facilitate the later removal of the cubes. They were then completely filled with freshly mixed concrete. Following vibration, the tops of the specimens were leveled with a trowel. After one hour, the concrete was marked for identification. The cubes were then left to set for 24 hours before being de-molded and placed into the curing tank.

3.6.4 Curing

The cast concrete cubes were de-molded after 24 hours and promptly immersed in a curing tank filled with potable tap water. Following a one-day setting period, the cubes were moved to the curing tank to undergo the curing process.

3.7 Compressive Strength Test

Apparatus

i) Weighing balance

ii) Compressive strength testing machine

Procedure

i. Before testing, the concrete cubes tested were removed from curing tank and dried.

ii. The weights of the cubes were measured using the weighing balance and the values were recorded before taking them to the compression testing machine.

iii. A cube whose crushing load was determined was taken and placed on the lower plate of the machine which was already been put on. The upper plate was displaced downward till the cube made contact with both plates.

iv. After mounting the cube, the machine was set to load the the cube. Loading continued until failure by crushing occurred.

v. The value of the crushing load was read and was recorded against the cube's identification (sample no)

vi. The crushed cube was removed and another one mounted in place. The process will be repeated for other cubes.

vii. The value of the crushing load was used to calculate the compressive strength by dividing the value by the cross sectional area.

viii. The average compressive strength of the three cubes was calculated and taken as the compressive strength.

3.8 Flexural Strength Test

A flexure test is a common method for evaluating a material's flexural strength and modulus. This approach is often more cost-effective than a tensile test, although the resulting data can differ. In the procedure, the specimen is placed horizontally on two lower supports. A force is then applied downward from one or two points until the material fractures. The highest force value recorded during this test represents the material's flexural strength.

Calculations

1. The modulus of rapture is calculated as follows

Case I: Where fracture occurs within the middle third of span:

$$\boldsymbol{R} = \frac{\boldsymbol{P\,x\,L}}{\mathbf{bd^2}} \qquad (3.3)$$

Where;

R = modulus of rupture in kPa
P = maximum load in KN
L = span length in concrete
b = average width in metres
d = average depth in metres

Case II: Where fracture occurs outside the middle third of the span as measured along the beam bottom by no more than 5% of the span length.

$$\boldsymbol{R} = \frac{\boldsymbol{3\,x\,P\,x\,L}}{\mathbf{b\,x\,d^2}} \qquad (3.4)$$

Where; a = distance in metres of the fracture from the nearest support measured along the bottom centre line of the beam.

Case III: Where fracture occurs more than 5% outside the middle third, the results of the test are discarded (i.e. the test is indeterminate).

2. The constant k , which is sometimes used in converting compressive strength to modulus of rapture is calculated as follows:

$$\mathbf{K} = \frac{(\boldsymbol{R}/\mathbf{100})^2}{\mathbf{f^2c}} \tag{3.5}$$

Where;

f^2c = compressive strength in Mpa

R = modulus of rupture in Kpa

Note:

The mould used for casting the beam was dimension 100 × 100 × 500mm

CHAPTER FOUR

DATA PRESENTATION AND ANALYSIS

4.1 Results and Discussion

The results of the various test conducted on the aggregates (fine and coarse) which include; sieve analysis are presented in this chapter. The result obtained from the slump test is also recorded here which connotes the workability of the concrete used for this work. Finally, the result obtained from the compressive test and flexural test presented also.

4.2 Particle Size Distribution of Materials

The sieve analysis results revealed distinct differences in the grading of the fine aggregate, coarse aggregate, and e-waste materials used in this study. The coarse aggregate showed a well-graded distribution with particles ranging from 26.5 mm down to 3.35 mm, which promotes good interlocking, reduces voids, and contributes to higher concrete strength and durability (Aditya *et al.,*2016).

