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E-Waste (PCB) Used in Concrete as a Partial Replacement of Coarse Aggregate

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Abstract

This study explores the potential of using e-waste (Printed Circuit Boards, PCBs), by partially replacing the coarse aggregates with PCBs in the concrete. The research evaluates the compressive, tensile, and flexural strengths of M25-grade concrete, where coarse aggregate is replaced with 0%, 5%, 10%, and 15% e-waste. Test results indicate that up to 10% e-waste replacement in concrete maintains compressive strength levels comparable to standard concrete, with a slight improvement at 5% replacement. However, both split tensile and flexural strengths show a decreasing trend as the percentage of e-waste increases, with significant reductions observed at 15% replacement. The findings suggest that while e-waste can be incorporated into concrete up to 10% without significantly compromising structural integrity, higher replacement levels may negatively impact performance. This study demonstrates the viability of using e-waste in concrete, providing environmental benefits by reducing the use of natural aggregates and addressing e-waste disposal issues, thus contributing to more sustainable construction practices.

Major Findings: *Up to 10% PCB replacement in M25-grade concrete maintains compressive strength, with a slight improvement at 5% replacement. However, split tensile and flexural strengths decrease with increasing PCB content, with a significant drop at 15% replacement. While incorporating PCBs in concrete enhances sustainability by reducing landfill waste, higher replacement levels negatively impact mechanical properties.*

Keywords: *Compressive Strength, Concrete, E-Waste, Printed Circuit Board*

1.0 Introduction

In today's world, it's hard to imagine a construction project that doesn't involve concrete. In the construction business, concrete is the most commonly utilized building material. Its excellent strength and durability are the key factors contributing to its appeal[1]. The world is changing too quickly these days, and it is imperative that waste materials be recycled and natural resources be protected.

E-waste is a new material being used in the concrete industry. A practical way to deal with large amounts of E-waste is to reuse it in the concrete industry[2]. One of the waste sources with the fastest global growth is e-waste. It used to account for roughly 1% of all solid trash generated in wealthy nations, but by 2021, that percentage is expected to rise to 2%. It makes up between 0.01% and 1% of all municipal solid garbage generated in poor nations[3]. E-waste is a growing concern that poses major

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environmental and human health risks. Recycling ideas in particular need to be taken into consideration. E-waste is the term for excess, broken, outdated, and carelessly disposed of electrical or electronic equipment. The rapid growth of technology and low startup costs are causing a rise in electronic waste worldwide[4]. It is necessary to dispose of many tons of E-waste annually. If not handled properly, the various materials and chemicals in e-waste can lead to serious health and environmental problems for people and nature. A partial substitution of E-waste with coarse aggregate is attempted since coarse material is scarce for the preparation of concrete[5]. This study focuses on M25 grade concrete, where coarse aggregate is partially replaced with e-waste (specifically, PCBs) at varying levels of 0%, 5%, 10%, and 15%. The compressive strength of the concrete specimens incorporating these e-waste materials is then evaluated and compared to the compressive strength of a control concrete mix without any e-waste.

The growing worry about electronic waste, or e-waste, stems from the rising use of electronic devices. In 2014, the world generated an estimated 41.8 million tonnes of e-waste. This waste contains valuable metals like copper, gold, silver, palladium, and platinum. Sadly, only 15% of e-waste is recycled, which poses risks to both human health and the environment[6].

The integration of e-waste materials into concrete has been explored as a means to enhance sustainability and reduce environmental impact. E-waste plastics, when used as fine aggregates, can replace 5-20 % of the conventional material. This substitution typically leads to a decrease in compressive strength by 5-25 %, along with reduced flexural strength and workability. Optimal replacement is recommended to be ≤10% to maintain acceptable strength, making these materials best suited for lightweight applications[7].

CRT (Cathode Ray Tube) glass, which can be used as both fine and coarse aggregate, offers a replacement range of 5-30 %. It causes a slight decrease in compressive strength (up to 15%) with higher content but improves shrinkage control while increasing brittleness. This material is advantageous for reducing landfill disposal and is suitable for non-load-bearing structures[8].

