

Experimental study on compressive strength of permeable concrete with shredded plastic and plastic pellets

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Abstract - The rapid increase in plastic waste and urban flooding issues has created a need for sustainable construction materials that support both environmental protection and efficient stormwater management. Permeable concrete, characterized by interconnected pores, enables water infiltration, reduces surface runoff, enhances groundwater recharge, and mitigates urban heat island effects. This study investigates the compressive strength behavior of permeable concrete incorporated with shredded plastic fibers and plastic pellets as partial aggregate substitutes. The research aims to assess mechanical performance while promoting effective plastic waste utilization in concrete pavement systems. Various plastic dosage levels are experimentally evaluated to determine their influence on compressive strength, density, porosity, and structural performance. Shredded plastic fibers contribute to crack resistance and improved ductility, whereas plastic pellets reduce concrete density and promote permeability. However, due to weak interfacial bonding between hydrophobic plastic and cement paste, compressive strength experiences a reduction at higher replacement levels, indicating the importance of mix optimization. Findings highlight a balanced proportion of shredded plastic and pellets that maintains acceptable strength while improving drainage characteristics. The study contributes to sustainable concrete development by encouraging plastic waste recycling, reducing natural aggregate consumption, and enhancing permeable pavement performance, supporting eco-friendly infrastructure and sustainable urban development.

Keywords: Permeable concrete, Shredded plastic, Plastic pellets, Compressive strength, Sustainable pavement, Stormwater management

I. INTRODUCTION

Plastic waste has become one of the most pressing environmental concerns of the 21st century. The extensive use of plastics in packaging, construction, and consumer goods has led to an exponential increase

in non-biodegradable waste materials. According to global environmental studies, millions of tons of plastic waste are generated each year, and only a small percentage is effectively recycled or reused. The remainder accumulates in landfills, water bodies, and soil, leading to severe ecological and health problems. Plastic decomposition can take hundreds of years, releasing harmful toxins into the environment and affecting marine and terrestrial life. Burning plastic, on the other hand, produces toxic gases such as dioxins and furans, which are detrimental to air quality and human health. Therefore, utilizing plastic waste in construction materials offers a dual benefit—it helps in the safe disposal of non-biodegradable plastics and reduces the dependency on natural resources like aggregates. The construction industry, being one of the largest consumers of raw materials, provides an excellent platform for large-scale plastic waste utilization. Integrating plastics into concrete not only addresses environmental issues but also contributes to sustainable construction practices aligned with global waste management goals.

Permeable or porous concrete, also known as no-fines concrete, is an innovative material designed to allow water to percolate through its interconnected voids. Unlike conventional concrete, it lacks fine aggregates such as sand, resulting in a highly porous structure. This feature makes it particularly useful in applications such as pavements, parking lots, sidewalks, and low-traffic roads where surface runoff management is a concern. The key benefit of permeable concrete lies in its stormwater management capability. It facilitates groundwater recharge by allowing rainwater to infiltrate the soil rather than accumulating on the surface. This reduces urban flooding, mitigates the strain on drainage systems, and promotes sustainable water management. Additionally, the high porosity of the concrete

contributes to temperature regulation, reducing the urban heat island effect in paved areas. From an ecological perspective, permeable concrete supports sustainable urban infrastructure by conserving water, reducing surface runoff, and minimizing environmental degradation. Furthermore, the integration of plastic waste—such as shredded fibers and pellets—into permeable concrete can enhance certain mechanical and durability characteristics while maintaining permeability. This approach provides a cost-effective and eco-friendly construction material, contributing significantly to sustainable development goals.