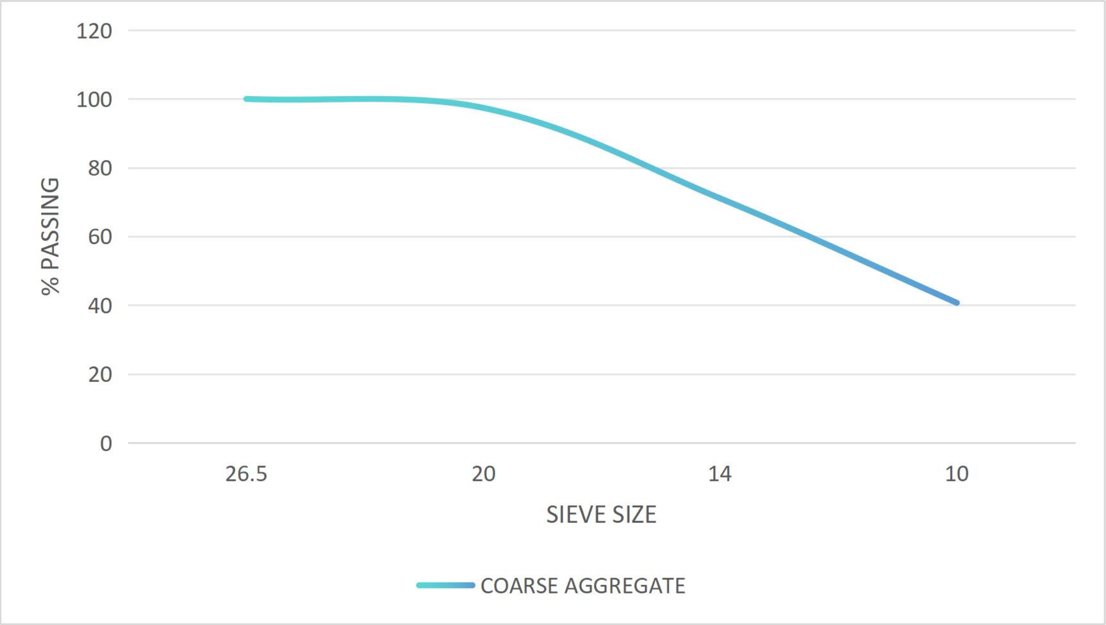

Fig 4.1 sieve analysis results of course aggregate

The fine aggregate was also well-graded, with about 99% passing the 2.36 mm sieve and only 4% passing the 0.075 mm sieve, indicating suitable fineness for adequate workability and bonding in the concrete mix.

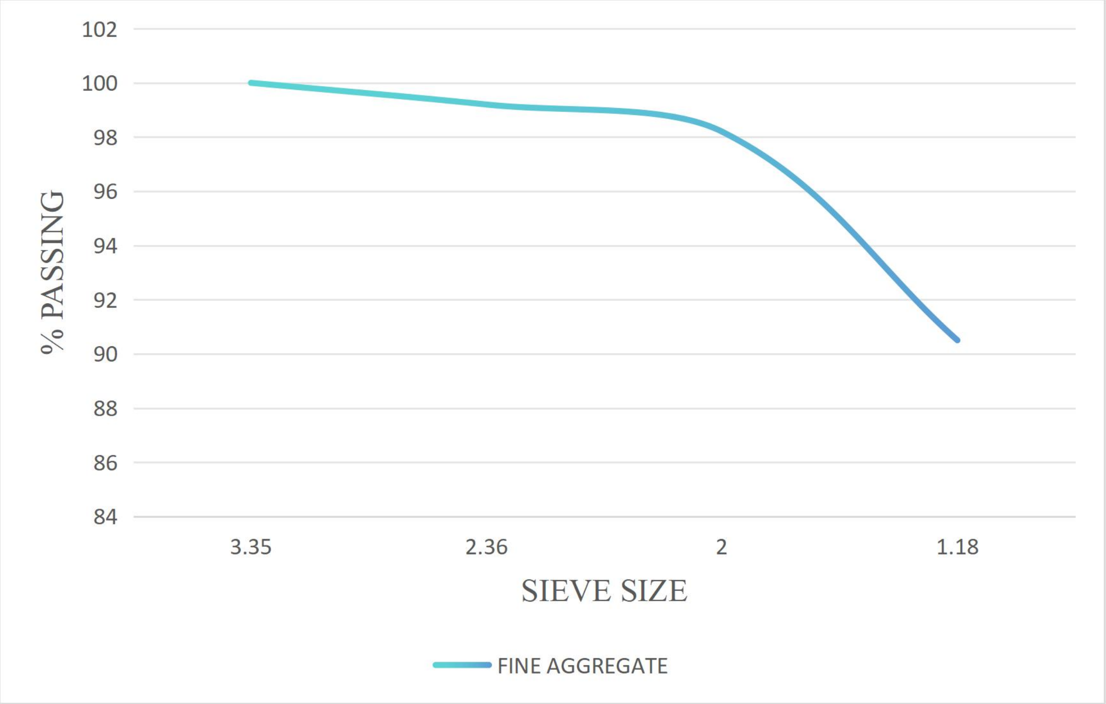

Fig 4.2: sieve analysis results of fine aggregates

The e-waste, used as a partial replacement for coarse aggregate, exhibited particle sizes mostly within the same range as the natural coarse aggregate (26.5 mm to 5 mm) but with a less uniform distribution, showing fewer intermediate particles. This less continuous grading can lead to slightly higher void ratios and weaker particle packing, which may affect the density and strength of the concrete at higher replacement levels.