PCBs used as fine aggregate (5-15 % replacement) often result in reduced compressive strength due to poor bonding. The inclusion of PCBs also increases brittleness and reduces the modulus of elasticity. Despite these drawbacks, they contribute to environmental sustainability but negatively impact ductility[9].

Copper wire, when used as coarse aggregate at 5-20% replacement, causes only a slight reduction (up to 10% at 20% replacement) in compressive strength. It also leads to lower flexural strength and decreased durability properties. This material supports recycling efforts but may need admixtures to enhance durability[10].

Aluminum waste used as coarse aggregate with a replacement range of 5-15 %, results in minimal reduction in compressive strength (up to 10%). It improves thermal properties and reduces density, making it ideal for lightweight concrete applications, particularly for insulation[11].

Plastic chips, when utilized as fine aggregate (5-20 % replacement), reduce compressive strength by 10-30 % and affect workability negatively. However, they improve impact resistance and are best suited for non-structural applications such as pavements and lightweight structures[12].

Silicon waste, used as fine aggregate with a 5-15 % replacement, leads to a slight reduction in compressive strength (5-10 %) but enhances toughness and reduces shrinkage. This makes it effective for improving the durability and crack resistance of concrete[13].

Plastic optical fibers, when used as reinforcement fibers in concrete at 0.5-2 % by weight, improve strength at lower percentages. They enhance flexural and tensile properties while improving ductility, making them valuable for high-strength fiber-reinforced concrete applications aimed at enhanced toughness and crack control[14].

PCB powder, used as a cement replacement (5-10 %), results in a 10-20 % decrease in compressive strength. It also reduces workability and increases brittleness, but offers potential for resource conservation, though further investigation is needed for optimal performance[15].

Waste rubber from e-waste, used as fine aggregate (5-15 % replacement), causes a moderate decrease in compressive strength (up to 20 %) but improves elasticity and energy absorption. This makes it suitable for shock-absorbing applications such as barriers and pavements[16].

Plastic e-waste, when used as fine aggregates with a 10-20 % replacement, increases tensile strength and reduces density. Although specific data on compressive

Table 1. Replacement proportions for various concrete

Sr. No.	Concrete type	Concrete design mix proportions				
		W/C ratio	Cement	FA	CA	EW
1	E0	0.55	1	2.5	3.65	----
2	E1	0.55	1	2.5	3.47	0.18
3	E2	0.55	1	2.5	3.29	0.36
4	E3	0.55	1	2.5	3.11	0.54

strength reduction is not provided, it is best suited for lightweight, non-structural applications due to its lower density[17].

E-glass waste, used as reinforcement in 3D printed concrete, enhances fracture energy and reduces plastic shrinkage cracking, although specific replacement percentages and compressive strength effects are not detailed. It is effective in improving durability and crack resistance in 3D-printed structures[18].

Lastly, printed circuit boards as fine aggregate (5-15 % replacement) result in a slight decrease in compressive strength but improve thermal insulation properties. This makes them suitable for non-load-bearing walls, where thermal benefits can offset the reduction in strength[19].

Most e-waste materials lead to a reduction in compressive strength, especially when used at high percentages. However, certain types like aluminum waste show minimal strength loss, making them suitable for structural applications in small proportions. Some e-waste, particularly plastic optical fibers and waste rubber, enhance the toughness and elasticity of concrete, useful for specialized applications requiring flexibility and impact resistance. Many e-waste materials negatively affect workability, requiring the use of plasticizers or other additives to improve concrete mixing and placement. Overall, incorporating e-waste in concrete reduces landfill burden and promotes sustainable construction practices, despite some mechanical trade-offs.

