E-Waste Management by Utilization Of E-Plastics in Concrete Mixture as Coarse Aggregate

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Abstract - Concrete is the most widely used building material in the construction industry, primarily due to its high strength and durability. As the world progresses rapidly, concerns for the environment and the need to safeguard natural resources have become increasingly important. One innovative approach is the recycling of waste materials, including electronic waste (E-waste), in the concrete industry. This research aims to utilize E-waste that is free from harmful chemicals as an alternative for coarse aggregate, while also exploring the use of wire and cable residues as a replacement for fine aggregate in concrete.

A literature review revealed that circuit board waste can substitute for up to 10% of coarse aggregate by weight. However, there has been no previous attempt to use wire and cable residues as an alternative for fine aggregates. Therefore, this study will implement varying dosages of cable residues. Concrete mix design will be carried out following IS 10262:2019 and IS 456:2000 standards for M20 grade concrete.

The compressive strength of the concrete with E-waste will be assessed at 7 day and 28 days using three cubes of size 150 mm x 150 mm x 150 mm tested in a Compression Testing Machine (CTM). The split tensile strength will be evaluated by testing three cylinders with a diameter of 150 mm and a height of 300 mm in the CTM, while the flexural strength will be determined by casting three prisms of size 500 mm x 100 mm x 100 mm and testing them in a flexural strength testing machine for each percentage of replacement.

Results indicate that beyond a 10% replacement of both coarse and fine aggregates, the compressive strength falls below the required minimum strength for this specific grade of concrete. Consequently, the maximum allowable replacement for coarse and fine aggregates is 10%. Additionally, both split tensile strength and flexural strength decrease as the percentage of fine aggregate replacement increases.

***Key Words*: E-Waste, Circuit board, Compressive strength, Flexural strength.**

1.INTRODUCTION

Concrete is the most commonly used building material in the construction industry, primarily due to its high strength and durability. As our world advances rapidly, there is growing attention toward environmental preservation and the recycling of waste materials. One emerging waste material utilized in the concrete industry is electronic waste (E-waste). E-waste refers to discarded electrical or electronic devices, including second-hand electronics destined for recovery, resale, salvage, recycling, or disposal. The rise of electronic waste has become a significant concern due to its potential for severe contamination of both human health and the environment. Utilizing E-waste in the concrete industry is seen as a feasible solution to manage the large volumes of waste generated.

In developing countries, the release of electronic waste can lead to serious health and pollution problems, as electronic equipment often contains hazardous materials such as mercury, nickel, silver, zinc, lead, cadmium, beryllium, arsenic, copper, chrome, and cobalt. This paper focuses on non-hazardous materials suitable for use in construction. Among the most common materials found in electrical and electronic equipment are iron and steel, followed by plastics, which constitute the second-largest component of e-waste. Depending on its chemical composition, e-waste can be repurposed as coarse aggregate, fine aggregate, or fine filler in concrete.

In recent years, there has been an increasing awareness of our environmental impact stemming from consumer habits, emphasizing the need for a more sustainable approach. This shift is particularly relevant to industries influencing consumer behavior, especially in the electronics sector, where short life cycles and rapidly evolving technology have led to growing volumes of e-waste. Unfortunately, a significant amount of e-waste ultimately ends up in landfills. Yet, the partial recyclability of many e-waste components has prompted the development of retrieval techniques for their recycling and reuse, underscoring the importance of e-waste management from both a waste minimization and material recovery perspective.

In Malaysia, the e-waste problem is escalating, with an estimated generation of 24.5 million tons of e-waste from electrical equipment, which continues to rise. The increase in e-waste is primarily attributable to consumer electronics, as reflected in data from the Department of Environment (DOE): estimates for television sets, personal computers, and rechargeable batteries have surged from 463,866 metric tonnes in 2011 to 832,692 metric tonnes in 2020, representing a 44% increase. This trend is expected to continue given the increasing usage of electrical equipment.

