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Performance of Non-Metallic E-Waste in Concrete - A Review

Tushar P. Kawale [1], Dr. Anantkumar N. Dabhade [2]

[1] Research Scholar (M.Tech in Structural Engineering), Civil Engineering Department, Kavikulguru Institute of Technology and Science, Ramtek, Maharashtra, India

[2] Professor, Civil Engineering Department, Kavikulguru Institute of Technology and Science, Ramtek, Maharashtra, India

Abstract- Electronic waste (E-waste) is one of the fastest growing solid waste streams in the world due to rapid technological advancement, short lifespan of electronic devices, and increasing consumer demand. The disposal of e-waste has become a critical environmental issue because it contains toxic substances such as lead, cadmium, mercury, brominated flame retardants, and other hazardous compounds that pose severe threats to human health and the ecosystem. The construction industry consumes huge quantities of natural resources such as river sand and coarse aggregates, leading to depletion of natural deposits and ecological imbalance. Hence, incorporating non-metallic fractions of e-waste such as plastics, printed circuit boards, and electronic casings in concrete as partial replacement of aggregates provides a sustainable approach for e-waste management while reducing the consumption of natural resources. This review paper presents a comprehensive discussion on the utilization of non-metallic e-waste in concrete, focusing on its influence on fresh properties, mechanical strength, durability characteristics, microstructural behavior, thermal performance, and environmental sustainability. Previous research indicates that e-waste aggregates generally reduce density and improve workability, but compressive strength tends to decrease at higher replacement levels due to poor bonding and lower stiffness of plastic materials. However, some studies show improved tensile and flexural strength due to fiber reinforcement effect and better energy absorption behavior. The review also highlights the optimum replacement percentage ranges and identifies key research gaps such as lack of long-term durability studies, limited microstructural investigations, absence of large-scale structural element testing, and insufficient standardization in processing and characterization of e-waste aggregates. The findings of this review indicate that non-metallic e-waste has strong potential for producing sustainable lightweight concrete, but further experimental validation, standard mix design guidelines, and durability-based investigations are necessary before its widespread structural application.

Keywords: E-waste concrete, non-metallic electronic waste, Plastic aggregates, Printed circuit board waste, Sustainable concrete, green construction, Workability, Compressive strength, Durability, Lightweight concrete.

I. INTRODUCTION

The modern world is experiencing an unprecedented technological revolution, where electronic gadgets and electrical appliances have become an essential part of daily life. Over the past few decades, rapid growth in industrialization, urbanization, digital transformation, and communication technologies has resulted in a massive increase in the production, consumption, and disposal of electronic devices. Equipment such as computers, laptops, mobile phones, televisions, printers, scanners, refrigerators, washing machines, air conditioners, microwave ovens, and many other electronic and electrical products are continuously being manufactured and upgraded to satisfy consumer demands. Due to the fast pace of technological advancement, electronic products quickly become outdated, leading to frequent replacement and shortened service life. This increasing trend of "use and throw" culture has created one of the most serious environmental problems globally, known as electronic waste or E-waste.

Electronic waste refers to discarded, obsolete, or unusable electrical and electronic equipment (EEE) that has reached the end of its useful life. E-waste contains a wide range of materials, including both metallic and non-metallic fractions. The metallic portion includes valuable materials such as copper, aluminum, iron, and precious metals like gold and silver, while the non-metallic portion contains plastics, glass, ceramics, printed circuit board resins, epoxy compounds, rubber, and other composite materials. Among these, the non-metallic fraction contributes significantly to the overall volume of e-waste and is extremely difficult to recycle due to its heterogeneous composition. A large portion of this non-metallic waste is typically dumped in landfills or burned, which creates severe environmental and health hazards.

The management and disposal of e-waste has become a critical issue because it is non-biodegradable in nature and contains toxic and hazardous substances. Many electronic devices contain heavy metals such as lead (Pb), mercury (Hg), cadmium (Cd), chromium (Cr), arsenic (As), and nickel (Ni), along with brominated flame retardants (BFRs), polyvinyl chloride (PVC), and other harmful chemicals. When e-waste is disposed of improperly through open dumping or uncontrolled incineration, it releases poisonous gases and dangerous pollutants such as dioxins and furans into the atmosphere. These toxic substances contaminate soil and groundwater, and they enter the food chain, causing long-term ecological damage. Additionally, exposure to e-waste pollutants can lead to serious health issues such as respiratory disorders, neurological problems, kidney damage, skin diseases, reproductive disorders, and even cancer.

