Discover Materials

Review

Comprehensive review on the use of plastic waste in sustainable concrete construction

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Abstract
The escalating global plastic waste crisis has prompted a search for sustainable solutions, particularly in the construction industry. Recycling plastic waste to create sustainable construction materials, such as concrete, has emerged as a promising approach. This paper explores the potential of utilizing plastic waste in concrete to mitigate environmental impacts while enhancing construction practices. The study emphasizes the urgent need for sustainable practices in response to increasing plastic consumption and waste generation. By recycling plastic waste into concrete, the construction industry can reduce dependence on natural aggregates and minimize environmental pollution. The paper also highlights the economic feasibility and long-term performance of plastic-containing concrete, addressing key challenges and limitations. Through a comprehensive analysis of the environmental, economic, and technical aspects, this paper aims to provide valuable insights into the sustainable use of plastic waste in concrete construction.

Keywords Concrete · Plastic waste · Sustainable construction

1 Introduction

In response to the escalating environmental concerns and the urgent need for sustainable practices in the construction industry, there has been a growing interest in finding innovative solutions to address the global plastic waste crisis [1]. With the rampant increase in plastic consumption, the world is faced with the formidable challenge of managing vast amounts of plastic waste that pose serious threats to the environment, ecosystems, and human health. In this context, the concept of recycling plastic waste to create sustainable construction materials, such as concrete, has emerged as a promising approach to mitigate the adverse impacts of plastic disposal while concurrently enhancing the environmental performance of the construction sector [2]. According to a worldwide database generator Statista, in 2019, around 460 million metric tons of plastic were used and around 353 million tons were generated as plastic waste. Out of the waste produced, a bulk of plastic waste was put for landfilling and incineration. Only 55 million metric tons were recycled (refer to Fig. 1), which shows global plastic usage statistics. The statistics produce serious causes of concern in the usage of plastic. Hence, the biggest challenge of the twenty-first century is to provide alternatives for the sustainable disposal of plastic waste. This work concentrates on the use of plastic waste in sustainable concrete.

Plastics, emblematic of the Anthropocene era, represent a profound environmental challenge owing to their non-biodegradable composition and enduring presence in ecosystems [3]. Despite enabling economic prosperity and technological progress, the negligent disposal of plastics has engendered widespread litter, exerting detrimental effects on

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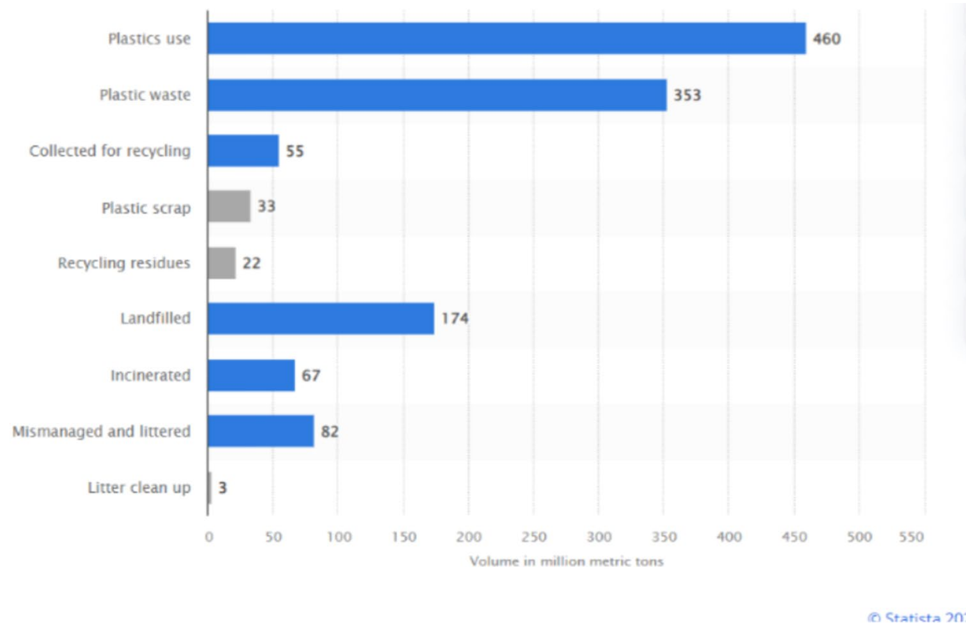
Fig. 1 Plastic usage statistics worldwide in the year 2019 by Statista



both the environment and human health. Extensive research into the physicochemical properties of plastics has aimed to optimize their utility across diverse applications [1]. However, their irresponsible use and disposal have precipitated environmental contamination. This escalating issue has prompted significant concern among scientists, governments, media outlets, and the public, given its profound repercussions on environmental integrity and human welfare [3]. Notably, the global annual consumption of plastics continues to surge, as depicted in Fig. 2, exacerbating the accumulation of plastic waste in our oceans [4].