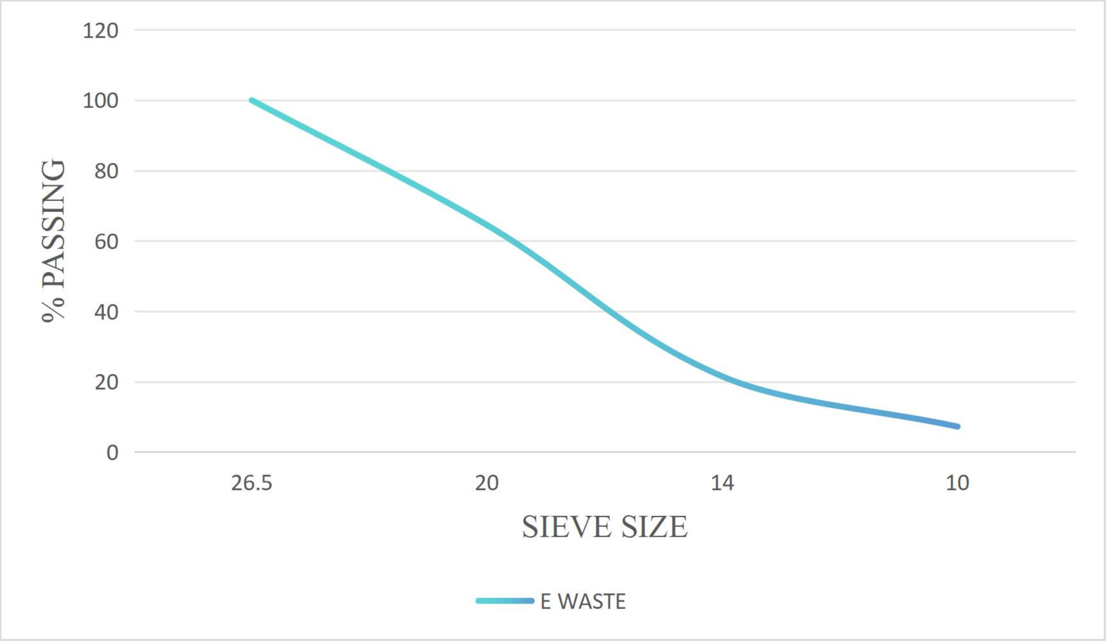

Fig 4.3: sieve analysis results of E-waste

The influence of particle size distribution on concrete performance was evident in the results: well-graded natural aggregates enhanced workability, strength, and compactness, while the irregular and less uniformly graded e-waste particles reduced these properties beyond certain replacement levels.

4.3 Workability of Concrete

The slump test results in fig 4.4 show that workability increased with higher e-waste content. The control mix had a slump of 27 mm, indicating low workability, while mixes with 5%, 10%, 15%, and 20% e-waste recorded 30 mm, 38 mm, 47 mm, and 61 mm respectively. This steady increase is due to the smooth and non-absorbent surface of e-waste particles, which reduces internal friction and water absorption, leaving more free water in the mix. As a result, the concrete became more fluid and easier to handle at higher replacement levels. However, the higher slump also suggests reduced cohesiveness, meaning excessive e-waste could lead to segregation. Therefore, moderate e-waste replacement (around 5–10%) offers better workability without compromising mix consistency.