2.0 Materials and Methods

This study aims to determine if e-waste, specifically PCBs, can partly replace coarse aggregate in concrete. To achieve this, the study includes compressive, split tensile, and flexural strength tests. The materials used for the concrete mix are as follows:

Cement: Ordinary Portland cement (OPC)

Fine Aggregate: Natural sand passing through a 4.75 mm sieve

Coarse Aggregate: 20 mm nominal size

PCB E-Waste: Recycled e-waste from household electronic devices (e.g., televisions, radios, computers), crushed to 20 mm nominal size, used as a partial replacement for coarse aggregate

Water: Potable water for mixing and curing

Concrete Mix Design: The mix is designed for M25 grade concrete with a water-cement ratio of 0.55.

Coarse aggregate is replaced with PCB e-waste at proportions of 0% (control), 5%, 10%, and 15% by weight. Details are shown in Table 1.

Basic material tests on cement, fine aggregate, coarse aggregate, and PCB e-waste are conducted, with results presented in Table 2 and Table 3.

Table 2. Properties of cement

Properties (IS 112:1989)	Values
Specific gravity	3.15
Consistency	30
Initial setting time	30.60 mins
Final setting time	560 mins

Table 3. Physical properties of fine aggregate and coarse aggregate

Property	Fine aggregate	Coarse aggregate	E-waste
Fineness modulus	3.37	5.6	1.44
Specific gravity	3.15	2.95	3.08
Bulk density(kg/m^3)	1820	1800	_
Water absorption (%)	1	0.64	_

2.1 Compressive Strength Test

Concrete cubes (150 mm × 150 mm × 150 mm) are cast for testing.

Three sets of cubes are prepared for each replacement proportion (0%, 5%, 10%, 15%).

Each set undergoes compressive strength testing after 7, 14, and 28 days of curing. The findings are shown in Table 4.

At 7 days, the compressive strength for e-waste concrete (E1, E2, and E3) was lower than the standard concrete (E0). However, the variation across the replacement levels (E1, E2, and E3) was minimal, indicating that early strength development was not significantly affected by the introduction of PCB e-waste. After 14 days, E1 (5% replacement) showed a higher compressive strength (25.9 N/mm^2) than the standard concrete (E0, 25.4 N/mm^2). This suggests that a 5% replacement of coarse aggregate with e-waste can enhance the early-age strength of concrete. At 28 days, E1 and E2 displayed compressive strengths slightly higher or comparable to E0, indicating that up to 10% replacement of coarse aggregate with PCB e-waste does not negatively affect the compressive strength of concrete. However, E3 (15% replacement) exhibited a noticeable reduction in compressive strength, suggesting that beyond 10% replacement, the mechanical properties begin to deteriorate.

2.2 Split Tensile Strength Test

Concrete cylinders (150 mm diameter × 300 mm height) are cast for testing. The results are shown in Table 5.

Three sets of cylinders are prepared for each e-waste replacement proportion (0%, 5%, 10%, and 15%). Cylinders are tested for split tensile strength after 28 days of curing.

The split tensile strength of concrete decreased with an increasing percentage of e-waste replacement. E0 (control) had the highest split tensile strength (3.36 N/mm^2), followed by E1 (3.042 N/mm^2), E2 (2.655 N/mm^2), and E3 (2.05 N/mm^2). This shows that while the compressive strength remains relatively unaffected up to 10% replacement, the tensile strength is more sensitive to the presence of e-waste. The trend

Table 4. Compressive strength of concrete

Concrete type	**Average compressive strength in N/mm^2**		
	7 Days	**14 days**	**28 days**
E0	13.5	25.4	30.6
E1	10.5	25.9	31.4
E2	10.4	24.7	30.9
E3	10.8	22.3	28.8

Table 5. Split tensile strength of concrete

Concrete type	Average split tensile strength in N/mm²
E0	3.36
E1	3.042
E2	2.655
E3	2.05

indicates a decline in tensile capacity as more e-waste is incorporated.

2.3 Flexural Strength Test

Concrete beams (100 mm × 100 mm × 500 mm) are cast for testing.

Table 6. Flexural strength of concrete

Concrete type	Average flexural strength in N/mm²
E0	5.6
E1	4.5
E2	3.5
E3	3.2

Three sets of beams are prepared for each e-waste replacement proportion (0%, 5%, 10%, and 15%). Beams are tested for flexural strength after 28 days of curing. The results are shown in Table 6.