In developing countries like India, the e-waste problem is even more alarming due to rapid population growth, increasing purchasing power, and expanding use of electronic products. Furthermore, India faces major challenges such as lack of advanced recycling infrastructure, poor collection and segregation systems, limited public awareness, and dominance of informal recycling sectors. Informal recyclers often use unsafe manual dismantling and crude burning methods to extract valuable metals, leaving behind large quantities of toxic plastic waste and glass waste that are dumped openly. According to reported data, India generated approximately 650,000 metric tons of e-waste in 2014, and this quantity has increased significantly in recent years due to continuous growth in electronic consumption. With the increasing dependence on digital technologies, the volume of e-waste is expected to rise rapidly, making it one of the most urgent environmental challenges for sustainable development.

At the same time, the construction industry is considered one of the largest consumers of natural resources worldwide. Concrete is the most widely used construction material because of its strength, durability, versatility, and cost-effectiveness. The production of concrete requires a large amount of raw materials such as cement, natural river sand, and coarse aggregates. Coarse aggregates alone contribute nearly 60–75% of the total volume of concrete. However, due to rapid infrastructure development, construction of highways, bridges, buildings, dams, and industrial structures, the demand for natural aggregates is continuously increasing. Excessive quarrying and mining of aggregates and river sand have resulted in severe environmental impacts such as depletion of riverbeds, soil erosion, groundwater level reduction, deforestation, destruction of aquatic habitats, and ecological imbalance. Moreover, cement manufacturing contributes significantly to global carbon dioxide emissions, thereby increasing greenhouse gas concentration and accelerating climate change.

Therefore, researchers and engineers are increasingly focusing on sustainable construction practices by exploring alternative materials and industrial waste utilization in concrete. The use of waste materials not only helps reduce the environmental burden but also contributes to conservation of natural resources and reduction in construction cost. Several waste materials such as fly ash, silica fume, ground granulated blast furnace slag (GGBS), waste glass, plastic waste, rubber waste, demolished concrete waste, and agricultural wastes have already been studied as partial replacement materials in concrete. In this context, non-metallic e-waste has emerged as a potential substitute material due to its availability in large quantities and its non-biodegradable nature.

In recent years, significant research efforts have been directed toward incorporating the non-metallic fraction of e-waste into concrete as a partial replacement of fine aggregates, coarse aggregates, or in some cases as a supplementary cementitious material. Non-metallic e-waste mainly consists of plastic casings, PCB resin powder, glass components, and composite polymeric materials. When processed and crushed into aggregate-like particles, these e-waste materials can potentially replace a portion of natural aggregates in concrete. The primary objective behind this approach is to provide an effective and eco-friendly solution for e-waste disposal while simultaneously reducing the consumption of natural aggregates. Additionally, due to the low density of plastic-based e-waste, its incorporation in concrete can result in lightweight concrete, which may be beneficial for non-structural components, partition walls, pavement blocks, and precast elements.

Another important advantage of e-waste incorporation is its potential to improve ductility and energy absorption capacity of concrete. Conventional concrete is a brittle material and fails suddenly under tensile stresses. E-waste plastic aggregates and PCB-based materials may contribute to improved flexibility, crack resistance, and impact energy absorption due to their polymeric nature. This makes e-waste concrete promising for applications requiring toughness and improved post-cracking behavior. Furthermore, e-waste particles generally have low thermal conductivity, which may improve the thermal insulation properties of concrete and contribute to energy-efficient building construction.

