

Development of Sustainable Concrete using Treated Waste Plastic as Fine Aggregate

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Abstract

The purpose of this study was to evaluate the fresh and mechanical properties of M50 grade concrete incorporating chemically treated waste plastic as a partial replacement for fine aggregate. Due to the increasing accumulation of plastic waste and depletion of natural resources, the use of recycled plastic in concrete offers a sustainable solution for the construction industry. Waste plastic was collected, cleaned, powdered, shredded into 2–4 mm particles, and chemically treated using a 1–5% NaOH solution for 24 hours to improve bonding characteristics. Five concrete mixes were prepared: a control mix (0% plastic) and mixes containing 5%, 10%, 15%, and 20% treated plastic as partial fine aggregate replacement by weight. Fresh concrete properties were evaluated using slump tests, while compressive strength tests were conducted at 3, 7, and 28 days of curing. The results showed that workability decreased with increasing plastic content due to the irregular shape and hydrophobic nature of plastic particles. However, the 5% replacement mix achieved satisfactory compressive strength with only a slight reduction compared to conventional concrete, while higher replacement levels caused gradual strength reduction. The NaOH treatment enhanced the surface roughness of the plastic, improving mechanical interlocking between plastic particles and cement paste. The study demonstrates that treated waste plastic can be successfully incorporated into sustainable concrete, reducing environmental pollution and conserving natural aggregates for eco-friendly construction applications.

Keywords: Sustainable concrete; Waste plastic; Fine aggregate replacement; NaOH treatment; Compressive strength

INTRODUCTION

The purpose of this study was to evaluate the fresh and mechanical properties of M50 grade concrete incorporating chemically treated waste plastic as a partial replacement for fine aggregate. Due to the increasing accumulation of plastic waste and depletion of natural resources, the use of recycled plastic in concrete offers a sustainable solution for the construction industry. Waste plastic was collected, cleaned, powdered, shredded into 2–4 mm particles, and chemically treated using a 1–5% NaOH solution for 24 hours to improve bonding characteristics. Five concrete mixes were prepared: a control mix (0% plastic) and mixes containing 5%, 10%, 15%, and 20% treated plastic as partial fine aggregate replacement by weight. Fresh concrete properties were evaluated using slump tests, while compressive strength tests were conducted at 3, 7, and 28 days of curing. The results showed that workability decreased with increasing plastic content due to the irregular shape and hydrophobic nature of plastic particles. However, the 5% replacement mix achieved satisfactory compressive strength with only a slight reduction compared to conventional concrete, while higher replacement levels caused gradual strength reduction. The NaOH treatment enhanced the surface roughness of the plastic, improving mechanical interlocking between plastic particles and cement paste. The study demonstrates that treated waste plastic can be successfully incorporated into sustainable concrete, reducing environmental pollution and conserving natural aggregates for eco-friendly construction applications.

CHAPTER 2 :LITERATURE REVIEW

The increasing generation of plastic waste and the environmental impact associated with conventional concrete production have encouraged researchers to explore sustainable alternatives in the construction industry. Plastic waste is non-biodegradable and accumulates rapidly in landfills, rivers, and oceans, creating severe ecological problems. At the same time, the production of cement and extraction of natural aggregates for concrete contribute significantly to carbon emissions and depletion of natural resources. To address these concerns, many researchers have investigated the possibility of utilizing recycled plastic waste in concrete either as aggregate replacement, reinforcing fibers, or fillers. The use of plastic waste in concrete not only reduces environmental pollution but also supports sustainable development and resource conservation.

Several studies have focused on the replacement of natural aggregates with plastic waste materials. Mohamedsalih et al. (2024) examined the use of plastic waste as a replacement for coarse aggregate in concrete. Their study investigated replacement levels

ranging from 2.5% to 12.5% and evaluated the effects on workability, density, compressive strength, tensile strength, and flexural strength. The researchers observed that workability decreased with increasing plastic content because plastic particles created more friction and reduced the flowability of concrete. In addition, the density of concrete decreased because plastic materials possess lower specific gravity compared to conventional aggregates. The study found that low replacement levels, particularly around 2.5%, caused only minor reductions in strength, whereas higher replacement percentages significantly reduced compressive, tensile, and flexural strengths. Despite these reductions, the authors concluded that lightweight and sustainable concrete can still be produced using waste plastic for non-structural and certain structural applications.