2. LITERETURE SURVEY

Varsha Rathore and Aruna Rawat define concrete as a material composed of various components mixed based on their material composition. It includes coarse and fine aggregates that act as fillers, combined with cement paste. The properties of concrete depend on the size of the aggregates (Rathore & Rawat, 2019). Concrete serves as the backbone of modern infrastructure and is produced in large quantities to meet the increasing demand for development (Raut et al., 2018). However, excessive production of concrete material may lead to a scarcity of raw materials. Therefore, it is essential to adequately replenish suitable constituents to ensure a sustainable supply of concrete in construction (Alagusankareswari et al., 2016). Concrete is recognized for its excellent compressive strength, stiffness, and durability. However, it is brittle and weak under tension. Plain concrete has two significant weaknesses: low tensile strength and low strain at fracture (Srinivasa Rao et al., 2010). Economically, inflation poses a serious challenge that many countries face, making it crucial to reduce construction costs while maintaining structural strength and durability. In Malaysia, electronic waste (e-waste) is defined as non-useful electronic products categorized as waste under the First Schedule in Code 110 (Ministry of Mineral and Environment, 2017). According to Mohammad Tapir Mapa, e-waste can contain pollutants such as lead (Pb), mercury (Hg), cadmium (Cd), nickel (Ni), polybrominated diphenyl ethers (PBDEs), and polychlorinated biphenyls (PCBs). The increasing generation of e-waste primarily results from both industrial and household usage. Currently, legislation focuses mainly on industrial e-waste disposal methods, with no regulations enforced for household e-waste, leading to a rise in home-generated electronic waste (Mohammad Tapir Mapa et al., 2018). E-waste, also known as electronic waste, refers to any electronic product that has reached the end of its usable human life cycle. E-waste can be divided into two main types: industrial and household. According to MarketWatch in 2018, consumers typically replace their mobile devices every 15 months. Today, many people prefer buying new appliances rather than going through the hassle of repairing old ones (Sunil Ahirwar et al., 2016). Examples of e-waste include mobile phones, tablets, laptops, and other electronic devices. This proliferation of digital devices could become a significant problem in the future because e-waste contains hazardous chemicals such as cadmium, lead, antimony, nickel, and mercury. These substances can pose health risks to humans and can pollute the environment, impacting rivers, lakes, and seas, as well as releasing toxic gases that harm the ecosystem. Meanwhile, Salmbanu Lahar, in an article about the potential application of e-waste in the construction industry, defines e-waste as unwanted electronic products that can be recycled, resold, salvaged, disposed of, reused, or restored. Each year, a significant amount of e-waste ends up in landfills, contributing to environmental pollution. The materials in e-waste may include potentially envorantment harmful components like cadmium, lead, beryllium, and brominated flame retardants. E-waste includes electronic devices that operate on electricity, such as mobile phones, machines, refrigerators, televisions, and other electric and electronic items. For example of e waste, smartphones contain mercury in their batteries, while elements like cadmium, tin, aluminum, and copper are found in printed circuit boards (PCBs). Additionally, polychlorinated biphenyls are located in capacitors and transformers, germanium is present in transistorized electronics, and silicon is used as the material in transistors (Salmabanu Luhar et al., 2019).

3. MATERIALS

3.1 FINE AGGREGATE

Natural sand particles obtained through mining processes this is know as Fine aggregates . These materials typically include natural sand or crushed stone particles that are ¼ inch or smaller in size. This type of aggregate is often referred to as "1/4 inch minus," indicating its size or grading.

Fine aggregate, or sand, plays a crucial role in construction. It fills the voids between larger aggregates, forms the bulk of mortar or concrete, and contributes to the material's resistance against shrinking and cracking. While natural sand, commonly known as river sand, is diminishing in availability, manufactured sand (M-Sand) has emerged as an effective substitute for use in concrete construction.

Manufactured sand is produced by crushing hard granite stone, resulting in cubical particles with rounded edges that are washed and graded for construction use. The size of Fine aggregates is less than 4.75mm. With the rapid growth of the construction industry, the demand for sand has surged, leading to a significant shortage of suitable river sand in many parts of the world.

The increase in the use of manufactured sand can be attributed to the depletion of quality river sand and its advantages in availability and transportation costs. Since M-Sand can be produced from granite rocks, it is often readily available nearby, reducing the transportation costs associated with sourcing river sand from distant locations. Consequently, using manufactured sand can help control construction costs.