However, despite its promising sustainability advantages, the utilization of non-metallic e-waste in concrete is still limited and not widely adopted in practical construction. This is mainly due to several concerns related to the performance of e-waste concrete. Many studies have reported that compressive strength decreases when e-waste replacement percentage increases beyond optimum limits. This reduction is often attributed to poor bonding between cement paste and smooth plastic surfaces, weak interfacial transition zone (ITZ), and increased void content. Durability issues such as increased permeability, chloride penetration, carbonation, and long-term degradation behavior are also not fully understood. Moreover, the variability in e-waste composition, lack of standard processing methods, and absence of mix design guidelines create uncertainty in achieving consistent concrete performance. In addition, limited research is available on fire resistance behavior, toxic gas emission under high temperature, and long-term environmental safety of e-waste concrete, which are critical for structural applications.

Therefore, it is essential to conduct a comprehensive review of existing research works to evaluate the influence of non-metallic e-waste on fresh properties, mechanical strength, durability characteristics, microstructural behavior, and sustainability aspects of concrete. A systematic review is necessary to identify optimum replacement percentages, highlight key benefits, and understand the limitations associated with e-waste concrete. Furthermore, by analyzing the existing literature, significant research gaps can be identified, which will help future researchers develop advanced methodologies for improving bonding characteristics, enhancing durability, and establishing standard guidelines for large-scale practical implementation.

Hence, the present review paper aims to provide an in-depth analysis of the performance of non-metallic e-waste in concrete by critically reviewing past experimental studies and review papers. This paper focuses on evaluating the behavior of e-waste concrete in terms of workability, density, compressive strength, tensile strength, flexural strength, durability, thermal properties, and microstructural characteristics. In addition, this study identifies major research gaps and future scope, emphasizing the need for long-term durability investigations, standardized processing techniques, structural element testing, environmental impact assessment, and development of mix design models. Ultimately, this review intends to contribute to sustainable construction development by promoting the utilization of non-metallic e-waste as an alternative construction material, thereby supporting waste management, natural resource conservation, and eco-friendly infrastructure growth.

II. LITERATURE REVIEW

Manatkar and Deshmukh (2015) focused on the utilization of non-metallic e-waste as a partial replacement for coarse aggregate in concrete, addressing the growing environmental and health concerns caused by the massive generation of electronic waste. In India alone, around 650,000 metric tons of e-waste were produced in 2014, including discarded televisions, computers, refrigerators, and other electrical equipment, much of which ends up in landfills or incinerators, releasing toxic substances that can severely affect human health and the environment. Recognizing the urgent need for sustainable waste management, the authors explored the possibility of incorporating non-metallic e-waste into M20 and M25 grade concrete as a coarse aggregate replacement. The e-waste materials were crushed and sieved into sizes of 4.75 mm, 10 mm, and 20 mm, followed by a series of tests including crushing value, abrasion value, and impact value to ensure their suitability for concrete use. Concrete cubes measuring 150 mm × 150 mm × 150 mm were prepared with 0% to 20% replacement of coarse aggregate with non-metallic e-waste, and compressive strength tests were conducted at 7, 14, and 28 days using a machine with a loading capacity of 2000 kN.

A. Arun Kumar et. al. (2017) The article studies “Performance of Recycled E-waste as Aggregates in Green Concrete”, examined the feasibility of incorporating E-waste as both fine (10%, 20%, and 30%) and coarse (5%, 10%, and 15%) aggregate replacements in fibre-reinforced green concrete containing 30% ground granulated blast furnace slag (GGBS) as a cement substitute. The study found that E-waste used as fine aggregate resulted in lower compressive strength compared to conventional concrete, whereas E-waste used as coarse aggregate exhibited

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compressive strength values comparable to the control mix. Interestingly, the split tensile and flexural strengths of concrete with both fine and coarse E-waste replacements were superior to those of conventional concrete, attributed to the combined pozzolanic activity of GGBS, improved tensile behaviour from steel fibres, and better bonding characteristics of E-waste aggregates. In terms of durability, chloride ion penetration was moderate for E-waste concrete mixes, as opposed to low penetration in control concrete. Overall, the study concluded that E-waste can effectively be used in green concrete to improve mechanical properties while also supporting sustainable construction practices.