The unparalleled user-friendliness, remarkable adaptability, ease of fabrication, and processability, combined with significant cost-effectiveness and durability, have fuelled the astronomical growth of plastics [5]. Apart from their extensive use in packaging, automotive, and industrial sectors, plastics find wide applications in medical delivery systems, artificial implants, and various healthcare applications, as well as in water desalination and bacteria removal processes. Additionally, plastics play vital roles in food preservation, household appliances, telecommunications, and the electronics industry, among others.

The primary aim of this work is to identify key research gaps to encourage the use of plastic in concrete for enhanced sustainability. These gaps include understanding long-term mechanical properties, conducting economic feasibility and life-cycle cost analyses, evaluating environmental impact, developing standardized guidelines, and improving public acceptance through education. Addressing these gaps is essential for the sustainable, economical, and widespread adoption of plastic waste in concrete in the construction industry.

Fig. 2 Plastic pollution in oceans (Source: Forbes India)

1.1 The benefits and advantages of plastics

The surge in plastic usage can be attributed to its advantageous characteristics, including unequalled versatility and the ability to be tailored to meet specific technical needs precisely. Being lighter than alternative materials, plastic contributes to reduced fuel consumption in transportation [6]. Moreover, its excellent safety and hygiene properties make it well-suited for food packaging. Additionally, plastic stands out for its durability, resilience to chemicals, water, and impact, as well as its exceptional thermal and electrical insulation capabilities. With relatively lower production costs, plastic also possesses the unique capability to seamlessly integrate with other materials such as aluminium foil, paper, and adhesives [7]. Furthermore, plastic's aesthetic appeal is undeniable, making it an indispensable component of modern lifestyles, often sought after for its intelligent features, smart materials, and innovative systems [8].

1.2 The disadvantages of plastics

The production of plastics involves the use of potentially harmful chemicals, such as stabilizers or colourants, many of which have not undergone thorough environmental risk assessments [3]. Consequently, their impact on human health and the environment remains uncertain. For example, phthalates, commonly found in PVC manufacturing, raise concerns about potential exposure, particularly in toys intended for young children, where phthalates may be released through contact with saliva. Assessments of the environmental impacts of phthalates are currently underway. Additionally, the disposal of plastic products significantly contributes to their environmental footprint [9].

The increasing volume of plastic waste, particularly plastic packaging, being discarded long after purchase, raises concerns about the growing demand for landfill space. Figure 3 illustrates the plastic landfills accumulated on a global scale. With an estimated 11.2 billion tonnes of solid waste collected annually, contributing approximately 5% of global greenhouse gas emissions [10].

2 Research methodology

This section presents the methodology adopted in this paper. Figure 4 presents the methodology in the diagrammatic form. The outcome of the paper is to provide valuable insights into the use of plastic waste in the concrete. 89 papers were found based on selected parameters like recyclability, environmental impact, economic consideration, and mechanical properties of plastic waste. In the end, based on plastic waste use in concrete 53 research papers were shortlisted by screening 89 research papers. The critical review is further conducted to showcase the use of plastic waste in the concrete.

Fig. 3 Plastic landfills (Source: (earth.org))