Another benefit of M-Sand is that it can be produced to be dust-free, and its size can be easily regulated to meet the required grading specifications for various construction applications. In this project, we utilized M-Sand with a specific gravity of 2.58

3.2 COARSE AGGREGATE

Coarse aggregate is the largest component of a concrete mixture and plays a crucial role in the overall composition of concrete. Its properties, such as strength, maximum size, shape, and water absorption, significantly affect the concrete mix design, impacting the water demand and the quantities of cement and fine aggregate needed.

Research shows that using larger coarse aggregate sizes results in lower water demand for the mixture. This is because larger aggregates have a smaller surface area compared to smaller ones. In terms of shape, rounded aggregates are ideal for creating economical mix designs for normal-strength concrete, while angular aggregates are preferred for high-strength concrete. Proper grading of coarse aggregates is essential to minimize the risk of segregation, emphasizing the importance of good grading in concrete mix design.

When it comes to strength, using higher-strength aggregates can enhance the overall strength of the concrete, provided that other contributing factors are appropriately managed. In this case, we used a coarse aggregate blend consisting of 70% 20 mm aggregate and 30% 12.5 mm aggregate. The coarse aggregate selected has a specific gravity of 2.85.

3.3 CEMENT

Cement is a binder used in construction that sets, hardens, and binding them together. It is commonly combined with sand and gravel (aggregate) to create different mixtures. When combined with fine aggregate, cement produces mortar for masonry. When mixed with sand and gravel, it forms concrete, the most widely used material globally and second only to water as the most consumed resource on Earth.

In this project, we used Portland Pozzolana Cement (PPC). PPC is a blended cement made by combining Ordinary Portland Cement (OPC) with pozzolanic materials in a specific ratio. This type of cement is often considered eco-friendly because the materials used in its production are derived from natural recycled waste. PPC is very fine, making it particularly effective for plastering work.

Pozzolana consists of silica material, which makes it cost-effective and economical to use. PPC exhibits excellent resistance to sulfate attacks, making it suitable for hydraulic structures, marine structures, and construction near coastlines and dams. It is utilized in both prestressed and post-tensioned concrete components.

Furthermore, PPC reduces carbon monoxide emissions from concrete, enhancing its environmental friendliness. The fine nature of the pozzolanic materials can fill gaps between reinforcement and aggregate, minimizing issues such as shrinkage, honeycombing, and bleeding. This is given strength and durability of the concrete

3.4 CIRCUIT BOARDS

A circuit board is a valuable component derived from electronic waste (e-waste) materials, showcasing the potential for recycling and repurposing discarded electronics. We used low grade circuit boards plastic as e-waste. We collected the e-wastes from a recycling firm called Green Era Recyclers which is located in Edayarpalayam, Coimbatore. These E-wastes are used as partial replacement for coarse aggregate in cement concrete. They were in the form of chips, which are flaky in shape. The properties of the circuit boards are shown in table 3.1 given below. The pictures of the circuit boards are also given below,

Fig. 1. Low Grade Circuit Board

Table 1 : Properties of Circuit Board Plastics

Sr. No.	Characteristics	Value
1	Size	12.5 – 20 mm
2	Specific Gravity	1.226
3	Type	Crushed

3.5. RESIDUES OF WIRES AND CABLES

Residues of wires and cables are also a product of e-waste materials. Here, the powdered form of the coverings of wires and cables are used for the project. The coverings of wires and cables are made up of Polyvinyl Chloride (PVC), which are plastics. These materials are also collected from the same recycling firm called Green Era Recyclers. The specific gravity of this material is found by pycnometer test and the value is 1.014.

4. EXPERIMENTAL PROGRAM

Experimental Program was carried out in three stages:
Stage 1
Determination of physical properties of ingredients.
Stage 2
Mix Design for M25 Concrete as per IS method of concrete mix design.
Stage 3
Experimental work conducted on concrete by replacing coarse aggregate with
E-waste with 0.42% water content.

4.1 Stage 1

Determination of physical properties of ingredients

4.1.1 Fine Aggregate

Table 2 : Physical Properties of Sand

Sr. No.	Property	Average
1	Specific Gravity	2.70
2	Fineness Modulus	3.47
3	Water Absorption	0.50%
4	Surface Texture	Smooth
5	Particle Shape	Granular
6	Density	1725.33 kg/m^3

Table 3 : Physical Properties of Coarse Aggregates

Sr. No.	Property	Average
1	Specific Gravity	2.80
2	Fineness Modulus	7.40
3	Water Absorption	0.60%
4	Particle Shape	Angular
5	Density	1636.10 kg/m^3

4.2 Stage 2

Mix Design for M25 Concrete as per IS method of concrete mix design.