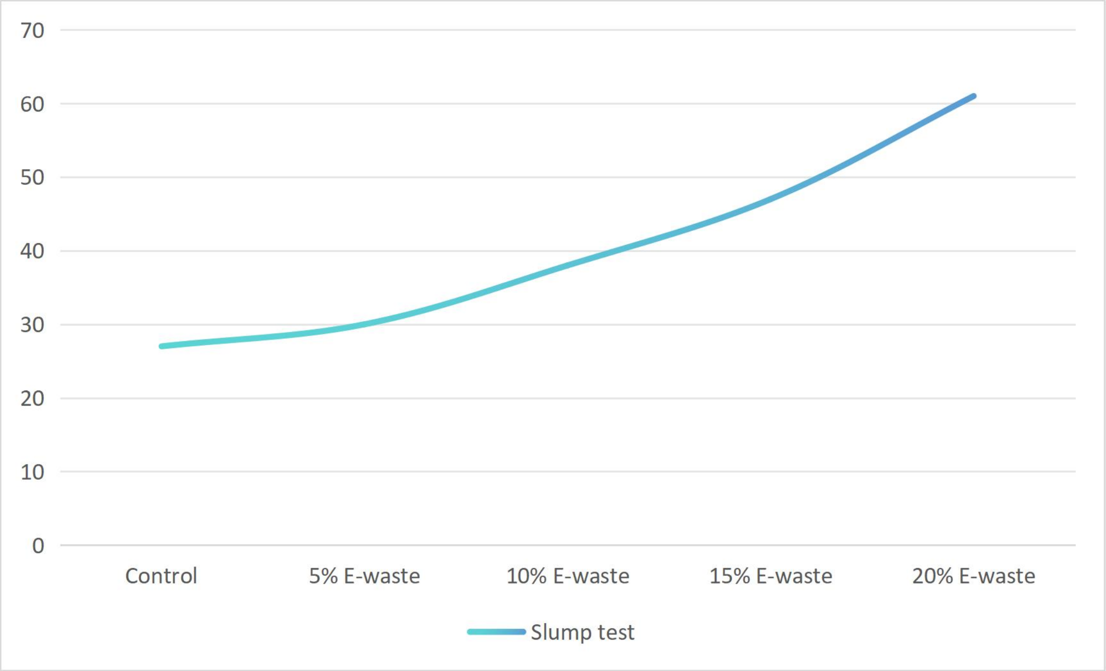

Fig 4.4: Slump test result

From the slump test carried out on the control concrete, a slump of 27mm was obtained which indicates a concrete of low workability (25 – 50). According to (Handoo, et-al, 1997) concrete with slump ranging from 0-25mm are classified as very low workability concrete. The slump test in this research therefore show low concrete workability in each percentage replacement, except at 20% replacement which indicates medium workability (50 – 100). According to (Kourd *et al*, 2010) low workability mix as in 0%, 5%, 10% and 15% replacement is used for foundations with light reinforcement.

4.4 Effect of E-waste on Compressive Strength of Concrete

The compressive strength results presented in figure 4.5 to 4.8 show a clear decreasing trend as the percentage of e-waste replacing coarse aggregate increased. The control mix achieved the highest strength of 20.09 N/mm² at 28 days, while the mixes with 5%, 10%, 15%, and 20% e-waste recorded 18.12 N/mm², 16.04 N/mm², 14.02 N/mm², and 10.43 N/mm² respectively. This progressive reduction indicates that increasing e-waste content led to a decline in the concrete's load-bearing capacity.

The initial 5% replacement, however, produced a compressive strength close to the control value, suggesting that a small amount of e-waste can be used without significantly compromising strength. The reduction at higher percentages is attributed to the smooth, lightweight, and non-porous nature of e-waste particles, which weakens the bond between the aggregate and the cement paste, leading to poorer stress transfer within the concrete matrix. In contrast, natural coarse aggregates provide rougher surfaces that promote better interlocking and stronger adhesion. The observed mechanical behaviour aligns with expectations as the proportion of weaker, less rigid materials increases, overall compressive strength decreases. Therefore, the trend confirms that limited substitution (up to about 5%) maintains satisfactory mechanical performance, while higher replacements reduce strength due to poor aggregate (Muhsina *et al*., 2024).

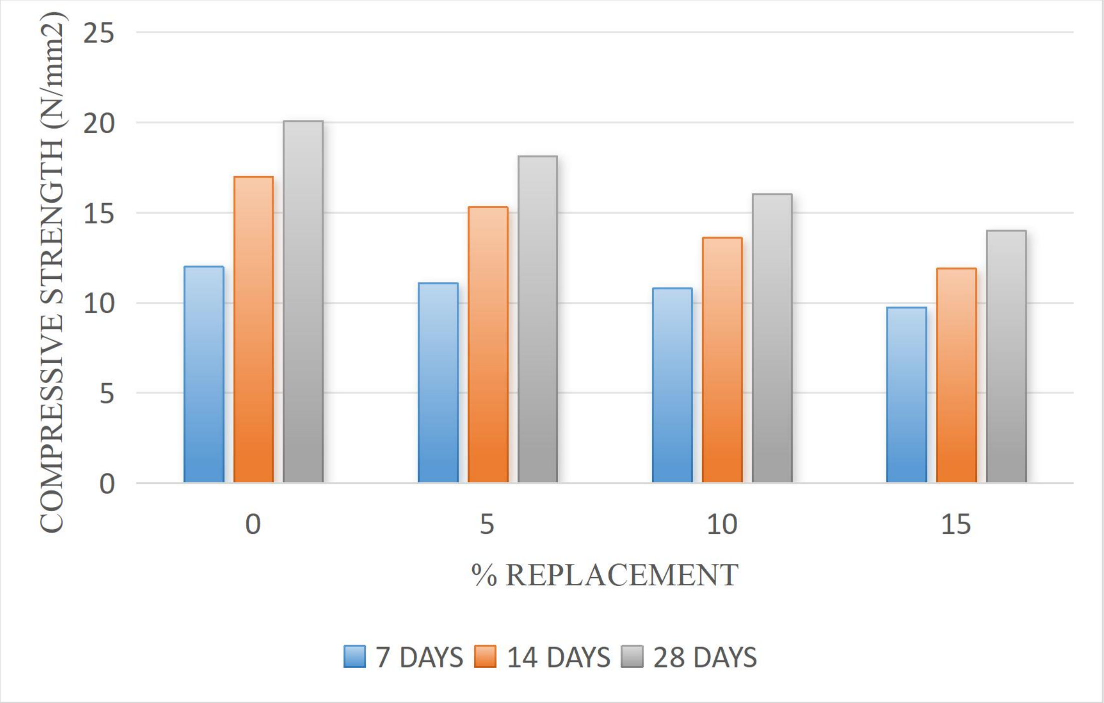

Fig 4.5: Average Compressive strength incorporate E-Waste at all Ages

The compressive strength was measured on concrete containing various percentages of e-waste materials presented in figure 4.5. Replacement of 5% e- waste show a highest strength (18.12 N/mm^2) compare to other percentage replacement. This implies that 5% replacement of e-waste in coarse aggregate yields a better concrete for construction.