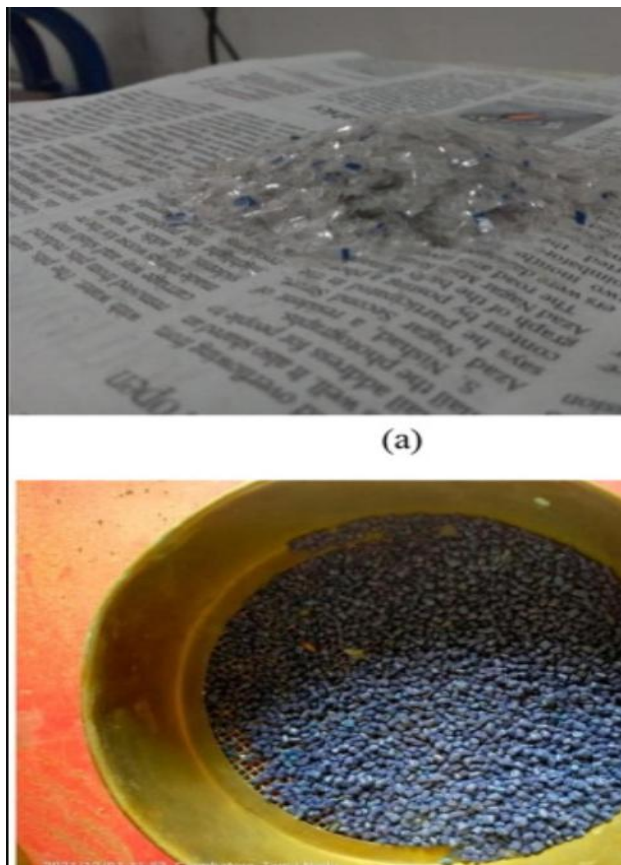


Figure 1: Permeable Concrete with Shredded Plastic Fibers and Plastic Pellets

Figure 1 illustrates the integration of shredded plastic fibers and plastic pellets into the permeable concrete mix, which enhances porosity, promotes stormwater infiltration, and supports sustainable waste utilization (Vijayakumar et al., 2022).

Limitations of Conventional Concrete in Drainage and Sustainability

Traditional concrete, although widely used for its strength and durability, is an impervious material that restricts water infiltration. As a result, it contributes to surface runoff, waterlogging, and urban flooding—especially during heavy rainfall. In areas like parking lots, highways, and industrial zones, this leads to significant maintenance challenges and increased costs for drainage systems. Conventional concrete also relies heavily on natural aggregates and cement, the production of which contributes substantially to carbon emissions and environmental degradation. Moreover, conventional concrete pavements do not promote groundwater recharge, resulting in declining water tables and increased dependency on artificial drainage networks. From a sustainability perspective, the disposal of plastic waste and depletion of natural aggregates remain unresolved challenges. Hence, there is a growing need for alternative construction materials that can balance structural performance, permeability, and environmental sustainability. Permeable concrete incorporating waste materials like shredded plastics and pellets addresses these limitations effectively. It not only enhances drainage and water management but also promotes the reuse of non-biodegradable waste, reducing the ecological footprint of construction activities.

Objectives of Reviewing Research Related to Plastic-Based Permeable Concrete

The main objective of this review is to examine and synthesize existing research on the utilization of shredded plastic fibers and plastic pellets in permeable concrete and to understand their impact on the mechanical and hydraulic properties of the material. Specifically, the review aims to:

- Evaluate how plastic waste can be effectively incorporated into concrete without significantly compromising its compressive strength.
- Analyze the relationship between the proportion of plastic materials and the performance characteristics such as permeability, porosity, and durability.
- Identify the optimal mix proportions for achieving a balance between strength and permeability.
- Discuss the environmental and economic benefits of using plastic waste in concrete.

- Highlight research gaps, challenges, and potential areas for future investigation in sustainable concrete technology.

By compiling and assessing experimental and theoretical studies, this review intends to provide insights into the feasibility of using plastic waste as a partial replacement for aggregates or fibers in permeable concrete. Ultimately, the goal is to contribute to the development of greener and more sustainable construction materials that support environmental conservation and resource efficiency.