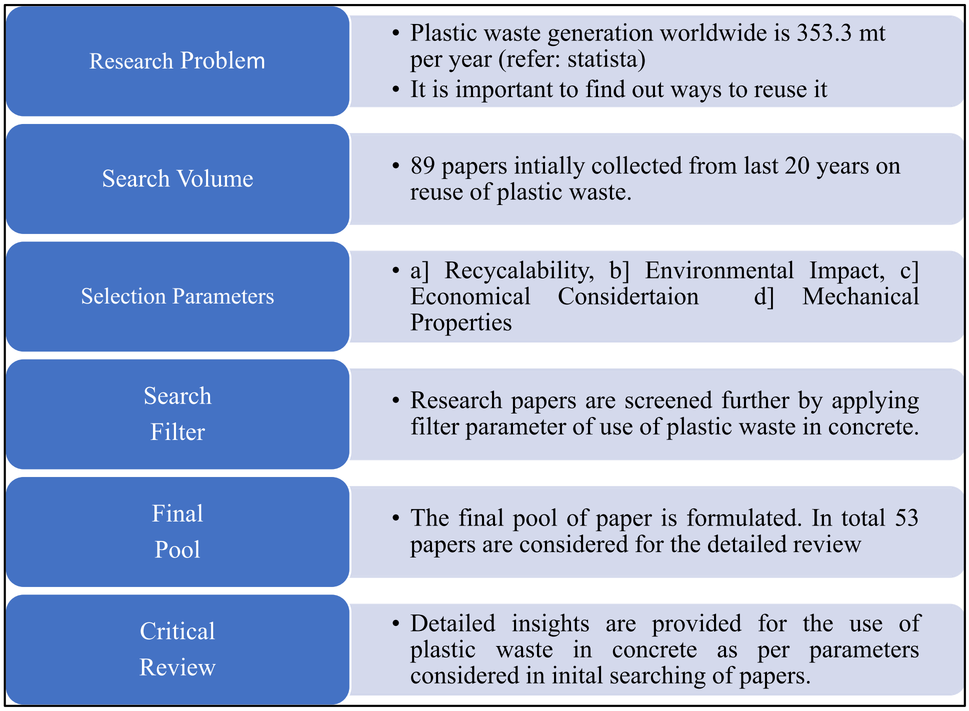


Fig. 4 Research Methodology

3 Plastic waste management

Plastic, a ubiquitous material in modern life, has become a major environmental worry due to its day-by-day bigger production, limited biodegradability, and improper disposal. The existing system for managing plastic waste is facing significant challenges in coping with the escalating problem, necessitating a comprehensive approach to foster a more sustainable future [11]. This exploration delves into an overview of plastic waste management, its environmental ramifications, and the imperative for crafting and enacting sustainable solutions.

3.1 Overview of plastic waste management

The process of managing plastic waste involves a series of interconnected steps [12]:

- Collection: Collecting plastic waste efficiently from households, businesses, and other sources is crucial for proper management. This can be achieved by curb-side pick-up programs, designated drop-off bins, and extended producer responsibility schemes.
- Sorting: Separating different types of plastics is necessary for effective recycling and treatment. This can be done manually by trained personnel or through automated sorting technologies using optical sensors and other identification methods.
- Recycling: Recycling converts plastic waste into new products, reducing virgin plastic production and the associated environmental footprint [13]. However, not all plastics are recyclable due to their complex composition or economic limitations.
- Energy recovery: Incineration can be used to recover energy from non-recyclable plastics, although concerns exist regarding air pollution and the release of harmful toxins.
- Landfill disposal: Landfills remain the destination for a significant portion of plastic waste, despite concerns about land use, potential leakage of pollutants, and greenhouse gas emissions.

Figure 5 shows the amount of plastic in the form of landfills over the years.

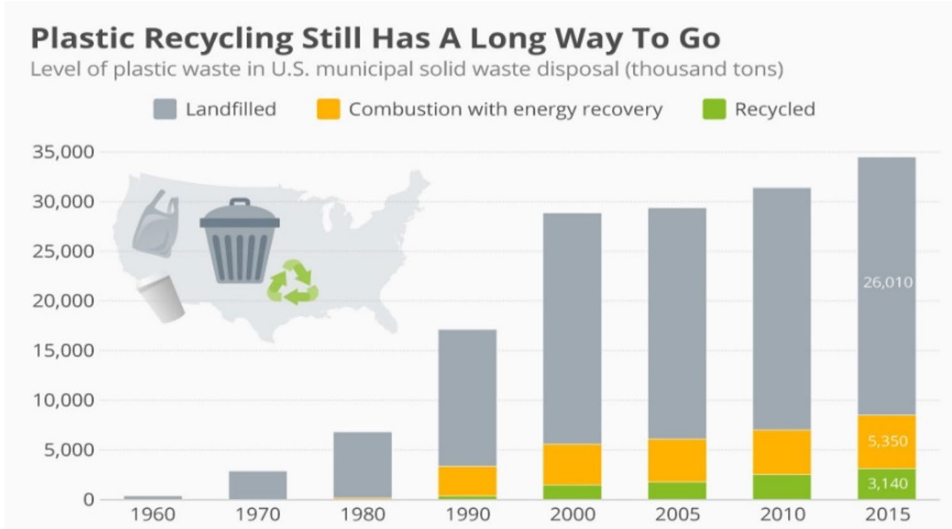


Fig. 5 level of plastic waste in landfilled form (Source: Centre for International Environment and Law)

3.2 Environmental impact of plastic waste

The environmental consequences of improper plastic waste management are far-reaching and pose significant threats [14]:

- Pollution: Plastic debris pollutes our oceans, rivers, and landscapes, posing a threat to wildlife through entanglement and ingestion. Microplastics, tiny plastic fragments, have been found in everything from marine life to the human food chain, raising concerns about potential health risks.
- Habitat degradation: Plastic pollution disrupts ecosystems by altering physical habitats, impacting biodiversity and ecosystem services. Marine debris, for instance, can harm coral reefs, critical for marine life and coastal protection.
- Climate change: Plastic production and disposal contribute to change in climate through greenhouse gas emissions and fossil fuel consumption. Incineration further exacerbates the problem by releasing additional greenhouse gases.