4.5 Effect of E-waste on Flexural Strength of Concrete

The flexural strength fell sharply as e-waste content increased: the control mix averaged ≈5.25 N/mm², dropping to 3.45 N/mm² at 5% replacement, 2.16 N/mm² at 10%, 0.85 N/mm² at 15% and 0.38 N/mm² at 20%. This steady, steep decline indicates that e-waste particles substantially weaken the concrete's resistance to bending.

Mechanically, this behaviour is consistent with the nature of the replacement material paste interface and provide poorer stress transfer under tensile/bending loads. Reduced interlock and fewer load-bearing contacts increase crack initiation and growth under flexure, lowering toughness and serviceability. Structurally, the implication is that beams, slabs and other flexural members will lose capacity and become more prone to deflection and brittle cracking as e-waste content rises; only the 5% replacement comes close enough to the control to be considered for lightly loaded or well-reinforced members (Senthil and Baskar, 2018).

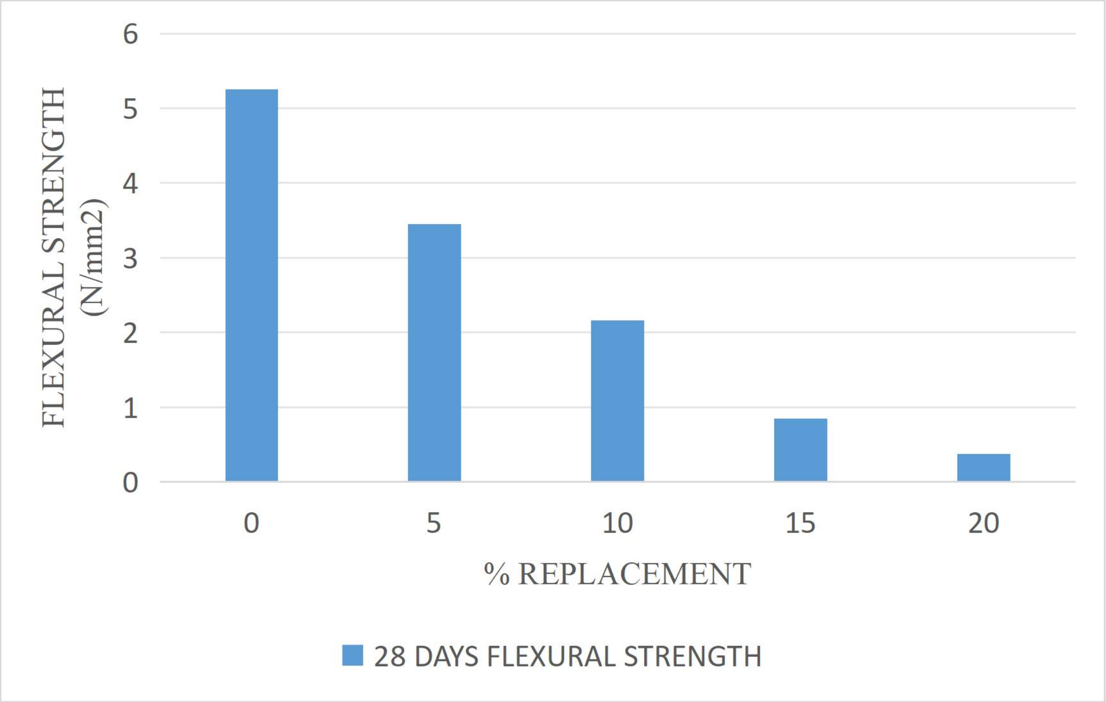

Fig 4.6: Flexual strength result of partially replaced coarse aggregate at 28days of curing

The flexural strength at variation of 0%, 5%, 10%, 15% and 20% are 5.25N/mm^2, 3.45N/mm^2, 2.16N/mm^2 0.85N/mm^2 and 0.38N/mm^2 respectively. This shows that the higher the percentage replacement the lower the flexural strength of the concrete.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This research evaluated the viability of using electronic waste as a partial substitute for coarse aggregate in concrete cubes and beams. The key findings are summarized below:

The mix with a 5% e-waste replacement achieved the highest compressive strength, measuring 18.12 N/mm² after 28 days.

Conversely, the 20% e-waste mix resulted in the lowest compressive strength of 10.43 N/mm² at 28 days.

Results indicate that replacing more than 10% of coarse aggregate with e-waste is not advisable for concrete construction due to a significant reduction in strength.

While a 5% e-waste replacement showed promising flexural strength results, this performance declined as the e-waste percentage increased.

In conclusion, this study demonstrates that e-waste can be successfully utilized as a partial replacement for coarse aggregate in concrete, albeit within limited proportions.

