Experimental Investigation on Properties of Permeable Concrete Pavement Using Plastic Waste

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Abstract—**The increasing generation of plastic waste and the growing need for sustainable pavement systems have encouraged the development of innovative construction materials. This study investigates the properties of permeable concrete pavement incorporating Low-Density Polyethylene (LDPE) plastic waste as a partial replacement for coarse aggregate. Permeable concrete is widely recognized for its ability to reduce surface runoff and enhance groundwater recharge through its interconnected void structure.**

In this research, LDPE plastic waste was used at replacement levels of 0%, 5%, 10%, and 15% by weight of coarse aggregate. Concrete specimens were prepared and tested for compressive strength, permeability, density, void ratio, and water absorption. The experimental results showed that compressive strength decreased from 24.8 MPa to 16.7 MPa with increasing plastic content, while permeability increased from 3.8 mm/s to 7.1 mm/s. Similarly, void ratio and water absorption increased, whereas density decreased due to the lightweight nature of plastic waste.

The findings indicate that the incorporation of LDPE plastic waste improves the hydraulic performance of permeable concrete but reduces its mechanical strength. Among the mixes studied, the 5–10% plastic replacement level provided the most suitable balance between strength and permeability. Therefore, plastic-modified permeable concrete can be effectively utilized for low-volume traffic applications such as footpaths, parking areas, pedestrian walkways, and landscaping pavements. The study demonstrates a sustainable approach for plastic waste management while promoting the development of eco-friendly and permeable pavement systems, contributing to environmental protection and sustainable infrastructure development.

Index Terms—**Permeable Concrete, LDPE Plastic Waste, Sustainable Pavement, Compressive Strength, Permeability, Groundwater Recharge, Waste Management.**

I. INTRODUCTION

Rapid urbanization and rising environmental concerns have made sustainable development a global priority within the construction industry. A critical challenge facing modern society is the accumulation of non-biodegradable plastic waste such as Low-Density Polyethylene (LDPE), a highly flexible polymer widely used in single-use packaging and consumer goods which severely impacts landfills and ecosystems. Concurrently, the construction sector is depleting finite natural resources through the massive consumption of traditional aggregates.

To mitigate these environmental pressures, permeable concrete pavement technology has emerged as a key innovation for sustainable storm water management. Characterized by interconnected voids, pervious concrete allows water infiltration, effectively reducing surface runoff, minimizing urban flooding, and enhancing groundwater recharge.

This study bridges these two sustainability challenges by evaluating the mechanical and hydraulic performance of permeable concrete pavements incorporating processed LDPE waste as a partial replacement for coarse aggregates. Permeable concrete mixtures are prepared at various plastic replacement levels (0%, 5%, 10%, and 15% by mass) to systematically quantify the trade-offs between hydraulic permeability and structural strength. Ultimately, this research aims to determine the optimum waste-plastic thresholds to develop eco-friendly, low-traffic pavements that advance both waste utilization and resource conservation.

II. STUDY AREA

The present study was carried out in the Civil Engineering Department laboratory of Sandip Institute of Technology and Research Centre (SITRC), Nashik, Maharashtra, India. The experimental work focused on developing sustainable permeable concrete pavement by incorporating Low-Density Polyethylene (LDPE) plastic waste as a partial replacement for natural coarse aggregate.
Nashik is one of the rapidly developing urban regions in Maharashtra, experiencing increasing challenges related to plastic waste disposal, storm water runoff, groundwater depletion, and urban flooding. The growing generation of plastic waste and the need for sustainable pavement systems make the region suitable for investigating eco-friendly construction materials.

The study area was selected considering the following factors:

1. Availability of significant quantities of LDPE plastic waste from domestic and commercial sources.
2. Increasing demand for sustainable pavement materials in urban infrastructure.
3. Need for effective storm water management through permeable pavement systems.
4. Possibility of reducing environmental pollution by utilizing waste plastic in construction.