3.3 The urgency of sustainable solutions

The current plastic waste management system is unsustainable due to limitations in recycling, reliance on landfills, and the environmental drawbacks of energy recovery. Therefore, transitioning to a more sustainable system requires [3]:

- Reduction at the source: Implementing policies to restrict single-use plastics, promoting product redesign towards reusability and recyclability, and encouraging consumer behaviour change towards responsible consumption.
- Innovation in material science: Developing biodegradable, compostable, or chemically recyclable plastics can significantly reduce long-term waste generation and environmental impact.
- Improving recycling infrastructure: Investing in advanced sorting and processing technologies, expanding recycling infrastructure, and establishing extended producer responsibility schemes can significantly increase recycling rates and reduce reliance on landfills.
- Promoting waste-to-energy solutions: Utilizing advanced technologies for waste-to-energy conversion can contribute to the circular economy while prioritizing technologies with minimal environmental impact.
- Education and awareness: Elevating public consciousness regarding the repercussions of plastic pollution and advocating for responsible waste management practices via educational campaigns and community engagement endeavours are indispensable for achieving enduring success.

Plastic waste management is a complex global challenge demanding urgent action. Implementing a combination of solutions at various levels, from individual responsibility to policy changes and technological advancements, is crucial to creating a sustainable future. By adopting practices that reduce plastic consumption, prioritize sustainable materials, improve waste management infrastructure, and invest in innovative solutions, we can collectively mitigate the environmental impact of plastic and build a healthier planet for current and future generations.

4 Use of plastic in construction

The solution to the plastic-related problem lies in utilizing plastics in construction. Concrete, being one of the most used construction materials globally, requires a substantial number of natural aggregates annually. To meet this demand, approximately 13.12 billion metric tons of natural aggregates are needed for concrete construction each year [15]. This expanding request for development materials produces a shortage of normal assets. In any case, to manage this request, specialists are reacting emphatically by proposing unused details of utilizing elective materials. Incorporating plastic waste into concrete can reduce dependency on natural aggregates, thereby reducing associated manufacturing and transportation expenses. Hence, it facilitates the disposal of waste materials without environmental impact.

While several studies have explored the technical feasibility and mechanical attributes of concrete blends incorporating different proportions of plastic waste as aggregate substitutes, this research aims to further explore the broader implications of utilizing plastic waste in concrete. It will examine its effects on the overall sustainability and environmental friendliness of concrete structures.

4.1 Thermoplastic and thermoset

There is a world of difference between thermoplastics and thermosets, and their behavior when used with concrete reflects this. Thermoplastics soften upon heating, allowing them to be molded and shaped. Think of them like kneading dough. In concrete, thermoplastics might be used for crack fillers or waterproofing membranes. However, their reusability becomes an issue [16]. When heated for repair, surrounding concrete might also get affected. Additionally, the bond between the thermoplastic and concrete might not be as strong due to the lack of a permanent chemical reaction [17]. Unlike thermoplastics, thermosets undergo a permanent chemical change (like baking a cake) during curing. They form a rigid, cross-linked structure, making them impossible to melt and reshape [18]. In concrete, thermosets like epoxies are often used for bonding or strengthening existing structures. The strong chemical bond between the epoxy and concrete leads to excellent adhesion and durability. When we talk about recycle ability, many thermoplastics can be reheated and remolded into new products. This reusability makes them more environmentally friendly. However, the repeated heating cycles can degrade the material's properties over time.

Whereas thermosets undergo a permanent chemical change, they cannot be remolded or recycled in the traditional sense [19]. They often end up in landfills, posing a potential environmental concern [20]. But when we use them with concrete, Thermoplastic given the ability to soften with heat can be a drawback in concrete. High temperatures during fires or extreme weather events could lead to melting or weakening of the thermoplastic element, potentially compromising the integrity of the concrete [21]. On the other hand, Thermosets, due to their rigid structure, generally offer better heat resistance compared to thermoplastics in concrete applications. This can be crucial for structures exposed to high temperatures [22].

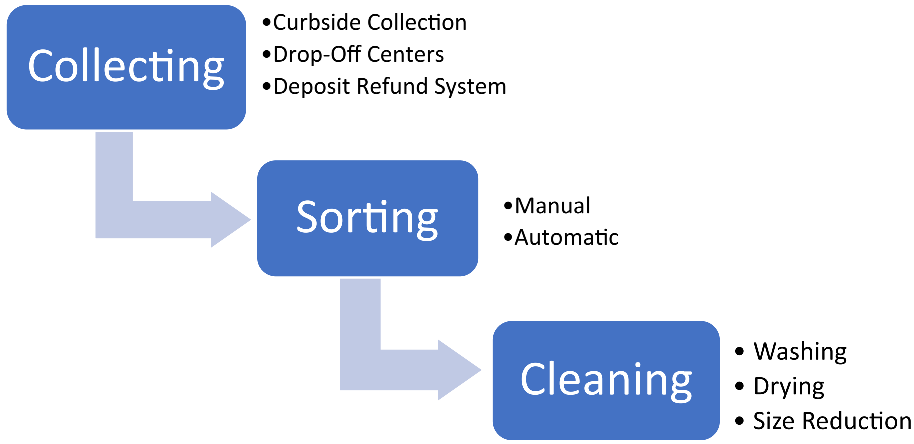
4.2 Process of collecting plastic

Figure 6 shows the schematic representation of the process of plastic collection. Each step has been explained in detail below.