5.2 Recommendations

While this investigation focused on employing e-waste as a coarse aggregate, the following recommendations for future research are proposed:

1. Although this study was conducted under controlled laboratory conditions, subsequent work should explore its application in real-world, on-site environments.
2. The strength properties should be assessed over a more extended period to determine the long-term performance and durability of this concrete mixture.

3. Further research could investigate the strength and durability of concrete where e-waste is used to replace fine aggregate, particularly in combination with other established waste materials such as slag, copper slag, foundry sand, or ceramic waste.

REFERENCES

Abdullahi M. (2012): Effect of aggregate type on compressive strength of concrete. International Journal of Civil and Structural Engineering.;2(3):791-800. 18.

ACI 318-19. (2019). Building Code Requirements for Structural Concrete. American Concrete Institute.

Aditya G., Dinesh S., Shubham S., Praveen P.., (2016), “Utilisation of E - Plastic Waste in Concrete”. International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181 Vol. 5 Issue 02, February-2016

Aginam CH, Chidolue CA, Nwakire C. (2013) Investigating the effects of coarse aggregate types on the compressive strength of concrete. International Journal of Engineering Research and Applications.;3:1140-1144. 20.

Alutu, K. (2007), The influence of Egg Shell Ash on some Mechanical Properties of Concrete. Civil Engineering Department, University of Benin, Edo State Nigeria.

ASTM C33/C33M-23. (2023). Standard Specification for Concrete Aggregates. ASTM International.

BS 1881 Part 108 (1983) method for making test cubes from fresh concrete.

Cui, J., & Forssberg, E. (2003). Mechanical recycling of waste electric and electronic equipment. Journal of Hazardous Materials, 99(3), 243-263.

Elices, M., and Rocco, C.G., (2008), Effect of Aggregate Size on the Fracture and Mechanical Properties of a Simple Concrete, Engineering Fracture Mechanics, 75(13), pp 3839-3851.

Finlay, A., & Liechti, D. (2008). E-waste assessment South Africa. Empa: Johannesburg, South Africa: Openresearch.

Forti, V., Baldé, C. P., Kuehr, R., & Bel, G. (2020). The Global E-waste Monitor 2020. United Nations University.

Gupta R. Sangita K., Verinder, (2011). "Electronic waste, Research Journal of Chemical sciences, volume 1, 49-56.

Hariharan S., Punitha K. A., (2024). “A study on the bond strength and durability characteristics of high-performance concrete modified with toughened glass waste aggregates”.

Hassan NS. (2014): Effect of grading and types of coarse aggregates on the compressive strength and unit weight of concrete. Accessed on 10th September, 2014: Available:http://www.iasj.net/iasj?func=fullt ext &aId=29047

Investigation of concrete for E-plastic waste management. International Journal of Engineering Trend and Technology, Vol. 10, No 4 April 2014.

Islam, M. J., Meherier, M. S., & Rakin, R. (2016). Effects of waste PET as coarse aggregate on the fresh and harden properties of concrete. Construction and Building Materials, 125, 946-951.

Jimoh A. A., and Awe S. S. (2007). A study on the influence of aggregate size and type on the compressive strength of Concrete. Journal of Research information in Civil Engineering.; 4(2):157-168.

Jin Y., and Dehuai Z., (2013). Material Science and Chemical Engineering. Trans Tech Publication Ltd, Volume 699 of advanced material research, ISSN print

Kahhat, R., Kim, J., Xu, M., Allenby, B., Williams, E., & Zhang, P. (2008). Exploring e-waste management systems in the United States. Resources, Conservation and Recycling, 52(7), 956.

Kaiqi W., (2023): Advances in E-Waste Recycling: Physical and Chemical Treatment Methods. Vol. 73 (2023): 5th International Conference on Energy Material, Chemical Engineering and Mining Engineering (EMCEME 2023)

Kale, S.P. HI Pathan Recycling of Demolished concrete and E-waste; International Iftekar Gull, Mr. M Balasubramanian.

Kim, Y., Park, H., & Kim, H. (2017). Novel approach for enhancing the bonding strength of recycled PET aggregate concrete. Construction and Building Materials, 151, 776-783.

Kosmatka, S. H., Kerkhoff, B., & Panarese, W. C. (2008). Design and Control of Concrete Mixtures (14th ed.). Portland Cement Association.

Kou, S. C., Lee, G., Poon, C. S., & Lai, W. L. (2012). Properties of lightweight aggregate concrete prepared with PVC granules derived from scraped PVC pipes. Waste Management, 29(2), 621-628.

Krishna, P. P., and Kanta, M. R., (2014). "Strength Variations in Concrete by Using E-Waste as Coarse Aggregate" International Journal of Education and applied research, Vol. 4, Issue Spl-2, Jan -June 2014, 82-84.

Lakshmi, R. and Nagan, S. (2011). Utilization of waste E –plastic particles in cementitious mixtures. Journal of Structural Engineering. 38 : 26-35. Lakshmiand, R. and Nagan, S. (2010). Studies on concrete containing E plastic waste. International journal of Environmental sciences. 1(3) : 0976-4402.