Similarly, Saxena, Jain, and Agrawal (2016) reviewed several experimental investigations related to the utilization of waste plastic in concrete. Their review discussed the use of polyethylene terephthalate (PET), polypropylene fibers, plastic bags, and other recycled plastic materials in concrete production. The researchers observed that the incorporation of plastic waste generally reduces compressive strength due to weak bonding between plastic particles and cement paste. However, the review also highlighted several positive outcomes such as improved toughness, impact resistance, crack resistance, and ductility. The authors emphasized that the use of recycled plastic waste in concrete offers a sustainable solution for reducing environmental pollution and minimizing landfill disposal problems. Furthermore, they suggested that optimized proportions of plastic waste can help achieve a balance between sustainability and mechanical performance.

The reinforcement of concrete using recycled fibers has also attracted considerable attention among researchers. Wang, Wu, and Li (2000) conducted an extensive study on the use of recycled fibers obtained from carpet waste, tire waste, and industrial by-products in concrete reinforcement. Their research demonstrated that recycled fibers significantly improve toughness, energy absorption capacity, shrinkage resistance, and crack control in concrete. The inclusion of fibers helped prevent brittle failure and enhanced the post-cracking behavior of concrete. The researchers explained that fiber reinforcement bridges cracks within the concrete matrix and delays crack propagation, thereby improving durability and structural performance. Additionally, the study emphasized the environmental benefits associated with recycling waste materials into useful construction products.

Many researchers have further explored the use of waste plastic fibers to improve the mechanical and durability properties of concrete. Lakshmi et al. reviewed the efficiency of polypropylene fiber reinforced concrete and highlighted that polypropylene fibers effectively improve crack resistance, tensile strength, and durability of concrete. The addition of polypropylene fibers reduces plastic shrinkage cracking and enhances the ductility of concrete structures. Similarly, Rao, Patro, and Acharya (2023) studied the utilization of plastic waste as synthetic fibers and aggregates in concrete. Their review concluded that plastic fibers can improve toughness and energy absorption while contributing to environmental sustainability through waste utilization.

Babafemi et al. (2018) investigated the engineering properties of concrete containing recycled plastic waste. Their review analyzed the effects of plastic waste on compressive strength, tensile strength, durability, and workability. The study observed that while compressive strength often decreases with increasing plastic content, improvements in toughness and resistance to crack propagation are commonly reported. The authors emphasized that recycled plastic concrete can be successfully used in lightweight and non-structural applications where high compressive strength is not the primary requirement.

Research conducted by Anas et al. (2022) on fiber reinforced concrete highlighted that fibers improve tensile strength, flexural performance, and durability by controlling microcrack formation within the concrete matrix. Their review discussed different types of fibers including steel, glass, synthetic, and recycled fibers. The study concluded that recycled plastic fibers are effective in enhancing the toughness and post-cracking behavior of concrete while reducing environmental pollution caused by plastic waste disposal.

Carrión, Guerra, and Cervantes (2024) reviewed literature on the use of plastic waste in concrete mixes and found that the incorporation of recycled plastic can improve sustainability and reduce the demand for natural aggregates. However, they also reported that excessive plastic replacement may negatively affect compressive strength and bonding characteristics due to the hydrophobic nature of plastic materials. Therefore, optimization of plastic content is essential to maintain satisfactory concrete performance.

Several studies have focused specifically on waste plastic fibers in concrete. Nagar and Khan (2022) reviewed the properties of concrete using waste plastic fibers and concluded that plastic fibers improve crack resistance, toughness, and impact strength. Their review also indicated that plastic fibers help reduce shrinkage cracking during the early stages of concrete hardening. Similarly,

Khalil and Mahdi (2020) investigated sustainable concrete containing mixed plastic waste aggregate and observed that low percentages of plastic waste can produce concrete with acceptable mechanical properties and reduced density.