➢ **Data**:

- Type of cement – OPC 53 Grade
- Maximum size of aggregate – 20 mm
- Workability – 60 mm slump
- Minimum cement content – 280 kg/m^3
- Maximum water cement ratio – 0.45
- Grading of F. A. conforming to grading zone III
- Grading of C. A. conforming to IS 383 Table No. 2

➢ **Step 1**: Target mean strength

Target mean strength = fck + 1.65 * S

Target mean strength = 25 +1.65 * 4 =31.6 N/mm^2

(Where, S = standard deviation taken from IS: 456 Table No. 8.)

➢ **Step 2**: Water cement ratio

W/c = 0.42

Water cement ratio is taken from experience of similar work.

This w/c is to be selected from both from strength consideration and maximum w/c denoted in IS: 456 Table No. 5.

W/c = 0.42 < 0.45, ok

➢ **Step 3**: Selection of water content

Max. Water content as per Table No. 11.23 is 186 lit.

Estimated water content for 60 mm slump = (186 * 3/100) + 186 = 192 lit.

(3 % increase for every 25 mm slump over and above 50 mm slump.)

➢ **Step 4**: Calculation of cement content

W/c ratio = 0.42

Cement content = 192/c = 0.42

c = 192 * 0.42 = 457.14 = 458 kg/m^3 > 280 kg/m^3 ok.

➢ **Step 5**: Calculation of coarse aggregate and fine aggregate

From Table No. 11.24 volume of C. A. corresponding to 20 mm size aggregate. And F. A. of zone III for w/c ratio of 0.50 is found to be 0.64.

In present case w/c ratio 0.42 it is less by 0.08.

The C. A. is increased at the rate of 0.01 for every decrease in w/c ratio of 0.05.

(0.01/0.05) * 0.08 =0.016

volume of C. A. = 0.62 + 0.016 =0.636 = 0.64

volume of F. A. = 0.36

(from Table No. 3, IS 10262:2009)

➢ **Step 6**: Calculation of mix proportion

Volume of concrete = 1 m^3

Volume of cement = (458/3.15) * (1/1000) = 0.1453 m^3

Volume of water = 0.1920 m^3

Total volume = 0.1453 + 0.1920 =0.3373 m^3

Volume of C. A. = 1 - 0.3373 = 0.6627 m^3

Weight of C. A. =0.6627*2.80*1000*0.64 = 1187.55 = 1188 kg/m^3

Weight of F. A. = 0.6627*2.70*1000*0.36 = 644.14 = 645 kg/m^3

➢ **Quantity:**
- Water cement ratio = 0.42
- Cement = 458 kg/m^3
- Fine aggregate = 645 kg/m^3
- Coarse aggregate = 1188 kg/m^3

➢ **Proportion**:
Cement: Fine Aggregate: Coarse Aggregate
1: 1.40: 2.60

4.3 Stage 3
Experimental work conducted on concrete by replacing coarse aggregate with E-waste.
Preparation of Specimens
Constant parameters
• Mix proportion of concrete selected – 1:1.40:2.60
• Type of cement: OPC
• Type of aggregate
i) Sand < 4.75mm
ii) Coarse Aggregates for flexural test < 20mm and for compressive test and split tensile test < 20mm.
• Period of curing: 7 & 28 days
• Water cement ratio: 0.42
Variable Parameters
• Coarse aggregate replaced by E-waste from 0% to 20% at the increment of 5%.
Test
• For each test of concrete, three cubes of 150mm x 150mm x150mm size were cast and tested to determine compressive strength of concrete.
• For each test three cylinders of 150 mm dia. x 300 mm height size were cast and tested to determine split tensile strength.
• For each test three prism of dimension 500 mm x 100 mm x 100 mm size were cast and tested to determine flexural strength.