Ling, T. C., & Poon, C. S. (2013). Use of recycled CRT funnel glass as fine aggregate in dry-mixed concrete paving blocks. Journal of Cleaner Production, 68, 209-215.

Magashi, A., & Schluep, M. (2011). E-waste Assessment Tanzania. UNIDO e-waste initiative for Tanzania. Cleaner Production Centre of Tanzania & Empa Switzerland.

Mehta, P. K., & Monteiro, P. J. M. (2017). Concrete: Microstructure, Properties, and Materials (4th ed.). McGraw-Hill.

Muhsina N., Kalaimathi D., and Prem Sudha, R, (2024). Experimental Investigation on Concrete Using E- Waste as Partial Replacement as Coarse Aggregate, International Journal of Research Publication and Reviews, Vol 5, no 8, pp 1748-1754 August 2024

Neville, A. M. (2011). “Properties of Concrete”: Properties of Concrete, 5th Edition. Pearson Education

Perkins, D. N., Drisse, M.-N. B., Nxele, T., & Sly, P. D. (2014). E-waste: A global hazard. Annals of Global Health, 80(4), 286–295.

Poon, C. S., & Chan, D. (2006). Feasible use of recycled concrete aggregates and crushed clay brick as unbound road sub-base. Construction and Building Materials, 20(8), 578-585.

Puckett, J., Westervelt, S., & Gutierrez, R. (2005). The Digital Dump:Exporting Re-use and Abuse to Africa. Seattle: The Basel Action Network.

Purchase D., Abbasi G., Bisschop L., Chatterjee D., Ekberg C., Ermolin M., Fedotov P., Garelick H., Isimekhai K., Kandile N. G., Lundström M., Matharu A., Bradley W. M., Antonio P., Oluseun E. P., Teodora R., Heinz R., Angela S., Yehuda S., Kiran R. S., Fiona W., Benjamin P. W., and Ming H. W. (2020). E-waste: Global occurrence, chemical properties, and ecological impacts of e-wastes. Pure Appl. Chem. 2020; 92(11): 1733–1767

Rajiv G., Harish P., Nakka R. (2015). “Application of Recycled Coarse Aggregates and E Waste for Pavements with Low Traffic”. IOSR Journal of Mechanical and Civil Engineering (IOSR JMCE), e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 12, Issue 2 Ver. II (Mar - Apr. 2015), PP 64 70.

Rocco, C.G., and Elices, M., (2009), Effect of Aggregate Shape on the Mechanical Properties of a Simple Concrete, Engineering Fracture Mechanics, (2009), 76(2), pp 286-298.

Sakar, A. (2016). Dad brought home lead, kids got sick. The Cincinnati Enquirer. Archived from the original on March 29, 2022. https://web.archive.org

Salma S.; Sikandar S. Shdab S., (2015), "Scope of utilization of e-waste in special concrete" international journal of Advance Research in science and Emerging vol. no 8 issue (01).

Schluep, M., Hagelueken, C., Kuehr, R., Magalini, F., Maurer, C., Meskers, C., (2009). Recycling - from e-waste to resources. Paris, France: Empa, Umicore, UNU.: Sustainable innovation and technology transfer industrial sector studies.

Schmidt, C. W. (2006). Unfair trade - E-waste in Africa. Environmental Health Perspectives, 114: A232-A235.

Senthil Kumar, K., & Baskar, K. (2018). "Effect of Temperature and Thermal Shock on Concrete Containing Hazardous Electronic Waste." Journal of Hazardous, Toxic, and Radioactive Waste, 22(2), 04017028. DOI: 10.1061/(ASCE)HZ.2153-5515.0000387.

Suchithra S, Indu V S., (2015), “Study on Replacement of Coarse Aggregate by E-Waste in Concrete”. International Journal of Engineering Research &

Technology (IJERT) Special Issue - 2015 ISSN: 2278-0181 NCRACE-2015 Conference Proceedings

Tam, V. W., Tam, C. M., & Le, K. N. (2015). Cross-cultural comparison of concrete recycling decision-making and implementation in developed and developing countries. Resources, Conservation and Recycling, 101, 103-111.

Wasswa, J., & Schluep, M. (2008). E-waste assessment in Uganda: A situational analysis of e- waste management and generation with special emphasis on personal computers. Empa: Uganda Cleaner Production Center.

World Health Organization. (2024). Electronic waste (e-waste). Retrieved April 7, 2024, from https://www.who.int

Zhang, L., & Xu, Z. (2016). A review of current progress of recycling technologies for metals from waste electrical and electronic equipment. Journal of Cleaner Production, 127, 19-36.