II.OVERVIEW OF PERMEABLE CONCRETE

Permeable concrete, also known as porous concrete, pervious concrete, or no-fines concrete, is a specially designed type of concrete that allows water to pass through its interconnected pores. It has gained prominence as an innovative material in sustainable construction, particularly in stormwater management and eco-friendly infrastructure development. Unlike traditional dense concrete, which is impervious to water, permeable concrete is characterized by high porosity, enabling natural water infiltration, groundwater recharge, and reduction in surface runoff. Its structural and environmental benefits make it an ideal material for sustainable pavements, parking lots, sidewalks, and low-traffic roads.

Composition of Permeable Concrete

The basic constituents of permeable concrete are cement, coarse aggregates, and water, with little or no fine aggregates such as sand. The absence of fine material creates a network of voids that facilitates water permeability. The typical mix ratio used in permeable concrete ranges from 1:4 to 1:6 (cement to aggregate), depending on the desired strength and porosity. Coarse aggregates, which occupy about 70–80% of the concrete volume, play a crucial role in forming the interconnected pore structure. Aggregates commonly used are single-sized and range between 4.75 mm and 12.5 mm. Cement acts as a binding medium, coating the aggregate surfaces and maintaining the skeleton structure of the concrete. The water–cement ratio is generally kept low, between 0.3 and 0.4, ensuring the paste coats the aggregates without filling the voids. In modern practice, supplementary materials like fly ash, silica fume, or plastic waste (in the form of shredded plastic fibers

and plastic pellets) are incorporated to enhance sustainability and modify mechanical behavior. The inclusion of these materials contributes to reducing environmental pollution while improving the concrete's durability and workability.

Key Characteristics

- Permeable concrete is primarily defined by its porosity, permeability, and compressive strength.
- Porosity: The void content typically ranges between 15% and 25%, depending on the mix design and compaction method. These pores are responsible for water infiltration and stormwater absorption.
- Permeability: The permeability rate of pervious concrete is generally between 2 to 5 mm/s, which is sufficient for effective drainage and water management.
- Compressive Strength: Owing to the lack of fine aggregates, the compressive strength of permeable concrete is lower than that of conventional concrete, typically varying between 2.8 MPa and 28 MPa. However, this range is adequate for low-load applications such as pavements and pedestrian paths. Achieving the right balance between strength and permeability is crucial in mix design.

Applications

Permeable concrete finds diverse applications in modern civil engineering due to its dual functionality of structural support and water management. It is widely used in pavements, parking lots, driveways, rural roads, footpaths, and green infrastructure projects. In urban environments, it mitigates flooding by allowing rainfall to percolate through the surface and recharge groundwater. It also reduces the strain on municipal drainage systems and minimizes the urban heat island effect due to its light color and cooling properties. Moreover, in rural regions, it provides a low-cost and sustainable alternative for road construction, especially in areas lacking proper drainage systems.

Factors Affecting Performance

The performance of permeable concrete depends on various design and environmental factors. The void ratio determines both permeability and strength; higher void content increases permeability but reduces compressive strength. The aggregate size and gradation influence the structure of the pores—larger and uniform aggregates create higher porosity, while a mix of different sizes improves strength. The water–cement ratio must be carefully controlled to ensure sufficient bonding without clogging the pores. Proper compaction is essential to maintain structural stability without collapsing the pore network, and adequate curing enhances strength and durability. Additionally, the inclusion of fibers, plastic waste, or admixtures can alter the mechanical and hydraulic properties, requiring optimized proportions for practical performance.

III.ROLE OF PLASTIC WASTE IN CONCRETE

The incorporation of plastic waste into concrete has emerged as a promising and sustainable approach to address both environmental pollution and resource scarcity. Plastics, being non-biodegradable and abundantly available as waste, pose a severe threat to soil and water ecosystems. Utilizing them in concrete not only minimizes plastic disposal issues but also contributes to sustainable construction practices by reducing dependence on natural aggregates. Various forms of plastic waste, including shredded fibers, plastic pellets, and recycled plastic aggregates, have been successfully integrated into concrete mixes, particularly in permeable concrete where lightweight and porous structures are desirable.