The experimental investigation was conducted under controlled laboratory conditions using Ordinary Portland Cement (OPC 53 Grade), natural coarse aggregates, potable water, and processed LDPE plastic waste. Concrete specimens were prepared with varying plastic replacement levels of 0%, 5%, 10%, and 15% by weight of coarse aggregate.
The performance of the developed permeable concrete was evaluated through compressive strength, permeability, density, void ratio, and water absorption tests. The findings aim to assess the suitability of plastic-modified permeable concrete for low-traffic applications such as pedestrian pathways, parking areas, footpaths, residential pavements, and landscaping projects.
This study contributes to sustainable infrastructure development by addressing two major environmental concerns: plastic waste management and groundwater recharge through permeable pavement technology.

III. LITERATURE REVIEW

The growing concern regarding plastic waste management and urban storm water runoff has encouraged researchers to investigate the application of waste plastics in permeable concrete pavements. Permeable concrete is a sustainable construction material that allows water infiltration through interconnected voids, thereby reducing surface runoff and improving groundwater recharge.
M. Ganesh Gupta (2023) investigated the incorporation of waste PET plastic in pervious concrete and reported that increasing plastic content improved permeability and porosity but reduced compressive, flexural, and tensile strength. The study suggested that a 10% replacement level provided an optimum balance between mechanical and hydraulic performance.
S. Sathvik (2024) evaluated lightweight pervious concrete produced using recycled plastic aggregates. The results indicated a significant reduction in density while maintaining adequate strength for non-structural applications. The study highlighted the environmental benefits of utilizing plastic waste in sustainable urban infrastructure.
Süleyman İpek et al. (2020) examined the use of Low-Density Polyethylene (LDPE) pellets as aggregate replacement in pervious concrete. Their findings revealed that plastic incorporation improved abrasion resistance but reduced compressive and tensile strength. A decrease in density and an increase in permeability was also observed with higher LDPE content.
Steve Supit et al. (2022) investigated the use of PET plastic waste as a partial replacement for fine aggregates in pervious concrete paving blocks. The research demonstrated that a 5% replacement level resulted in acceptable mechanical properties while contributing to plastic waste utilization and sustainable pavement development.
Byung-Hyun Ryu et al. (2020) developed pervious pavement blocks using recycled PET aggregates and evaluated their engineering properties, permeability, and durability. The study concluded that recycled

plastic aggregates could be effectively used in permeable pavement systems while providing environmental and economic benefits.

Sahil Lone and Amit Goel (2023) studied the effect of granulated waste plastic on the properties of permeable concrete. Their findings showed that permeability increased with plastic content, whereas compressive strength gradually decreased. The study reported that replacement levels up to 25% could be used without significant deterioration in performance.

Previous studies consistently indicate that the incorporation of plastic waste in permeable concrete improves permeability, porosity, and drainage characteristics while reducing density. However, excessive plastic replacement adversely affects compressive strength due to weaker bonding between plastic particles and cement paste. Most researchers have identified an optimum plastic replacement range between 5% and 15%, depending on the type and size of plastic used.

Therefore, the present study focuses on evaluating the performance of permeable concrete pavement incorporating LDPE plastic waste as a partial replacement for coarse aggregate. The investigation aims to determine the optimum plastic content that provides a suitable balance between mechanical strength and permeability for sustainable low-traffic pavement applications.

IV. MATERIALS AND METHOD

1 Materials

The materials used in this study included Ordinary Portland Cement (OPC) Grade 53, natural coarse aggregates, potable water, and shredded Low-Density Polyethylene (LDPE) plastic waste. OPC 53 Grade cement conforming to relevant Indian Standards was selected due to its high early strength and good binding properties. Coarse aggregates of size 4.75 mm to 12.5 mm were used, while fine aggregates were omitted to maintain the interconnected void structure required for permeable concrete.