Anoop Singh and Vikas Srivastava (2018) conducted an experimental investigation to explore the feasibility of utilizing plastic E-waste in concrete as a partial replacement for both fine and coarse aggregates in M25 grade concrete. In their study, fine aggregate was replaced with plastic E-waste at proportions of 10%, 20%, and 30% by weight, while coarse aggregate was replaced at 5%, 10%, 15%, 20%, and 25% by weight. The compressive strength of the concrete cubes was tested at 7 and 28 days to evaluate the effect of E-waste incorporation. The results revealed that as the percentage of plastic E-waste increased, the compressive strength of concrete decreased. This study concluded that although partial replacement of aggregates with plastic E-waste is possible, higher replacement levels adversely affect the structural performance of concrete. The research highlights a potential sustainable solution for managing non-biodegradable E-waste while also providing insights into the limitations regarding strength reduction in concrete containing E-waste.

Biradar Shilpa, Deshpande, Nagarajan, and Narwade (2019) investigated the use of electronic waste (e-waste) as a partial replacement for coarse aggregates in concrete, aiming to address environmental hazards and rising construction material costs. The study highlighted that e-waste is non-degradable and poses serious ecological risks, making its reuse in concrete a sustainable alternative. The research focused on optimizing the performance of E-waste concrete (EWC) by evaluating physical properties, workability, and mechanical strength. E-waste generated at Pillai HOC College of Engineering and Technology (PHCET), Rasayani, was incorporated in combination with fly ash to replace 0–30% of coarse aggregates. Concrete cubes were cast, and standard slump cone tests and 28-day compressive strength tests were conducted. Findings revealed that EWC exhibited improved workability and enhanced compressive strength, demonstrating its feasibility as a lightweight, sustainable construction material. The study concluded that incorporating e-waste in concrete not only contributes to sustainable construction practices but also offers a practical solution for e-waste management.

Swain et al. (2019) explored the potential of utilizing electronic waste (E-waste) as a partial replacement for coarse aggregate in concrete, addressing the growing environmental and disposal challenges associated with non-biodegradable and hazardous E-waste. Their study emphasized sustainable construction practices by incorporating E-waste into concrete to produce E-Waste Concrete (EWC), which also helps reduce the escalating costs of construction materials. E-waste generated at Pillai HOC College of Engineering and Technology (PHCET), Rasayani, was used in combination with fly ash to partially replace 0–30% of coarse aggregate in concrete mixes. Concrete cubes were cast and tested for workability using slump cone tests and for compressive strength after 28 days. The results demonstrated a notable improvement in both workability and mechanical strength, suggesting that EWC can serve as a lightweight, sustainable, and structurally efficient concrete material. This study highlights the dual benefit of E-waste management and enhanced concrete performance, promoting environmentally responsible construction practices.

Aamar Danish et. al. (2023) The study includes "A compendious review on the influence of e-waste aggregates on the properties of concrete", explored the potential of utilizing e-waste-derived aggregates such as plastics and cathode ray tube (CRT) glass in concrete. The study analyzed the impact of e-waste aggregates on workability, density, compressive strength, flexural strength, splitting tensile strength, and thermal resistance of concrete. The findings indicated that partial replacement of natural coarse aggregates with e-waste materials can produce sustainable concrete suitable for both structural and non-structural applications, provided the replacement levels are kept within optimum limits. The review concluded that while e-waste incorporation offers a viable solution for environmental conservation and resource efficiency, further large-scale experimental studies are necessary to fully validate its use in concrete production.

Mohammed Razin et. al. (2024) The research article inludes "Learning on Concrete Performance Using E-Waste for Partial Coarse Aggregate Replacement", investigated the performance of M30 grade concrete incorporating E-waste as a partial replacement for coarse aggregates. The experimental program evaluated replacement levels of 0%, 10%, 15%, and 20% using E-waste, while manufactured sand (M-sand) was used as fine aggregate. The study measured key mechanical properties such as compressive strength and split tensile strength. The findings revealed that the inclusion of E-waste up to an optimum percentage can achieve comparable strength with conventional concrete, while higher replacement levels led to a reduction in performance. The study concluded that E-waste can be effectively utilized in concrete to reduce environmental burden and conserve natural aggregates.