Qasim, Abbas, and Abed (2021) reviewed sustainable plastic waste in concrete and emphasized that plastic waste utilization contributes significantly to green construction practices. The study highlighted that plastic waste concrete reduces environmental pollution and landfill accumulation while promoting resource conservation. Noori and Numan (2020) studied reinforced concrete containing waste plastic and fibers and found improvements in crack control and durability performance. Their research demonstrated that plastic fibers enhance the structural behavior of reinforced concrete buildings.

Recent studies have also focused on optimizing concrete mixtures containing waste plastic through advanced analytical techniques. Shinde et al. investigated optimization of waste plastic fiber concrete with recycled coarse aggregate using response surface methodology (RSM) and artificial neural networks (ANN). Their findings showed that optimized combinations of plastic fibers and recycled aggregates can improve mechanical properties while maintaining sustainability objectives.

The durability performance of concrete containing waste plastic has also been extensively studied. Duraiswamy et al. investigated the impact of plastic waste fibers and treated construction demolition waste on concrete durability and sustainability. Their study concluded that plastic fibers improve resistance to cracking and enhance durability under aggressive environmental conditions. Mohammadhosseini et al. (2019) examined the effect of elevated temperatures on sustainable concrete composites containing waste metalized plastic fibers. The researchers observed that plastic fibers improved toughness and energy absorption but experienced degradation at very high temperatures.

Minde et al. (2024) conducted a comprehensive review on the use of plastic waste in sustainable concrete construction and concluded that plastic waste has strong potential as a sustainable construction material. The review highlighted environmental, economic, and engineering benefits associated with plastic waste utilization. Similarly, Gunat et al. (2025) emphasized that transforming plastic waste into durable concrete can support sustainable infrastructure development and reduce environmental pollution.

Noor Azline et al. (2023) reviewed the use of polyvinyl chloride (PVC) plastic as aggregate in construction materials and found that PVC waste can improve lightweight properties of concrete while reducing the need for natural aggregates. Park and Kim (2020) also reviewed cement-based materials containing recycled plastic and reported that recycled plastic fibers enhance toughness, ductility, and crack resistance.

Alqahtani and Zafar (2023) investigated green concrete incorporating fabricated plastic aggregate from waste processing. Their research showed that processed plastic aggregates can partially replace natural aggregates while maintaining acceptable engineering performance. The study highlighted the importance of proper treatment and sizing of plastic particles to improve bonding with cement paste.

Overall, the reviewed literature demonstrates that recycled plastic waste has significant potential in sustainable concrete production. Most studies agree that the inclusion of plastic waste generally reduces compressive strength at higher replacement levels due to weak bonding and lower stiffness of plastic materials. However, substantial improvements in toughness, crack resistance, ductility, impact resistance, and durability are frequently reported, particularly when plastic waste is used in fiber form. Recycled plastic fibers effectively control crack propagation and improve post-cracking behavior, thereby enhancing the long-term performance of concrete structures.

Furthermore, the utilization of waste plastic in concrete contributes to environmental sustainability by reducing landfill disposal, conserving natural resources, and lowering the demand for virgin construction materials. Although challenges related to workability, bonding characteristics, and strength reduction remain, optimized mix proportions and proper processing techniques can help overcome these limitations. Future research should focus on improving the interfacial bonding between plastic materials and cement paste, developing treatment methods for plastic waste, and evaluating long-term durability performance under different environmental conditions.

In conclusion, the incorporation of recycled plastic waste in concrete presents an effective solution for addressing environmental pollution and promoting sustainable construction practices. The reviewed studies confirm that waste plastic can be successfully utilized as aggregates, fibers, and fillers in concrete applications. With appropriate optimization and further technological

advancements, plastic waste concrete has the potential to become an important material for eco-friendly infrastructure development and sustainable engineering practices.

CHAPTER 3 :MOTIVATION FROM LITERATURE STUDY

The rapid growth of urbanization and industrialization has led to a substantial increase in plastic waste generation worldwide. Plastic materials are non-biodegradable and remain in the environment for several decades, causing severe ecological and environmental problems. Simultaneously, the construction industry is one of the largest consumers of natural resources such as sand, gravel, and crushed stone for concrete production. The excessive extraction of these materials contributes to environmental degradation, depletion of natural resources, and increased carbon emissions. Therefore, researchers and engineers are continuously searching for sustainable alternatives that can reduce environmental impact while maintaining the required performance of construction materials.