LDPE plastic waste was collected from household and commercial sources, including plastic carry bags, packaging films, milk pouches, and shopping bags. The collected plastic was sorted, cleaned, dried, and shredded into particles of approximately 5–10 mm size before use as a partial replacement for coarse aggregate. Potable water free from impurities was used for mixing and curing purposes.

2 Mix Proportions

Four permeable concrete mixes were prepared with varying percentages of LDPE plastic waste as a partial replacement for coarse aggregate by weight. The replacement levels considered were 0% (control mix), 5%, 10%, and 15%. The concrete was designed as pervious concrete without fine aggregates to ensure adequate porosity and water permeability.

Mix ID	Plastic Replacement (%)
PC-0	0%
PC-5	5%
PC-10	10%
PC-15	15%

3 Experimental Procedure

The collected LDPE plastic waste was first washed to remove impurities and then dried under sunlight. The dried plastic was shredded into uniform pieces and stored for use in concrete preparation.

The required quantities of cement, coarse aggregate, and shredded plastic were weighed according to the selected mix proportions. Dry mixing of cement and coarse aggregate was carried out for approximately two minutes, followed by the addition of shredded plastic waste. Water was then added gradually while mixing to obtain a uniform concrete mixture.

Concrete cubes of dimensions 150 mm × 150 mm × 150 mm were cast for testing. Care was taken to avoid excessive compaction in order to preserve the interconnected void structure characteristic of permeable concrete. After casting, specimens were covered and kept undisturbed for 24 hours before demoulding. The specimens were subsequently cured in water for 7, 14, and 28 days.

4 Testing Methods

The performance of permeable concrete containing plastic waste was evaluated through the following laboratory tests:

Compressive Strength Test:

Compressive strength tests were conducted on cube specimens after 28 days of curing using a Compression Testing Machine (CTM) in accordance with IS 516 guidelines. The maximum load at failure was recorded and the compressive strength was calculated.

Water Permeability Test:
The permeability characteristics of permeable concrete were determined using the falling-head permeability method. The time required for water to pass through the specimen was recorded and the permeability rate was calculated.

Density Test:
The density of hardened concrete was determined by measuring the mass and volume of the cured specimens. The density was calculated as the ratio of mass to volume.

Void Ratio Test:
The void ratio was evaluated using dry, submerged, and saturated specimen weights. The percentage of interconnected voids present in the concrete was calculated to assess porosity and drainage characteristics.

Water Absorption Test:
Water absorption tests were performed by measuring the difference between dry and saturated specimen weights after immersion in water. The percentage water absorption was calculated to evaluate the pore structure and durability characteristics of the concrete.

5 Data Analysis
The experimental results obtained from the compressive strength, permeability, density, void ratio, and water absorption tests were analyzed and compared with those of conventional permeable concrete. The influence of plastic replacement percentage on the engineering properties of permeable concrete was evaluated to determine the optimum plastic content suitable for sustainable low-traffic pavement applications.

V. RESULTS AND DISCUSSION

The experimental investigation was conducted to evaluate the influence of LDPE plastic waste on the performance of permeable concrete. The properties examined included compressive strength, permeability, density, void ratio, and water absorption. The results indicate that the incorporation of plastic waste significantly affects both the mechanical and hydraulic characteristics of permeable concrete.

1 Compressive Strength
The compressive strength of permeable concrete decreased with increasing plastic content. The control mix (0% plastic) achieved a compressive strength of 24.8 MPa, whereas mixes containing 5%, 10%, and 15% plastic exhibited strengths of 22.3 MPa, 19.5 MPa, and 16.7 MPa, respectively. The reduction in strength can be attributed to the hydrophobic nature of LDPE, which limits the bond formation between plastic particles and cement paste. Furthermore, the increase in void content reduces the effective load-carrying area of concrete. Despite the reduction, the 5% plastic mix maintained adequate strength for low-volume pavement applications.