Sharma, S., & Boora, A. (2024) – This review analyzed the incorporation of electronic waste (e-waste) as a reinforcement material in concrete pavements to promote sustainability. E-waste, including plastics, metals, glass, and ceramics, poses significant environmental and health hazards due to toxic elements like lead, mercury, and cadmium. The study concluded that recycling e-waste into concrete can improve mechanical properties and environmental performance without negative effects. Systematic analysis indicated that using e-waste in concrete not only addresses disposal challenges but also enhances the performance of concrete pavements, supports resource conservation, and contributes to sustainable construction practices. The research emphasizes e-waste concrete as an innovative material that combines waste management with improved structural performance.

Gaurav Kumar et. al. (2024) In this paper "Utilizing E-Waste as a Sustainable Aggregate in Concrete Production: A Review" published in Buildings, provided a comprehensive review of the role of E-waste as an alternative aggregate in concrete. The study examined the composition, properties, and production techniques of E-waste aggregates, with detailed discussion on their physical characteristics such as colour, shape, size distribution, aggregate crushing value, and water absorption. The review further summarized findings from multiple studies on the fresh and hardened properties of E-waste concrete, covering workability, compressive strength, flexural strength, tensile strength, and thermal resistance. The authors concluded that the particle shape and size of E-waste significantly influence the aggregate performance, while the percentage of E-waste replacement plays a crucial role in modifying the mechanical and thermal behaviour of concrete. This work emphasized the potential of E-waste in achieving sustainable concrete production, while also highlighting the importance of optimizing replacement levels to balance strength, workability, and durability.

Priyan, Ravella, and Alaneme (2024) conducted a comprehensive review on the utilization of electronic waste (e-waste) in sustainable building materials, highlighting its potential for mitigating environmental pollution and addressing waste management challenges. The study emphasizes that the rapid increase in electronic component production has led to a significant surge in e-waste generation, which poses serious environmental and health hazards due to the presence of toxic chemicals. While developed countries possess advanced e-waste management technologies and systematic frameworks, underdeveloped regions face major challenges due to limited infrastructure, inadequate policies, and lack of technological expertise. The review analyzed numerous studies on the incorporation of e-waste into construction materials, focusing on mechanical and durability properties of concrete containing e-waste as partial replacement for fine and coarse aggregates. Findings indicate that e-waste can serve as an effective alternative to natural aggregates, with varying replacement percentages influencing the mechanical performance of concrete. By summarizing the trends in strength and durability characteristics across different studies, this review underscores the feasibility of transforming e-waste into sustainable construction materials, offering a practical solution for reducing environmental contamination while promoting resource efficiency in the construction sector.

Kumar et al. (2024) conducted a comprehensive review on the utilization of electronic waste (E-waste) as a sustainable aggregate in concrete production, addressing the growing environmental challenge posed by the accumulation of non-degradable E-waste from modern electronic devices. The study provided an extensive overview of the composition, characteristics, and production techniques of E-waste concrete, examining factors such as particle shape, size, colour, aggregate crushing value, and water absorption. Additionally, the review summarized findings from various researchers on the workability, including slump flow, and mechanical properties, such as compressive strength, flexural strength, and tensile strength, along with thermal resistance of E-waste concrete. The review concluded that the physical characteristics of E-waste particles, particularly shape and size distribution, significantly influence the aggregate properties, while the percentage of replacement directly affects workability, mechanical performance, and thermal behaviour. This study underscores the potential of E-waste as a viable sustainable aggregate, offering both environmental and structural benefits while highlighting the critical factors for optimizing concrete performance.

Rio J. (2024), In the study "Enhancing Concrete Performance with E-plastic Waste and Fly Ash: A Sustainable Approach", the authors explored the incorporation of electronic plastic waste (e-plastic) in concrete along with partial cement replacement by fly ash. The experimental program used e-plastic particles obtained from discarded electronic devices in varying proportions (4%–24%) while substituting 10% of cement with fly ash. The research focused on evaluating the mechanical, durability, and microstructural properties of the resulting concrete, including XRD analysis. The findings revealed that the addition of e-plastic significantly improved workability, mechanical strength, and durability when used in optimized proportions, while the inclusion of fly ash further enhanced the pozzolanic reactivity and densified the concrete microstructure. The study emphasized the potential of e-plastic with fly ash in producing sustainable concrete with improved structural integrity and environmental performance, thus offering a practical approach for large-scale waste management and eco-friendly construction.