Collection systems:

- Curbside collection: Households segregate plastic waste from other recyclables, which are then collected at designated intervals.
- Drop-off centers: Residents bring their plastic waste to dedicated centers for sorting and processing.
- Deposit refund systems: Consumers receive a small deposit for returning used plastic bottles, promoting collection, and reducing littering.

Fig. 6 The process of collecting plastic



Sorting technologies:

- Manual sorting: Workers visually sort plastics based on type (e.g., PET, HDPE) using conveyor belts and sorting stations.
- Automated sorting: Advanced systems utilize optical scanners and near-infrared technology to identify and separate different plastic types efficiently.

Cleaning and conditioning:

- Washing: Collected plastics undergo rigorous washing to remove dirt, debris, and contaminants.
- Drying: Washed plastics are dried thoroughly to prevent moisture issues during processing.
- Size reduction: Depending on the intended use in concrete, plastics might be shredded into flakes, granules, or fibers.

Experimental procedures:

- Mix design optimization: Determine the optimal amount and type of plastic waste to be incorporated into the concrete mix while maintaining desired strength and workability. This involve testing different ratios and configurations of plastic fibers or flakes.
- Mixing and casting: The prepared plastic (fibers or flakes) is added to the concrete mix along with other ingredients like cement, sand, and aggregates. The mixture is thoroughly mixed to ensure uniform distribution of plastic throughout the concrete. The mixed concrete is then cast into molds for shaping and curing.
- Curing: The concrete undergoes a controlled curing process to allow for hydration and strength development. This might involve maintaining specific temperature and humidity conditions.
- Testing and evaluation: The resulting concrete composite is subjected to rigorous testing to assess its mechanical properties (strength, ductility), durability (resistance to cracking, freeze–thaw cycles), and long-term performance.

4.3 Types of plastic used

Various types of plastics, such as polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), polyethylene terephthalate (PET), high-density polyethylene (HDPE), and low-density polyethylene (LDPE), can serve as additives in concrete, typically in the forms of fibers, particles, or aggregates [23]. Each plastic type possesses distinct properties that can enhance specific characteristics of concrete. For instance, the inclusion of plastic fibers can bolster concrete's toughness and longevity, while employing plastic aggregates can reduce its density. Also, plastics can contribute to improving concrete's ductility, impact resistance, and thermal properties. Integrating plastics into concrete mixtures can result in construction projects benefiting from heightened performance and sustainability.

Figure 7 illustrates the appearance of Polypropylene plastic. Research explores the integration of two recycled plastic waste types, PET and PP, as fine aggregates in concrete, across various replacement percentages (5%, 10%, 15%, 20%, and 25%) [24]. Findings indicate that with increasing percentages of recycled plastic waste, the workability of concrete

Fig. 7 Polypropylene (PP) plastic

diminishes. Nevertheless, an optimal replacement rate of 10% for PET is identified, while PP exhibits only a slight reduction in compressive strength at a 5% replacement level.

4.4 Method for use of plastic in concrete

4.4.1 Partial replacement of aggregates

This method involves substituting a portion of the sand or gravel aggregates (coarse or fine) with processed plastic particles [25].

The following approaches are commonly utilized:

- Flakes: PET bottles are shredded into small flakes, typically ranging from 2 to 10 mm in size. These flakes can partially replace fine aggregates and improve workability due to their smoother texture and spherical shape.
- Granules: Larger plastic pieces, usually between 5 and 20 mm, can be obtained by crushing various plastic waste sources. These can replace coarse aggregates but require careful optimization to avoid compromising strength and ensure proper interlocking within the concrete matrix.
- Melted aggregates: Melting certain plastics, like HDPE, allows them to be moulded into specific shapes resembling conventional aggregates. This approach offers greater control over the size and shape but requires additional energy consumption and might not be cost-effective for large-scale applications.

4.4.2 Fiber reinforcement

This method involves dispersing plastic fibres throughout the concrete mix. The following types of fibres are commonly used [26, 27].

- Microfibers: These are very fine fibres, typically less than 1 mm in diameter and several centimetres long. They are generally well-distributed within the matrix and primarily enhance crack resistance and ductility.
- Macrofibres: These are larger fibres, ranging from 5 to 25 mm in length and diameter. They contribute to improved tensile strength and can bridge larger cracks, providing additional structural reinforcement.