The literature review reveals that incorporating recycled plastic waste into concrete has emerged as a promising solution for addressing both waste management and sustainability challenges. Several researchers have investigated the use of plastic waste as partial replacement of coarse aggregates, fine aggregates, and reinforcing fibers in concrete. Studies conducted by Mohamedsalih et al. (2024) demonstrated that low percentages of plastic waste can be effectively utilized in concrete without causing significant reductions in strength properties. Their findings highlighted the potential of producing lightweight and sustainable concrete using recycled plastic materials. Similarly, Saxena et al. (2016) reported that the utilization of plastic waste in concrete can significantly reduce landfill accumulation and promote eco-friendly construction practices.

Another important motivation identified from the literature is the ability of recycled plastic fibers to improve certain mechanical and durability characteristics of concrete. Research conducted by Wang, Wu, and Li (2000) showed that recycled fibers obtained from carpet waste and tire waste improve crack resistance, toughness, shrinkage control, and post-cracking behavior of concrete. These findings indicate that recycled plastic fibers can act as an effective reinforcement material capable of enhancing the service life and durability of concrete structures. Furthermore, many researchers observed that plastic fibers help reduce brittle failure and improve the energy absorption capacity of concrete, making it more resistant to cracking under loading conditions.

The literature also highlights that although higher percentages of plastic replacement may reduce compressive strength due to poor bonding between plastic particles and cement paste, optimized proportions can provide acceptable structural performance along with sustainability benefits. This creates strong motivation for further investigation into the ideal percentage and form of plastic waste that can be incorporated into concrete while balancing mechanical performance and environmental advantages.

Another major motivation arises from the urgent need for sustainable waste management techniques. Millions of tons of plastic waste are generated every year, and only a small portion is effectively recycled. Most plastic waste is either burned or disposed of in landfills, causing serious environmental pollution. Utilizing this waste in concrete production offers a practical and economical recycling approach that can reduce environmental hazards and support circular economy principles.

In addition, the literature indicates limited studies on the combined influence of recycled plastic fibers on strength, durability, and long-term performance under varying environmental conditions. Therefore, further experimental research is necessary to understand the behavior of plastic fiber reinforced concrete in practical applications. The existing research gaps and the increasing demand for sustainable construction materials strongly motivate the present study to investigate the feasibility and performance of recycled plastic fiber concrete for eco-friendly infrastructure development.

CHAPTER 4 : METHODOLOGY

Step 1: Selection of Materials

The materials required for this study were first selected. Ordinary Portland Cement (OPC) was used as the binding material, along with natural river sand as fine aggregate and crushed stone as coarse aggregate. Clean potable water was used for mixing and curing. Waste plastic in the form of polyethylene terephthalate (PET) bottles was chosen for partial replacement of fine aggregate.

Step 2: Collection of Waste Plastic

Waste PET bottles were collected from local sources such as scrap dealers and nearby waste disposal areas. Care was taken to collect a uniform type of plastic to maintain consistency in the experimental work.

Step 3: Cleaning and Drying

The collected plastic was manually sorted to remove impurities such as caps, labels, and other unwanted materials. It was then washed using water and a mild detergent solution to remove dirt and oil residues. After washing, the plastic was dried under sunlight to eliminate moisture.

Step 4: Size Reduction

The cleaned plastic bottles were cut into smaller pieces and further shredded into particles of approximately 2–4 mm in size. This size was selected so that the plastic could act as a substitute for fine aggregate in the concrete mix.

Step 5: Mechanical Treatment

The shredded plastic particles were subjected to mechanical roughening to improve their surface texture. This process increased surface irregularities, which helps in better bonding with the cement paste.

Step 6: Chemical Treatment

After mechanical treatment, the plastic particles were chemically treated using a sodium hydroxide (NaOH) solution. A 2–5% solution was prepared, and the plastic was soaked in it for 24 hours. The plastic was then washed thoroughly with clean water to remove any remaining chemical and allowed to dry completely. This treatment enhanced the surface properties of the plastic and improved its bonding ability.