Figure 2. Different forms of plastic waste materials used in permeable concrete: (P1) Plastic powder, (P2) Shredded plastic fibers, and (P3) Plastic pellets.

The figure illustrates various forms of plastic waste used in permeable concrete—plastic powder (P1) for fine filling, shredded plastic fibers (P2) for reinforcement, and plastic pellets (P3) as aggregate substitutes—demonstrating their distinct textures and potential applications in sustainable concrete production.

Types of Plastic Used

1. **Shredded Plastic Fibers:** These are finely cut strips of waste plastic, typically ranging between 2 mm and 5 mm in width, which are mixed with cement to act as micro-reinforcement. They help in improving the tensile strength, crack resistance, and ductility of concrete.
2. **Plastic Pellets:** Small, round or disc-shaped plastic particles, usually 2–5 mm in diameter, are

often used as partial replacements for coarse aggregates. They contribute to lower density and improved permeability in concrete.

3. **Recycled Plastic Aggregates:** Derived from crushed plastic waste products such as bottles or packaging materials, these aggregates serve as a substitute for natural coarse or fine aggregates, enhancing the sustainability profile of the concrete.

Physical and Chemical Properties Influencing Concrete Behavior

Plastics are lightweight, hydrophobic, chemically inert, and corrosion-resistant, which significantly influence the behavior of the concrete mix. Their smooth surface texture reduces bonding with cement paste, often resulting in a slight decrease in

compressive strength. However, their low density reduces the overall unit weight of concrete, making it more suitable for lightweight structures. The hydrophobic nature of plastics limits water absorption, thereby improving the durability and resistance to moisture-related damage. Chemically, plastics remain stable in alkaline environments, ensuring long-term stability when embedded in cementitious matrices.

Benefits and Drawbacks

The inclusion of plastic waste in concrete offers several benefits, including the reduction of environmental pollution, lower material costs, and decreased density of the concrete. It promotes eco-friendly construction by reusing non-degradable waste

materials that would otherwise contribute to landfill accumulation. Additionally, the improved permeability of concrete containing plastic pellets makes it ideal for drainage-based applications such as permeable pavements and water-retaining structures. However, there are also drawbacks associated with plastic-modified concrete. The primary concern is the reduction in compressive strength and bonding efficiency due to the non-polar, smooth surface of plastics that inhibits effective adhesion with the cement paste. Excessive plastic content can lead to poor workability, segregation, and reduced load-bearing capacity. Therefore, optimizing the percentage of plastic addition is essential to achieve a balance between sustainability and structural performance.

Table 1. Effects of Different Types of Plastic Waste on Concrete Properties

Type of Plastic Waste	Form Used	Role in Concrete	Observed Effect	Remarks
Shredded Fibers	Plastic Fiber strips (2–5 mm)	Acts as micro-reinforcement, improves ductility	Increases tensile strength, reduces cracking	Excess use lowers workability
Plastic Pellets	Spherical (2–5 mm)	pellets Partial replacement for coarse aggregate	Reduces density, increases permeability	Slight reduction in compressive strength
Recycled Aggregates	Plastic Crushed particles	plastic Substitute for natural aggregate	Decreases weight, improves sustainability	Weak bonding with cement matrix

Plastic Powder or Chips	Finely ground waste	Filler material for improved texture	Enhances durability, limits water absorption	Overuse causes porosity variation
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plastic waste incorporation in concrete presents a sustainable, cost-effective, and environmentally responsible alternative to conventional materials. Although challenges such as strength reduction and poor bonding persist, ongoing research and mix optimization are steadily improving the feasibility of plastic-based permeable concrete as a green construction material.