Several techniques can be employed for fibre incorporation:

- Manual mixing: This involves adding the fibres directly to the concrete mix during mixing. However, consistent distribution can be challenging, especially for larger fibres.
- Collation: Fiber can be pre-collated with a small amount of cementitious material to form small bundles. This improves dispersion and reduces clumping during mixing.
- Spraying: Specialized equipment can spray the fibres onto the concrete mix during casting, ensuring a more uniform distribution.

4.4.3 Encapsulation

This method involves enclosing plastic waste within a cement matrix. This can be achieved through several approaches [28]:

- Pre-cast blocks: Plastic waste is compacted and encased in pre-cast concrete blocks. This method offers a potential solution for hazardous plastic waste management but requires a dedicated production process and may not be suitable for large-scale waste diversion [29].
- Grout injection: Crushed plastic waste can be mixed with grout and injected into existing cavities or cracks in structures. This approach is primarily used for repair and strengthening applications, not as a primary construction material.

4.4.4 Plastic with other admixtures in concrete

Numerous studies have investigated the influence of incorporating additives or admixtures, such as fly ash, silica fume, and chemical additives, on the performance of concrete containing plastic waste [30]. Among these studies, one specifically examined the use of silica fume as an additive in concrete incorporating plastic waste. The findings revealed that incorporating silica fume led to improved compressive strength of the concrete, while also decreasing its water absorption capacity [30].

Although these methods present promising avenues for integrating plastic into concrete, it's crucial to acknowledge that thorough research and development are necessary to grasp the long-term effects on performance, durability, and environmental footprint. As these methods progress and hurdles are tackled, the incorporation of plastic waste in concrete could potentially enhance the sustainability of the construction industry by reducing waste while safeguarding structural integrity and the long-term performance of constructed elements. [28].

5 Effect of plastic waste utilization on concrete

5.1 Strength of concrete

Other research findings also suggest that incorporating plastic waste can influence compressive strength, with optimal replacement percentages varying for different types of plastic waste. Additionally, using plastic waste as aggregate replacements has demonstrated potential benefits such as improved workability, reduced water absorption, and enhanced efficiency in lightweight concrete production.

Another study evaluated the performance of concrete incorporating waste plastic as a partial substitute for fine aggregate, revealing enhanced workability and reduced water absorption capacity of the concrete [31]. Similarly, a separate investigation examined the consequences of replacing coarse aggregate with recycled plastic waste in concrete. The results indicated that as the plastic content increased, the compressive strength of the concrete decreased, yet remained within acceptable limits for structural applications. Also, research demonstrates that concrete properties such as compressive strength, workability, self-setting, self-healing, and lightweight characteristics can be augmented with the addition of admixtures. One study focused on incorporating silica fume as an additive in concrete containing plastic waste, revealing enhanced compressive strength and reduced water absorption capacity. Researchers are also exploring the utilization of recycled plastic in concrete for sound and thermal insulation, showcasing its potential to enhance the efficiency of lightweight concrete, and reduce costs, and labor in building construction. Additionally, studies underscore the significance of the initial treatment of plastic waste in determining the properties of aggregate substitutes [15, 32].

5.2 Workability

Workability pertains to the ease of mixing, placing, compacting, and finishing fresh concrete. Incorporating plastic waste can potentially influence this property in several ways [24].

- Improved workability: Certain types of plastic, particularly fibers, act as lubricants, reducing friction between the concrete particles. This can lead to smoother flow, improved pumpability, and easier finishing, potentially translating to reduced labor costs and increased construction efficiency [33].
- Reduced water demand: few researchers indicate that integrating particular types of plastic waste, such as PET flakes, may enable a modest decrease in the water-to-cement ratio while preserving workability. This could result in more compact concrete with potentially enhanced strength and durability.
- Potential drawbacks: Utilizing large quantities of plastic aggregates, particularly irregular shapes, can hinder workability. Additionally, some plastics may require surface treatment to ensure proper compatibility with the cement, impacting the mixing process.

5.3 Economic considerations

The economic feasibility of utilizing plastic waste in concrete is a complex issue dependent on various factors [9]:

- Cost of processing plastic waste: The process of collecting, sorting, and processing plastic waste into usable forms for concrete can incur additional costs. These costs need to be compared to the cost of traditional aggregates to determine the economic viability [34].
- Potential cost savings: Utilizing plastic waste can potentially lead to reduced demand for virgin aggregates, which can be expensive in certain regions. Additionally, improved workability may translate to lower labour costs and faster construction times.
- Long-term performance: While initial costs may be lower, the long-term performance of plastic-containing concrete remains under investigation. The overall economic advantage could be negated if this type of concrete requires more frequent maintenance or repairs.