5. RESULTS

Table 4: Details of Mix Designations

Sr. No.	Mix Designation	Binding Materials		Fine Aggregate	Cement
		Coarse aggregate	E-waste		
1.	EW00	100%	0%	100%	100%
2.	EW05	95%	5%	100%	100%
3.	EW10	90%	10%	100%	100%
4.	EW15	85%	15%	100%	100%
5.	EW20	80%	20%	100%	100%

Table 5: Effect of E-Waste on Workability

% E-Waste	Workability	
	Slump (mm)	Compaction Factor
0	70	0.87
5	85	0.89
10	90	0.91
15	100	0.91
20	100	0.93

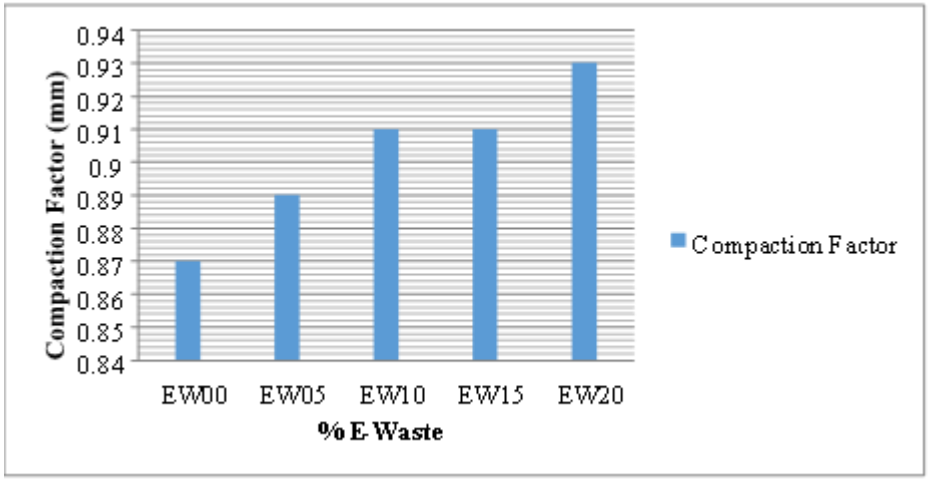

Fig. 2: Variation in Slump Value

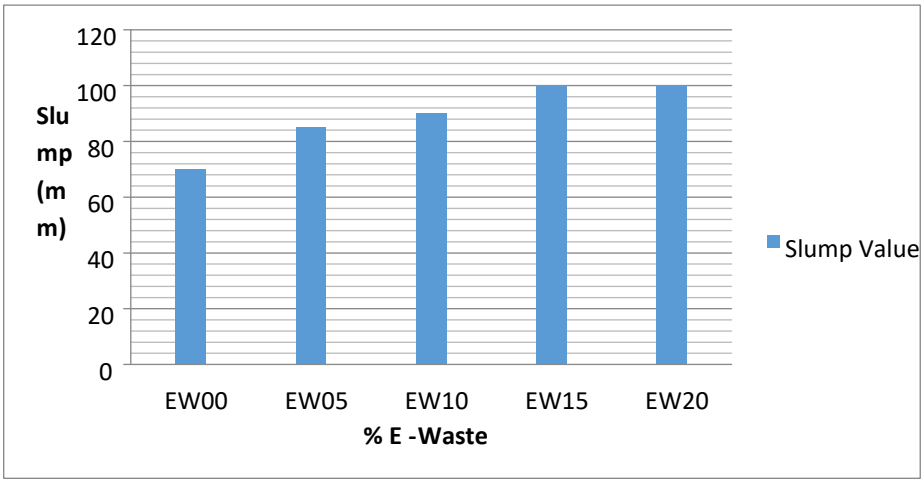

Fig. 3: Variation in Compaction Factor

Table 6: Effect of E-Waste on Compressive strength of concrete

Mix Designation	7 days	28 days
EW00	24.43	36.65
EW05	23.59	35.38
EW10	23.74	35.61
EW15	20.74	31.11
EW20	19.50	29.25