2 Permeability
Permeability increased from 3.8 mm/s in the control mix to 4.6 mm/s, 5.8 mm/s, and 7.1 mm/s for 5%, 10%, and 15% plastic replacement, respectively. The increase in permeability is primarily due to the formation of additional interconnected voids created by the inclusion of plastic particles. Improved permeability enhances storm water infiltration and groundwater recharge, which are essential characteristics of sustainable pavement systems. The observed trend confirms that plastic waste contributes positively to the drainage performance of permeable concrete.

3 Density
The density of concrete decreased with increasing plastic content. The control mix recorded a density of 1504 kg/m³, while the densities of 5%, 10%, and 15% plastic mixes were 1433 kg/m³, 1458 kg/m³, and 1385 kg/m³, respectively. This decrease is attributed to the lower specific gravity of LDPE compared to natural aggregates. The reduction in density indicates the development of lightweight permeable concrete, which may reduce dead load and improve handling during construction.

4 Void Ratio
The void ratio increased from 18% in the control mix to 21%, 24%, and 28% for 5%, 10%, and 15% plastic replacement levels, respectively. The increase in void ratio is associated with the irregular geometry and poor packing efficiency of plastic particles. Higher void content facilitates water flow through the concrete matrix, thereby improving permeability. However,

excessive voids adversely affect compressive strength due to reduced structural continuity.

5 Water Absorption

Water absorption increased from 4.2% for the control mix to 5.6%, 6.9%, and 8.3% for the 5%, 10%, and 15% plastic mixes, respectively. The increase in water absorption is directly related to the higher porosity and interconnected void structure developed within the concrete. Although greater water absorption supports infiltration performance, excessive absorption may influence long-term durability under severe environmental conditions.

6 Overall Performance Evaluation

The results reveal a clear trade-off between mechanical strength and hydraulic performance. Increasing LDPE content enhances permeability, void ratio, and water absorption while reducing density and compressive strength. The findings are consistent with previous studies on plastic-modified permeable concrete, which reported similar trends due to increased porosity and weaker aggregate-paste bonding.

Among the mixes investigated, the 5% and 10% plastic replacement levels demonstrated the most favourable balance between strength and permeability. These mixes provided adequate compressive strength while maintaining superior drainage characteristics. Therefore, permeable concrete containing 5–10% LDPE plastic waste can be recommended for sustainable pavement applications such as parking areas, pedestrian pathways, footpaths, cycle tracks, and other low-volume traffic infrastructures.

Plastic %	Compressive Strength (MPa)
0 %	24.8
5 %	22.3
10 %	19.5
15 %	16.7

Table No. 1 Compressive Strength Test (MPa)

Plastic %	Permeability (mm/sec)
0%	3.8
5%	4.6
10%	5.8
15%	7.1

Table No.2 Permeability Test results

Plastic %	Density (kg/cumec)
0%	1504
5%	1433
10%	1458
15%	1385

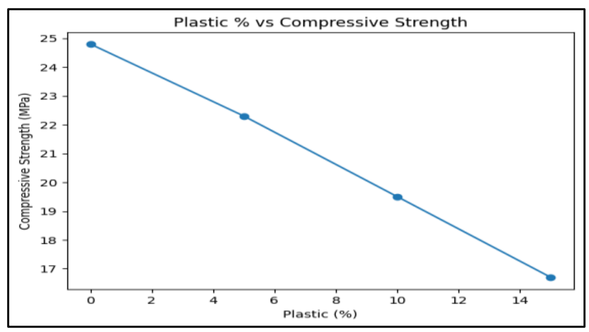
Table No. 3 Density Results

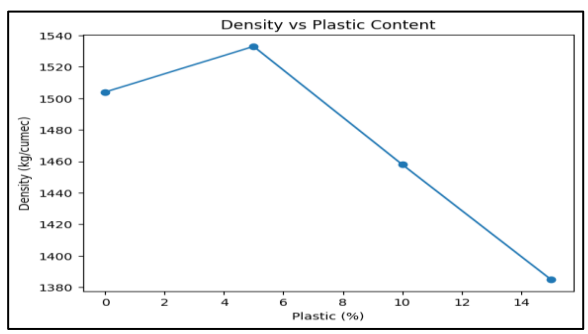
Plastic %	Void ratio %
0%	18
5%	21
10%	24
15%	28