Therefore, a comprehensive life-cycle cost analysis is crucial to assess the economic viability of using plastic waste in concrete for specific projects.

5.4 Weight

The weight of concrete is a critical consideration in various applications, particularly for structures with weight limitations. Incorporating plastic can potentially impact the weight of the resulting concrete [20]:

- Lightweight concrete: Replacing conventional aggregates, particularly heavier ones like natural stones, with lighter plastic alternatives can lead to the creation of lightweight concrete. This type of concrete is desirable for specific applications like high-rise buildings, bridges, and seismic zones due to its reduced weight burden on the structure [35].
- Optimization is key: The extent of weight reduction depends on the type and amount of plastic used. While some studies show promising results, using excessive amounts of plastic can compromise the structural integrity of the concrete and negate the weight reduction benefits.

Utilizing plastic waste in concrete poses a potential solution for waste management while offering intriguing possibilities for improving workability and creating lightweight concrete. However, it is crucial to acknowledge that this approach is still evolving, and its long-term implications on economic viability and overall performance require further research and optimization. Carefully evaluating the potential benefits and considerations mentioned above, including workability, economic factors, and weight impact, is essential before the widespread adoption of this approach in construction practices. Additionally, ensuring the structural integrity, durability, and environmental sustainability of plastic-containing concrete over its life cycle remains paramount. By addressing these challenges and conducting thorough research, this innovative approach can potentially contribute to a more sustainable construction industry while creating a viable solution for plastic waste management.

5.5 Sustainable concrete

Sustainable concrete offers a promising solution to the environmental and social challenges posed by conventional concrete production. By addressing key issues such as carbon emissions, resource depletion, and waste generation, it presents a multifaceted approach to sustainable construction. By integrating alternative binders and recycled materials, sustainable concrete significantly reduces its carbon footprint and promotes resource conservation. Moreover, its emphasis on energy efficiency and waste reduction aligns with the principles of a circular economy, fostering environmental stewardship. The durability and longevity of sustainable concrete structures not only minimize environmental impact but also reduce the need for costly repairs and replacements, ensuring economic efficiency over the long term. Furthermore, innovations in sustainable concrete formulations continually enhance performance characteristics, contributing to the overall resilience and sustainability of built environments [20]. The growing regulatory focus on sustainability and increasing consumer demand for eco-friendly products further drive the adoption of sustainable concrete in the construction industry. As a result, its use not only aligns with regulatory requirements but also serves as a market differentiator, positioning companies as leaders in environmental responsibility.

The utilization of plastic waste in concrete aligns with efforts to promote sustainable construction practices. By diverting plastic waste from landfills and oceans, this approach contributes to waste reduction and resource conservation. Also, incorporating plastic waste into concrete can enhance the performance of lightweight concrete, offering cost and labor-saving advantages in building construction. However, the success of such endeavors hinges on the proper treatment and processing of plastic waste to ensure the quality and performance of the resulting concrete products. Ongoing research is essential to optimize the use of plastic waste in concrete and advance the development of sustainable construction materials.

5.6 Case studies

Table 1 shows Case studies from various parts of the world demonstrate the use of plastic in concrete applications. For instance, Eco-beams in the Netherlands incorporate 1–2% shredded HDPE in precast concrete beams for buildings. In India, recycled plastic roads utilize 6% of mixed plastic waste in highway construction. Australia's Waste-to-Resource Concrete employs 1.5% PET fibers in precast concrete panels. Project NEXT in Belgium uses 5% recycled HDPE flakes in concrete blocks for flood defence systems. Scotland's Green Roads project incorporates up to 10% mixed plastic waste in road construction trials. Refer to Table 1.

Table 1 Various examples where plastic has been used

Project	Plastic Type & %	Application	References
Eco-beams, Netherlands	Shredded HDPE (1–2%)	Precast concrete beams for buildings	[36]
Waste-to-Resource Concrete, Australia	PET fibers (1.5%)	Precast concrete panels	[37]
Green Roads, Scotland	Mixed plastic waste (up to 10%)	Road construction trials	[38]

6 Challenges and limitations of utilizing plastic waste in concrete

The integration of plastic waste into concrete, while offering intriguing possibilities for waste management and potentially improved construction characteristics, presents an array of challenges and limitations that require in-depth consideration [9]. This exploration delves into these challenges, highlighting the crucial aspects that need to be addressed for the responsible and effective utilization of plastic waste in concrete.