Muhammad Shahrukh Pasha (2025) The article includes "Sustainable construction: Performance analysis of concrete incorporating E-waste plastic aggregates and silica fume", developed sustainable concrete by partially replacing natural coarse aggregates with sand-treated plastic coarse aggregates (PCA) from E-waste and cement with silica fume (SF). The experimental program studied PCA replacement at 10%, 15%, and 20% along with SF at 5%, 10%, and 15%. Tests included compressive strength, split tensile strength, abrasion resistance, porosity, thermal conductivity, and sulfuric acid resistance, supported by microstructural analysis through SEM. The results showed that PCA improved workability and thermal resistivity, while SF enhanced mechanical strength by densifying the microstructure and improving bonding with PCA. The combination of 10% SF and 15% PCA demonstrated improved split tensile strength and lowest abrasion loss, whereas higher PCA content led to a reduction in compressive strength. Furthermore, SF and PCA together significantly reduced acid attack deterioration, indicating enhanced durability. The study concluded that E-waste PCA combined with SF can be effectively used to produce sustainable, durable, and thermally efficient concrete for urban construction.

Farhan Ahmad et. al. (2025) In this paper "E-waste in concrete construction: recycling, applications, and impact on mechanical, durability, and thermal properties—a review", presented a comprehensive review of the utilization of E-waste in concrete. The study emphasized that non-metallic fractions of E-waste, including plastics, glass, and fibers, can be effectively incorporated in concrete as supplementary cementitious materials or as partial replacement for aggregates. The findings revealed that E-waste concrete composites exhibit promising improvements in durability, serviceability, and thermal performance, while mechanical strength may decline at higher replacement levels. The review highlights both the potential and the limitations of E-waste incorporation, concluding that it offers significant scope for enhancing sustainability in the construction industry.

Srinivasan Krishnan et al. (2025) conducted an extensive experimental investigation on the performance of concrete and mortar with partial replacement of fine aggregate by printed circuit board (PCB) E-waste, published in Recycling. The study addresses the growing environmental concern posed by e-waste accumulation, particularly focusing on the disposal challenges and the necessity for sustainable resource management. The researchers explored the feasibility of utilizing PCBs as a partial substitute for fine aggregates in cement mortar and concrete, with replacement levels ranging from 0 to 35 wt% in mortar and 0 to 30 wt% in concrete. Specimens were cured for 7 and 28 days and subsequently tested for flowability, static mechanical properties, and durability under aggressive environmental conditions. Additional evaluations included acoustic and thermal conductivity tests to assess the multifunctional potential of the developed mixes. The findings revealed that the optimal replacement levels of fine aggregate with PCBs were 25 wt% for mortar and 20 wt% for concrete, beyond which a decline in mechanical properties was observed. These results confirm that the integration of PCB e-waste in cementitious materials is feasible and can serve as a sustainable solution for managing electronic waste while maintaining adequate structural performance and multifunctionality in construction materials. Overall, the study highlights the dual benefits of environmental conservation and effective resource utilization by transforming hazardous e-waste into functional building materials.

III. GAP IDENTIFIED

After reviewing the available literature on the utilization of non-metallic e-waste in concrete, it has been observed that although significant research has been carried out to explore its feasibility, there are still several technical limitations and unresolved issues that restrict its large-scale application in real construction practices. Most studies are limited to laboratory-scale testing and focus mainly on short-term strength evaluation. Therefore, based on the detailed analysis of previous research works, the following major research gaps have been identified:

3.1 Lack of Standardization in Collection, Segregation, and Processing of E-Waste

One of the most critical gaps identified from the literature is the absence of a standardized methodology for collecting, segregating, and processing non-metallic e-waste before using it in concrete. Different researchers have used different types of e-waste such as plastic casings, printed circuit board (PCB) particles, CRT glass, and mixed electronic plastics. Since e-waste composition varies significantly depending on the type of electronic product, manufacturer, and recycling process, the properties of e-waste aggregates also vary widely. This leads to inconsistent experimental results and makes it difficult to compare outcomes from different studies. Moreover, there is no standard guideline regarding crushing techniques, size distribution, cleaning methods, and removal of hazardous contaminants. Hence, further research is required to develop standardized processing and characterization procedures for e-waste aggregates.