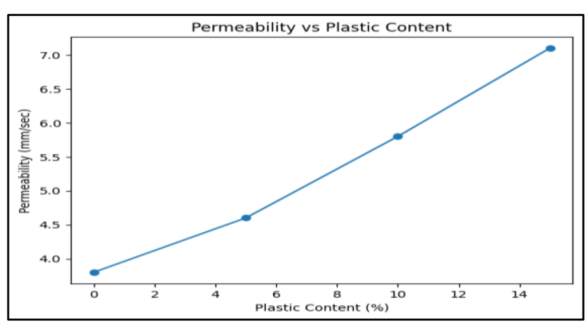
Table No. 4 Void Ratio Results

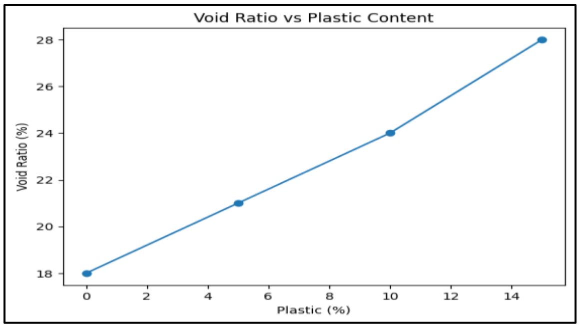
Plastic %	Water Absorption %
0%	4.2
5%	5.6
10%	6.9
15%	8.3

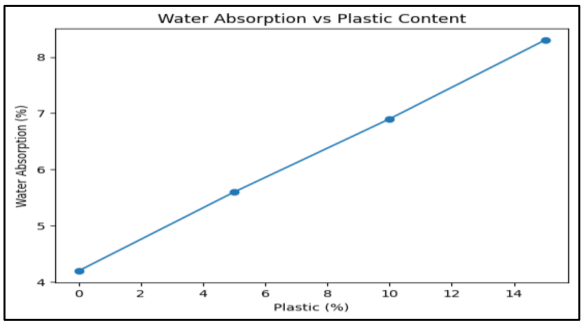
Table No. 5 Water Absorption results











VI. CONCLUSION

The present study investigated the feasibility of utilizing LDPE plastic waste as a partial replacement for coarse aggregate in permeable concrete pavement. The experimental results demonstrated that the incorporation of plastic waste significantly influences both the mechanical and hydraulic properties of permeable concrete.

The compressive strength decreased with increasing plastic content, reducing from 24.8 MPa for the control mix to 16.7 MPa at 15% replacement. In contrast, permeability, void ratio, and water absorption increased with higher plastic content, indicating enhanced drainage performance and groundwater recharge potential. Additionally, the density of concrete decreased due to the lightweight nature of LDPE plastic.

The results revealed that plastic replacement levels of 5% to 10% provide an optimum balance between strength and permeability. These mixes maintained adequate compressive strength while offering improved infiltration characteristics required for sustainable pavement systems. The findings confirm that waste plastic can be effectively utilized in permeable concrete, contributing to the reduction of plastic pollution and the conservation of natural aggregate resources.

Therefore, permeable concrete incorporating 5–10% LDPE plastic waste is recommended for low-volume traffic applications such as footpaths, pedestrian walkways, parking areas, cycle tracks, and landscaping pavements. The study demonstrates a sustainable and environmentally friendly approach for the development of green infrastructure while promoting efficient plastic waste management.

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