6.1 Impact on mechanical properties

The primary concern surrounding the use of plastic waste in concrete lies in its potential negative impact on mechanical properties, which are crucial for ensuring the structural integrity and safety of constructed elements. Here are some key aspects to consider:

- Reduced compressive strength: Studies have shown that incorporating certain types or excessive amounts of plastic waste can lead to decreases in compressive strength, and the ability of concrete to resist compression forces. This is particularly concerning for structural applications where strength is paramount.
- Compromised tensile and flexural strength: Similarly, the use of plastic can potentially lead to reduced tensile and flexural strength, impacting the concrete's ability to resist cracking, and bending stresses. This can affect the overall performance and durability of the concrete structure.
- Bonding issues: The compatibility between plastic and cement can be problematic, leading to weak interfaces and poor bonding between the aggregates and the cement matrix. This weak bond can compromise the strength and integrity of the concrete, potentially leading to premature failure.

6.2 Durability and long-term performance

The long-term performance and durability of concrete containing plastic remain uncertain and require further investigation. Several factors contribute to this uncertainty:

- Weathering and degradation: Plastic materials can be susceptible to degradation from various environmental factors like sunlight, heat, and freeze–thaw cycles. This degradation can weaken the plastic over time, potentially impacting the overall durability of the concrete and leading to long-term performance issues.
- Chemical reactions: Interactions between certain plastics and the cement matrix over extended periods are not fully understood. Potential chemical reactions could affect the properties of the concrete and lead to unforeseen consequences for its performance and durability.
- Limited data: Long-term data on the performance of plastic-containing concrete in real-world applications is currently limited. This makes it challenging to definitively assess its suitability for various construction projects and predict its long-term behaviour.

6.3 Economic considerations

While the potential for reduced demand for virgin aggregates offers economic advantages, utilizing plastic waste in concrete also presents economic challenges:

- Processing costs: The collection, sorting, cleaning, and processing of plastic waste into forms suitable for concrete applications can be cost-intensive. These costs need to be carefully evaluated against the potential savings from reduced use of virgin aggregates [39].
- Uncertain long-term costs: The uncertainty surrounding the long-term performance of plastic-containing concrete raises concerns about potential increased maintenance and repair costs compared to traditional concrete. This needs to be factored into the overall economic life cycle analysis.

- Market fluctuations: The cost of virgin aggregates and the cost of processing plastic waste can fluctuate over time, impacting the relative economic attractiveness of utilizing plastic in concrete. This necessitates careful consideration of market trends and potential economic risks.

6.4 Environmental impact assessment

While utilizing plastic waste in concrete offers the benefit of waste diversion, a comprehensive life cycle assessment is crucial to understanding its true environmental impact. Several aspects need careful evaluation:

- Energy consumption: The processing of plastic waste into usable forms for concrete requires energy. This energy consumption needs to be assessed and compared to the energy used for extracting and processing virgin aggregates.
- Carbon footprint: The entire life cycle, including processing, transportation, and potential end-of-life scenarios for plastic-containing concrete, needs to be evaluated to determine its overall carbon footprint and potential environmental impact.
- Potential for unintended consequences: Utilizing plastic waste in concrete may lead to unforeseen environmental consequences. Leakage of microplastics from the concrete over time or potential environmental impacts during the processing or disposal of plastic waste need to be thoroughly investigated.

6.5 Other challenges and limitations

Beyond the aspects above, other challenges and limitations associated with utilizing plastic waste in concrete require attention:

- Fire performance: Concrete containing plastic may have compromised fire resistance due to the lower melting point of plastic in comparison to traditional aggregates. This could impact the applicability of such concrete for certain applications that demand stringent fire safety measures [40].
- Standardization and regulations: Currently, there is a lack of widely accepted standardization and regulations regarding the use of plastic waste in concrete. This can hinder widespread adoption and raise concerns about consistency and quality control [41].
- Social acceptance: Public perception and acceptance of utilizing plastic waste in construction materials may need to be addressed through education and awareness campaigns [42].

7 Conclusions

Integrating plastic waste into concrete offers promising benefits but presents challenges that require thorough consideration. Research indicates that incorporating plastic waste affects compressive strength, workability, and durability, with optimal replacement percentages varying by plastic type. For example, PET performs best at 10% replacement, while PP shows minor strength reductions at 5%. Using plastic waste as aggregate replacements can enhance workability, reduce water absorption, and increase efficiency in lightweight concrete production. Additionally, adding materials like fly ash and silica fume can further improve the performance and sustainability of plastic-containing concrete. Although using plastic waste in concrete could help address the global plastic waste crisis and advance construction practices, challenges remain. Further investigation is needed to understand its impact on mechanical properties, long-term performance, and economic feasibility. Environmental considerations such as energy consumption and carbon footprint must also be evaluated, and standardization and regulations need to be established for widespread adoption. Despite these challenges, plastic waste has significant potential to contribute to a more sustainable construction industry and waste management practices. Continued research and development are essential to optimize its use and address associated challenges. Plastic waste has high potential as a natural aggregate. Researchers should explore various forms of plastic waste beyond conventional types to increase its use as an aggregate replacement, thereby improving sustainability in plastic waste disposal.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Competing interests The authors declare no competing interests.

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