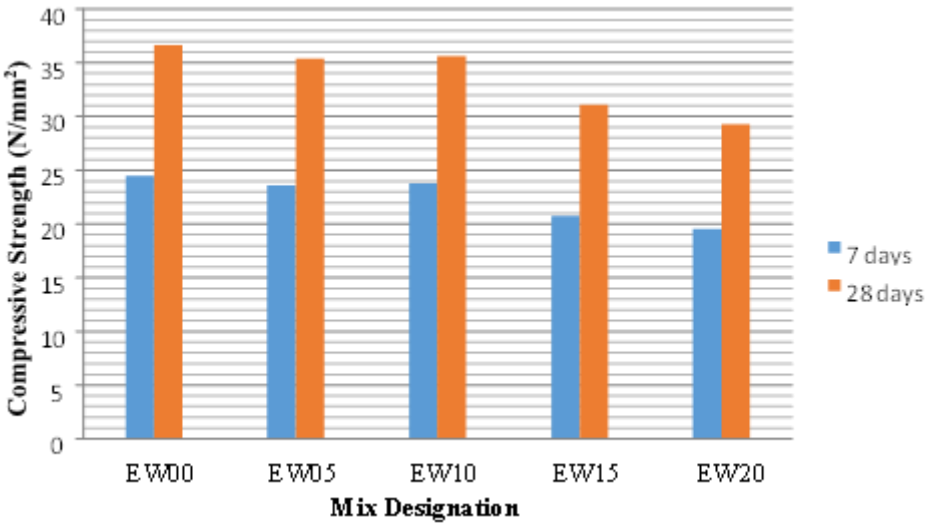

Fig. 4 : Variation in Compressive strength of concrete

Table 7 : Effect of E-Waste on Split tensile strength on concrete

Mix Designation	7 days	28 days
EW00	2.84	4.26
EW05	2.78	4.17
EW10	2.81	4.21
EW15	2.51	3.76
EW20	2.15	3.22

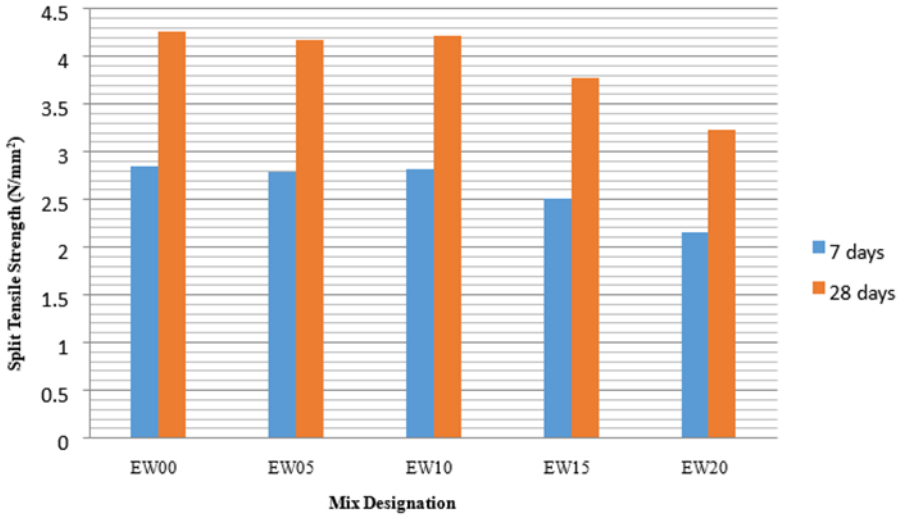

Fig. 5 : Variation in Split tensile strength of concrete

Table 8 : Effect of E-Waste on Flexural strength of concrete

Mix Designation	7 days	28 days
EW00	3.84	5.76
EW05	3.74	5.61
EW10	3.79	5.68
EW15	3.44	5.16
EW20	3.16	4.74

Fig. 6 : Variation in Flexural strength of concrete

6. CONCLUSION

In conclusion, this study successfully utilized M25 grade concrete with a minimum strength rating of 15 N/mm^2. The objective was to explore alternatives to coarse aggregate in concrete production. As technology advances, the amount of electrical and electronic waste is increasing, posing risks to surrounding communities and potentially elevating radiation levels in the environment.

This study also aimed to determine the compressive strength of concrete that incorporates e-waste. Tests indicated that concrete with 10% e-waste nearly achieved a compressive strength of 15 N/mm^2. However, some defects during the production process, such as inaccurate water measurements, adversely affected the concrete's compression rate. Moreover, errors in reading and weighing tools also impacted the mixing proportions of the concrete produced.

Finally, the study also evaluated the rate of water infiltration in the concrete that was produced.

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