IV. LITERATURE REVIEW

Several studies have investigated the effectiveness of permeable and sustainable materials for pavement and stormwater management. Shinde and Valunekar (2015) examined cost and time control in stormwater management using pervious concrete, emphasizing its feasibility for efficient surface runoff control. Similarly, Thasni and Shareef (2018) explored the use of porous concrete for water-absorbing pavements,

confirming its ability to enhance infiltration and minimize surface water stagnation. Shah, Pitroda, and Bhavsar (2013) highlighted pervious concrete as a new era solution for rural road pavement, noting its environmental benefits and suitability for low-volume traffic roads. Kayhanian et al. (2019) demonstrated the application of permeable pavements in highways, focusing on stormwater runoff reduction and pollutant prevention, indicating significant improvements in water quality and drainage. Vikram and Mehla (2015) discussed applied research progress in construction materials, supporting the need for sustainable pavement solutions. Hande et al. (2017) further validated the efficiency of water-permeable pavements, reporting enhanced groundwater recharge and reduced runoff volume in urban settings. Vijayakumar et al. (2020a) investigated the utilization of Sansevieria Cylindrica fibers in rural paver blocks, showing improved strength and flexibility. In another study, Vijayakumar et al. (2020b) assessed processed sand as a partial replacement for manufactured sand, finding improved workability and mechanical strength. A third study by Vijayakumar et al. (2020c)

evaluated high-strength concrete incorporating mineral admixtures and copper slag, demonstrating superior durability and load-bearing performance. Kamaruddin et al. (2017) reviewed the potential of plastic waste as construction material, identifying significant environmental advantages and future development prospects. Karapanagioti et al. (2007) analyzed plastic resin pellets found in coastal regions,

offering insight into polymer durability and degradation behavior in environmental conditions. Finally, Prahallada et al. (2011) studied waste plastic fiber-reinforced concrete using recycled aggregates, concluding that the addition of plastic fibers enhances tensile strength, crack resistance, and overall workability.

Table 2: Literature Survey

Author & Year	Topic Name	Method	Research Gap
Vijayakumar et al. (2022)	Experimental study on compressive strength of permeable concrete with shredded plastic fiber and plastic pellets	Laboratory investigation; compressive strength testing, mix design trials with shredded plastic & pellets	Limited analysis on long-term durability and field performance under varying environmental conditions
Lone & Goel (2019)	Behavior of permeable concrete pavement with granulated waste plastic	Experimental study on concrete mix with waste plastic granules; mechanical strength evaluation	Lack of optimization studies on ideal percentage of plastic for both strength and permeability balance
Rahul et al. (2024)	Influence of nano-silica and shredded plastics in pervious concrete	Experimental mix design; mechanical strength tests with nano-silica + shredded plastic additives	Insufficient evaluation of performance without nano-silica to isolate the effect of shredded plastic alone
Pahsha et al. (2024)	Mechanical and hydraulic properties of pervious concrete with PET plastic fibers	Experimental analysis on strength, permeability, and hydraulic behavior using PET fibers	Limited comparison with other plastic forms such as pellets, flakes, or mixed plastic waste
Oddo (2024)	Integrating plastic waste into concrete	Review and analytical assessment of plastic waste inclusion in concrete composites	Lacks specific experimental validation for permeable concrete with shredded plastic and pellet combinations

V. RESEARCH GAP

Although numerous studies confirm the potential of permeable concrete with plastic additives, critical research gaps still exist. Most investigations, including those by Vijayakumar et al. (2022), Lone and Goel (2019), and Pahsha et al. (2024), primarily focus on initial compressive strength and permeability, with limited emphasis on long-term durability, aging, clogging effects, and real-time field performance under varying environmental and traffic conditions. Studies using shredded plastic, plastic pellets, PET fibers, and granulated plastic lack a comparative approach to determine the most effective plastic form and optimum proportion that balances strength, infiltration rate, and structural reliability. Additionally, research by Rahul et al. (2024) incorporates nano-silica along with shredded plastic, making it difficult to isolate the independent influence of plastic waste on

strength improvement. Further, Oddo (2024) highlights plastic integration conceptually but lacks experimental validation specific to permeable concrete mixtures using combined shredded plastic and pellets. Overall, standardization of mix design, performance benchmarking, sustainability assessment, and lifecycle analysis remain insufficient, indicating a need for comprehensive, real-world, and long-term experimental validation.