3.2 Limited Studies on Chemical Composition and Toxicity Behavior of Non-Metallic E-Waste

Although many studies mention that e-waste contains toxic materials, very few researchers have experimentally investigated the chemical composition, leaching characteristics, and long-term toxicity of e-waste concrete. Non-metallic e-waste contains brominated flame retardants, epoxy resins, and heavy metals in trace amounts. When incorporated into concrete, these materials may undergo leaching due to water infiltration, carbonation, and acid exposure. However, long-term studies on heavy metal leaching, environmental safety, and potential contamination of groundwater are extremely limited. Without proper toxicological assessment, the use of e-waste in concrete may raise environmental concerns, especially in water retaining structures, pavements exposed to rainwater, and coastal structures.

3.3 Lack of Long-Term Durability Performance Studies

Most experimental studies have focused mainly on compressive strength evaluation at 7 days and 28 days, while long-term durability behavior has not been adequately studied. Durability is a critical factor for concrete structures exposed to aggressive environmental conditions. Only limited studies have examined chloride penetration, sulfate attack, carbonation resistance, freeze-thaw resistance, acid attack, and alkali-silica reaction in e-waste concrete. Since e-waste aggregates are mostly plastic-based and have poor bonding with cement paste, they may create micro-voids and weak interfacial transition zones, which can increase permeability and reduce durability. Hence, detailed long-term durability investigations under realistic field exposure conditions remain a major research gap.

3.4 Insufficient Microstructural Investigations (ITZ, SEM, XRD, FTIR Analysis)

The microstructural behavior of e-waste concrete is not fully understood. The performance of concrete strongly depends on the interfacial transition zone (ITZ) between aggregates and cement paste. Many researchers have reported strength reduction due to weak bonding between plastic aggregates and cement paste. However, only a few studies have used advanced microstructural techniques such as scanning electron microscopy (SEM), X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), and energy dispersive spectroscopy (EDS) to study ITZ characteristics. The lack of microstructural analysis makes it difficult to identify the actual mechanisms responsible for strength loss, crack formation, and durability reduction. Therefore, extensive microstructural studies are needed to improve understanding and optimize e-waste concrete performance.

3.5 Absence of Standard Mix Design Guidelines for E-Waste Concrete

Another major gap identified is the lack of standard mix design procedures for e-waste concrete. Most studies use conventional IS or ACI mix design methods with trial-and-error modifications. Since e-waste aggregates have different specific gravity, water absorption, particle shape, and surface texture compared to natural aggregates, the same mix design principles may not produce consistent results. Additionally, optimum replacement levels vary significantly in different studies. Therefore, there is a strong need to develop a separate mix design methodology for e-waste concrete, considering workability, density, strength, and durability requirements.

3.6 Limited Research on Structural Behavior of Reinforced Concrete Members

Most researchers have evaluated e-waste concrete performance only through cube and cylinder testing. Very limited work has been conducted on reinforced structural elements such as beams, slabs, columns, footings, and pavement panels. Structural behavior includes flexural strength, shear strength, deflection behavior, cracking patterns, ductility, and load carrying capacity, which cannot be fully understood through cube tests alone. Without testing large-scale reinforced concrete elements, it is difficult to recommend e-waste concrete for real structural applications. Therefore, experimental studies on full-scale structural components are necessary.

3.7 Lack of Research on Bond Strength Between Reinforcement and E-Waste Concrete

Bond strength between steel reinforcement and concrete is a crucial parameter for structural safety. Since e-waste aggregates affect the ITZ and overall matrix quality, the bond behavior between steel bars and e-waste concrete may also be affected. However, only limited studies have examined bond strength, pull-out behavior, and anchorage performance of reinforcement in e-waste concrete. This is a major gap because inadequate bond may lead to premature structural failure. Hence, further research is required on bond characteristics, development length, and reinforcement anchorage behavior in e-waste concrete.

3.8 Insufficient Investigation on Shrinkage, Creep, and Long-Term Deformation

Concrete structures undergo shrinkage and creep over time, which significantly affects long-term serviceability. E-waste aggregates have low modulus of elasticity and different thermal properties compared to natural aggregates, which may influence shrinkage and creep behavior. However, most studies have not evaluated drying shrinkage, autogenous shrinkage, creep deformation, and long-term strain behavior of e-waste concrete. This gap is important because excessive shrinkage and creep may cause cracking, deflection, and reduction in durability of concrete structures.