Step 7: Mix Design

Concrete mixes were prepared based on standard M20 grade proportions. Plastic was used as a partial replacement for fine aggregate at different percentages, namely 0%, 5%, 10%, 15%, and 20%. The mix without plastic served as the control, while mixes with treated and untreated plastic were prepared for comparison.

Step 8: Mixing and Casting

All materials were mixed thoroughly to ensure uniform distribution. The fresh concrete was then poured into cube molds of size 150 mm × 150 mm × 150 mm. Proper compaction was carried out to remove air voids and achieve a dense structure.

Step 9: Curing of Specimens

After casting, the specimens were kept undisturbed for 24 hours. They were then removed from the molds and placed in a water curing tank. The curing process was carried out for 7 days and 28 days.

Step 10: Testing of Concrete

After curing, the specimens were tested to evaluate their performance. Compressive strength tests were conducted using a compression testing machine. Workability was measured using a slump test, and density was also calculated. In some cases, water absorption tests were performed to assess durability.

Step 11: Analysis of Results

The results obtained from different mixes were recorded and compared. The performance of control concrete, untreated plastic concrete, and treated plastic concrete was analyzed. Graphs and tables were used to clearly present variations in strength, workability, and other properties.

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CHAPTER 6 : CONCLUSION

The present study focused on the development of sustainable concrete using treated waste plastic as a partial replacement for fine aggregate. The increasing accumulation of plastic waste and the environmental issues associated with its disposal have created a strong need for innovative and sustainable recycling methods. Simultaneously, the construction industry faces challenges related to excessive consumption of natural resources such as sand and aggregates. In this context, the utilization of treated waste plastic in concrete provides an environmentally friendly and resource-efficient solution that addresses both waste management and sustainable construction requirements.

In this project, waste PET plastic bottles were collected, cleaned, shredded into small particles, and subjected to both mechanical and chemical treatment using sodium hydroxide (NaOH) solution. The treatment process was intended to improve the surface roughness and bonding characteristics of plastic particles with the cement matrix. Concrete mixes were prepared with different

percentages of treated plastic replacement, namely 0%, 5%, 10%, 15%, and 20%, and their fresh and hardened properties were studied through slump tests, density evaluation, and compressive strength testing.

The experimental investigation demonstrated that the inclusion of treated waste plastic influences the workability and strength characteristics of concrete. It was observed that workability decreased gradually with increasing plastic content due to the irregular shape and hydrophobic nature of plastic particles. However, the chemical treatment improved the interaction between plastic and cement paste compared to untreated plastic concrete. The compressive strength results indicated that lower replacement levels, particularly around 5%, produced satisfactory performance with only minor reduction in strength compared to conventional concrete. Higher replacement percentages resulted in a noticeable decrease in compressive strength because excessive plastic content weakens the internal bonding and increases void formation within the concrete matrix. Nevertheless, the treated plastic concrete exhibited better bonding characteristics and improved performance compared to untreated plastic concrete.

Another important outcome of this study is the reduction in concrete density due to the lightweight nature of plastic materials. Lightweight concrete can be advantageous in reducing dead loads in structures and improving thermal insulation properties. In addition, the use of waste plastic contributes to reducing landfill accumulation, minimizing environmental pollution, and lowering the demand for natural fine aggregates. Therefore, this research supports sustainable development and circular economy principles by converting waste materials into useful construction products.

The study also confirmed that surface treatment of waste plastic plays a significant role in improving the mechanical performance of plastic concrete. Mechanical roughening increased the surface irregularities of the plastic particles, while chemical treatment enhanced surface wettability and adhesion with cement paste. The combined treatment approach effectively improved the interfacial transition zone between plastic and concrete, thereby reducing the negative effects generally associated with untreated plastic waste in concrete.

Overall, the project successfully demonstrated the feasibility of utilizing treated waste plastic in concrete production. Although high replacement levels may reduce mechanical strength, optimized proportions can produce sustainable and lightweight concrete suitable for non-structural and certain structural applications. The research highlights the importance of adopting sustainable materials in civil engineering to reduce environmental impact and promote eco-friendly infrastructure development. Future studies can further investigate long-term durability, flexural behavior, thermal properties, and large-scale practical applications of treated plastic concrete. The findings of this project indicate that treated waste plastic has strong potential to become an alternative construction material capable of supporting sustainable and green building technologies.