VI. METHODOLOGY

The experimental methodology focused on assessing the compressive strength of permeable concrete incorporating shredded plastic fibers and plastic pellets as partial replacements for coarse aggregates. Ordinary Portland Pozzolana Cement (PPC) conforming to IS:1489 (Part 1) – 1991 was used. Locally available coarse aggregates passing through

11.3 mm and retained on 6.3 mm sieves were selected. Shredded plastic fibers (2.36–4.75 mm) and plastic pellets (2–5 mm) were added in varying proportions of 0.5%, 1.0%, and 1.5% by weight of cement and aggregates, respectively. Concrete was mixed manually in a 1:6 ratio (cement: aggregate) with a controlled water–cement ratio of 0.35. Cubic specimens (150 mm × 150 mm × 150 mm) were cast and cured under water for 7, 14, and 28 days. Compressive strength tests were conducted using a compression testing machine, and results were analyzed to identify the optimal plastic content achieving a balance between strength and permeability, contributing to sustainable concrete design.

VII CONCLUSION

The study confirms that integrating shredded plastic fibers and plastic pellets in permeable concrete is an effective and sustainable approach to addressing plastic waste disposal and urban water management challenges. The inclusion of plastics modifies both the mechanical and hydraulic behavior of concrete. Shredded plastic fibers enhance crack resistance and ductility, while plastic pellets contribute to increased porosity and reduced density, improving water permeability. However, due to poor bonding properties between plastic and cement paste, a controlled percentage of plastic addition is essential to avoid excessive reduction in compressive strength. Experimental observations indicate that permeable concrete with optimized plastic content demonstrates sufficient strength for low-load applications such as pedestrian paths, driveways, parking areas, and rural roads. The findings emphasize that balanced plastic dosage enhances environmental sustainability without significantly compromising performance. Additionally, plastic-incorporated permeable concrete supports stormwater infiltration, decreases surface runoff, reduces dependency on drainage infrastructure, and promotes groundwater recharge. This study highlights the feasibility of converting non-biodegradable plastic waste into a constructive resource, contributing to eco-friendly construction practices, reduced landfill burden, conservation of natural aggregates, and the development of sustainable and resilient infrastructure systems.

VIII. FUTURE SCOPE

Although the incorporation of shredded plastic and plastic pellets in permeable concrete shows promising results, several areas require further exploration for large-scale implementation. Future studies should focus on long-term durability performance, including aging, freeze–thaw resistance, chemical exposure, abrasion resistance, and clogging behavior under real environmental conditions. Extensive field testing on traffic loads, seasonal temperature variations, and stormwater sediment effects is necessary to validate laboratory outcomes. The development of surface treatment methods or chemical additives to improve bonding between hydrophobic plastics and cement paste can further enhance compressive strength without reducing permeability. Advanced material characterization, microstructural analysis, and the use of coupling agents or supplementary cementitious materials (such as silica fume, fly ash, and nano additives) may also support performance improvement. Future research can explore hybrid combinations of different waste materials, life-cycle assessment (LCA), carbon footprint analysis, and cost–benefit comparisons for sustainable scaling. Incorporating machine learning-based mix optimization, 3D pore structure analysis, and predictive strength modeling could provide deeper insights. Standardization of design codes, mix guidelines, and performance benchmarks will accelerate practical adoption of plastic-based permeable concrete in urban and rural infrastructure development.

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