3.9 Limited Studies on Fire Resistance and Thermal Degradation of E-Waste Concrete

Since most non-metallic e-waste is plastic-based, it is vulnerable to thermal degradation at high temperatures. When exposed to fire, e-waste particles may soften, melt, or emit toxic gases. However, only limited studies have investigated fire resistance, spalling behavior, and toxic smoke emission of e-waste concrete. Fire safety is a critical requirement for buildings and infrastructure. Therefore, further research is necessary to evaluate high-temperature performance and fire resistance of e-waste incorporated concrete.

3.10 Lack of Life Cycle Assessment (LCA), Cost Analysis, and Sustainability Evaluation

Although many studies claim that e-waste concrete is sustainable, only a few have performed quantitative life cycle assessment (LCA), embodied energy calculations, carbon footprint analysis, or cost-benefit analysis. Without detailed sustainability assessment, it is difficult to prove whether e-waste concrete is truly environmentally beneficial compared to conventional concrete. Moreover, economic feasibility studies considering processing cost, transportation cost, and availability of e-waste aggregates are rarely performed. Therefore, further research is needed on environmental impact analysis, carbon reduction potential, and economic viability.

3.11 Insufficient Research on Hybrid Use of E-Waste with Supplementary Cementitious Materials (SCMs)

Some studies have combined e-waste aggregates with fly ash, silica fume, and GGBS to improve performance. However, systematic research on hybrid mixes is still limited. Since SCMs can improve ITZ bonding, reduce permeability, and enhance durability, combining SCMs with e-waste aggregates may significantly improve overall concrete performance. But there is a lack of detailed parametric studies that investigate optimum proportions of SCMs and e-waste together. Therefore, more research is required to establish the best combination for achieving high-strength durable e-waste concrete.

3.12 Lack of Research on Field Implementation and Real-Time Performance Monitoring

Almost all studies are laboratory-based and do not provide field application evidence. Real construction conditions involve temperature variations, moisture changes, compaction challenges, and exposure to aggressive environments. The performance of e-waste concrete under field conditions may differ significantly from laboratory results. Hence, pilot-scale field studies, pavement trials, and monitoring of long-term performance are necessary before recommending e-waste concrete for practical use.

3.13 Uncertainty in Optimum Replacement Levels for Different Concrete Grades

Different researchers suggest different optimum replacement levels ranging from 5% to 30%, depending on concrete grade, type of e-waste, particle size, and additional admixtures. This creates confusion in selecting a standard optimum replacement percentage for practical applications. Additionally, very limited research is available on high strength concrete (M40, M50 and above) containing e-waste. Hence, systematic studies are needed to establish grade-wise optimum replacement limits for structural and non-structural concrete.

CONCLUSION

This review paper critically examined the performance of non-metallic e-waste materials in concrete by analyzing previous experimental and review-based research. The findings reveal that incorporating e-waste into concrete provides a sustainable solution for managing hazardous electronic waste while reducing dependency on natural aggregates. Most studies confirm that e-waste aggregates improve workability and reduce concrete density, making it suitable for lightweight concrete applications. However, compressive strength generally decreases at higher replacement levels due to weak bonding, lower stiffness of plastic materials, and poor ITZ formation. On the other hand, tensile and flexural strength may improve at optimum replacement levels due to crack bridging and enhanced ductility. Durability performance remains uncertain as limited studies exist on long-term exposure conditions, permeability, carbonation, and chloride diffusion behavior. The review concludes that e-waste concrete has significant potential in non-structural and semi-structural applications, especially when combined with supplementary cementitious materials such as fly ash, GGBS, and silica fume. Nevertheless, future research must focus on long-term durability, microstructural evaluation, fire resistance, toxicity analysis, large-scale structural element testing, and standardized mix design procedures. Therefore, non-metallic e-waste can become a promising construction material for sustainable development, but more scientific and standardized research is necessary to ensure its safe and efficient implementation in real-world infrastructure.

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