The flexural strength decreased as the percentage of e-waste increased. E0 had the highest flexural strength (5.6 N/mm²), while E1, E2, and E3 recorded progressively lower strengths (4.5 N/mm², 3.5 N/mm², and 3.2 N/mm², respectively). This result confirms that e-waste adversely affects the flexural performance of concrete, with the most significant reductions occurring at higher replacement levels (10% and 15%).

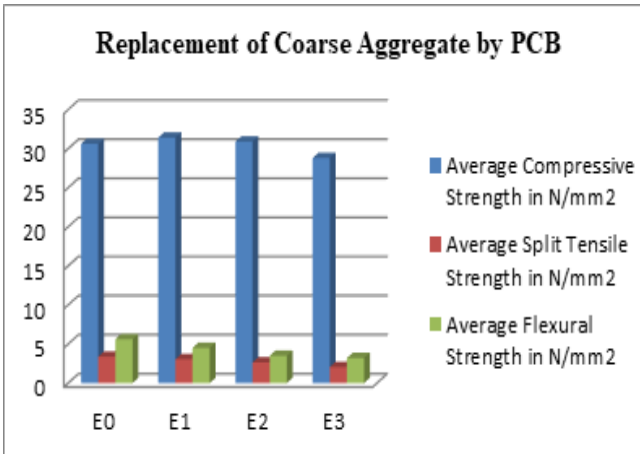


Figure 1. Average Strengths of Concrete by replacement of coarse aggregate by PCB.

3.0 Results and Discussion

Figure 1 indicates that addition of PCB as a replacement for coarse aggregate initially shows a positive effect on compressive strength, with a peak at 10% replacement (E1). After this point, replacing more parts leads to a reduction in compressive strength. This could be due to the change in aggregate properties or a reduction in the effective aggregate volume available for load transfer. The split tensile strength decreases with increasing PCB replacement. The decrease in strength may be because PCB has lower tensile strength than regular coarse aggregates. This difference can harm the concrete's ability to handle tensile stress. Like the split tensile strength, the flexural strength also goes down as the amount of PCB increases. This trend indicates that the inclusion of PCB might negatively affect the concrete's ability to resist bending forces, likely due to the weaker bonding and reduced strength of PCB material compared to conventional coarse aggregates.

4.0 Conclusion

The study concludes that incorporating PCBs as a partial replacement for coarse aggregate in M25 grade concrete provides an environmentally sustainable solution for managing e-waste but introduces trade-offs in concrete performance. The results indicate that replacing up to 10% of the coarse aggregate with PCB e-waste can have a

positive or neutral impact on compressive strength, with a slight increase observed at the 5% replacement level. This suggests that a small amount of PCB can improve early-age strength without significantly compromising the overall concrete quality. However, as the PCB replacement level increases beyond 10%, particularly at 15%, a noticeable reduction in compressive, split tensile, and flexural strengths occurs. The decrease in mechanical properties can be attributed to the inherent characteristics of PCB material, such as weaker bonding and reduced strength compared to conventional aggregates. This decline in strength may affect the concrete's ability to resist tensile and bending forces, highlighting the need to carefully manage the proportion of PCB used. Overall, while the use of PCB in concrete promotes recycling and reduces landfill waste, it necessitates a balance between environmental benefits and mechanical performance.

5.0 Future Scope

Further studies should focus on determining the optimal percentage of PCB replacement that maximizes the benefits while minimizing negative impacts on concrete strength. Investigating finer gradations and varying proportions of PCB could help identify the most effective balance. Research could explore the treatment or modification of PCB material to enhance its bonding properties and overall performance when used in concrete. Techniques such as chemical treatment or blending with other materials might improve strength characteristics and workability. The inclusion of plasticizers, super plasticizers, or other admixtures could mitigate the negative effects of PCB on concrete properties. Future studies should evaluate the effectiveness of these additives in improving the workability and mechanical performance of PCB-incorporated concrete.

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