APPENDIX

Table A.1 sieve analysis results of E-waste

STANDARD SIEVE SIZES (mm)	RETAINED (g)	PASSING (g)	PERCENTAGE PASSING (%)
26.5		2970	100
20	1055	1915	64.5
14	1275	640	21.5
10	425	215	7.23
8	120	95	3.20
5	65	30	1.01
3.35	30	0	0

Table A.2 sieve analysis results of fine aggregates

STANDARD SIEVE SIZES (mm)	RETAINED (g)	PASSING (g)	PERCENTAGE PASSING (%)
3.35		100	100
2.36	0.69	90.5	99.2
2	0.94	89.56	98.2
1.18	7.00	82.56	90.5
0.6	28.53	54.03	59.2
0.425	20.54	33.49	36.7
0.3	14.25	19.24	21.1
0.212	9.07	19.03	20.9
0.15	5.21	8.608	9.4
0.075	4.96	3.648	4.0

Table A.3 sieve analysis results of course aggregate

STANDARD SIEVE SIZES (mm)	RETAINED (g)	PASSING (g)	PERCENTAGE PASSING (%)
26.5		5000	100
20	130	4870	97.4
14	1315	3555	71.1

10	1520	2035	40.7
8	1070	965	19.3
5	875	90	1.8
3.35	65	25	0.5

Table A.4: Slump test result

MIX	HEIGHT OF SLUMP (mm)
Control	27
5% E-waste	30
10% E-waste	38
15% E-waste	47
20% E-waste	61

Table A.5: Compressive strength result of partially replaced coarse aggregate at 7days of curing

DATE CAST	DATE TESTED	WEIGHT (kg)	E-WASTE (%)	CRUSHING LOAD (KN)	AVERAGE COMPRESSIVE STRENGTH (N/mm^2)
August 7th	August 14th	2.62	0	99.46	
		2.42	0	102.95	
		2.58	0	102.29	12.0
August 14th	August 21st	2.67	5	119.94	
		2.57	5	130.68	
		2.40	5	82.47	11.10
August 14th	August 21st	2.30	10	85.36	
		2.40	10	93.30	
		2.16	10	139.67	10.8
August 14th	August 21st	2.40	15	98.97	
		2.46	15	101.31	
		2.44	15	92.23	9.75
August 14th	August 21st	2.20	20	86.91	
		2.47	20	71.65	
		2.19	20	89.04	8.40

Table A.6: Compressive strength result of partially replaced coarse aggregate at 14 days of curing

DATE CAST	DATE TESTED	WEIGHT (kg)	E-WASTE (%)	CRUSHING LOAD (KN)	AVERAGE COMPRESSIVE STRENGTH (N/mm^2)
August 7th	August 21th	2.43	0	171.12	
		2.70	0	175.92	
		2.33	0	154.29	17.0
August 14th	August 28th	2.67	5	130.47	
		2.57	5	127.73	
		2.40	5	192.76	15.3
August 14th	August 28th	2.30	10	138.27	
		2.40	10	116.71	
		2.16	10	145.88	13.6
August 14th	August 28th	2.40	15	114.40	
		2.46	15	102.48	
		2.44	15	133.87	11.9
August 14th	August 28th	2.20	20	102.491	
		2.47	20	93.042	
		2.19	20	105.112	10.2

Table A.7: Compressive strength result of partially replaced coarse aggregate at 28days of curing

DATE CAST	DATE TESTED	WEIGHT (kg)	E-WASTE (%)	CRUSHING LOAD (KN)	AVERAGE COMPRESSIVE STRENGTH (N/mm^2)
August 7th	September 4th	2.60	0	195.35	
		2.28	0	210.75	
		2.42	0	196.65	20.09
August 14th	September 11th	2.67	5	185.18	
		2.57	5	183.67	
		2.40	5	161.71	18.12
August 14th	September 11th	2.30	10	159.05	
		2.40	10	160.63	

		2.16	10	151.923	16.04
August 14th	September 11th	2.40	15	146.72	
		2.46	15	134.46	
		2.44	15	133.87	14.02
August 14th	September 11th	2.20	20	107.46	
		2.47	20	109.14	
		2.19	20	96.35	10.43

Table A.8: Average Compressive strength incorporate E-Waste at all Ages of Test

MIX	COMPRESSIVE STRENGTH (N/mm^2)		
	7days	14days	28days
Control	12.0	17.0	20.09
5%	11.10	15.3	18.12
10%	10.8	13.6	16.04
15%	9.75	11.9	14.02
20%	8.40	10.02	10.43

Table A.9: Compressive strength result of partially replaced coarse aggregate at 28days of curing

DATE CAST	DATE TESTED	E-WASTE (%)	FAILURE LOAD (KN)	AVERAGE FAILURE LOAD (KN)	AVERAGE FLEXURAL STRENGTH (N/mm^2)
August 7th	September 4th	0	15		
		0	13	14	5.25
August 14th	September 11th	5	10		
		5	8.5	9.25	3.45
August 14th	September 11th	10	6.5		
		10	5	5.75	2.16
August 14th	September 11th	15	2.5		
		15	2	2.25	0.85
August 14th	September 11th	20	1.5		
		20	0.5	1	0.38